"EVALUATION OF ADAPTABILITY OF RAJMASH (*Phaseolus vulgaris* L.) TO DIFFERENT ENVIRONMENTS"

By

MR.THAKARE PRATIK ASHOK
(Reg. No. P/014/052)

A thesis submitted to the

MAHATMA PHULE KRISHI VIDYAPEETH,

RAHURI – 413 722, DIST. AHMEDNAGAR,

MAHARASHTRA STATE (INDIA)

In partial fulfillment of the requirements for the degree

Of

MASTER OF SCIENCE (AGRICULTURE)

In

AGRICULTURAL BOTANY
(GENETICS AND PLANT BREEDING)

DEPARTMENT OF AGRICULTURAL BOTANY,

COLLEGE OF AGRICULTURE, PUNE – 411 005

MAHARASHTRA STATE (INDIA)

2016

"EVALUATION OF ADAPTABILITY OF RAJMASH

(*Phaseolus vulgaris* L.) TO DIFFERENT ENVIRONMENTS"

By

MR.THAKARE PRATIK ASHOK
(Reg. No. P/014/052)

A thesis submitted to the

MAHATMA PHULE KRISHI VIDYAPEETH,
RAHURI – 413 722, DIST. AHMEDNAGAR,
MAHARASHTRA (INDIA)

In partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE (AGRICULTURE)

In

AGRICULTURAL BOTANY
(GENETICS AND PLANT BREEDING)
Approved by

Dr. D. B. Lad
(Chairman and Research Guide)
Associate Professor of Agril. Botany,
NARP, Ganeshkhind. Pune-07

Prof. B. H. Chavan
(Committee Member)
Assistant Professor of Agril. Botany,
College of Agriculture, Pune-05

Prof. P. D. Khade
(Committee Member)
Professor of Agril. Botany,
College of Agriculture, Pune-05

Dr. H. J. Rajput
(Committee Member)
Assistant Professor of Agril. Botany,
College of Agriculture, Pune-05

Dr. D. P. Kaledhonkar
(Committee Member)
Assistant Professor of Statistics,
College of Agriculture, Pune-05

2016

CANDIDATE’S DECLARATION

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

Place : Pune

Date : / /2016 **(PRATIK THAKARE)**

Dr. D. B. Lad
Associate Professor of Agril. Botany
NARP Ganeshkhind, Pune - 07.
Maharashtra (India)

CERTIFICATE

This is to certify that the thesis entitled, **"EVALUATION OF ADAPTABILITY OF RAJMASH (*Phaseolus vulgaris* L.) TO DIFFERENT ENVIRONMENTS",** submitted to the faculty of Agriculture, Mahatma Phule Krishi Vidyapeeth, Rahuri, Dist. Ahmednagar, Maharashtra State, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE (AGRICULTURE)** in **Agricultural Botany (Genetics and Plant Breeding)**, embodies the results of a *bonafide* research carried out by **MR.THAKARE PRATIK ASHOK** under my guidance and supervision and that no part of the thesis has been submitted for any other Degree or Diploma.

The assistance and help rendered during the course of this investigation have been duly acknowledged.

Place : Pune **(D. B. Lad)**
Date : / /2016 Research Guide

Dr. J. V. Patil
Associate Dean,
College of Agriculture,
Pune-05
Maharashtra (India)

CERTIFICATE

This is to certify that the thesis entitled**, "EVALUATION OF ADAPTABILITY OF RAJMASH (*Phaseolus vulgaris* L.) TO DIFFERENT ENVIRONMENTS",** submitted to the Faculty of Agriculture, Mahatma Phule Krishi Vidyapeeth, Rahuri, Dist. Ahmednagar, Maharashtra State in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE (AGRICULTURE)** in **Agricultural Botany,** embodies the results of a *bonafide* research carried out by **MR. THAKARE PRATIK ASHOK** under the guidance and supervision of **Dr. D. B. Lad**, Associate Professor of Agril. Botany, NARP, Ganeshkhind, Pune-07 and that no part of the thesis has been submitted for any other University for a Degree or Diploma.

Place : Pune (J. V. Patil)
Date : / /2016 Associate Dean

ABSTRACT

"EVALUATION OF ADAPTABILITY OF RAJMASH (*Phaseolus vulgaris* L.) TO DIFFERENT ENVIRONMENTS"

By

Mr. THAKARE PRATIK ASHOK

(Reg. No.P/014/052)

A candidate for the degree of

MASTER OF SCIENCE (AGRICULTURE)

In

AGRICULTURAL BOTANY
(GENETICS AND PLANT BREEDING)
COLLEGE OF AGRICULTURE, PUNE.
MAHATMA PHULE KRISHI VIDYAPEETH,
RAHURI – 413722.
2016

Research Guide	:	**Dr. D. B. Lad**
Department	:	Agricultural Botany
Major Discipline	:	Genetics and Plant Breeding

In the present investigation ten genotypes along with one check Varun of Rajmash evaluated in a Randomized Block Design, with three replications at Botany farm, College of Agriculture, Pune to study their stability across four environments, *i.e.* 25th meteorological week (E_1), 28th meteorological week (E_2), 31st meteorological week (E_3) and 34th meteorological week (E_4) during *kharif, 2015*.

The stability analysis as per Eberhart and Russell (1966) model showed significant genotypic differences for almost all the characters. Similarly, environmental variations were significant for all characters. G x E interactions were significant for days to 50 per cent flowering, plant spread, number of pods per plant, number of seeds per pod, seed yield per ha when tested against pooled deviation. The linear components of G x E interactions were significant for days to 50 per cent flowering, plant height, plant spread, pods per plant, seeds per pod, 100-seed weight, seed

yield per plant and seed yield per ha, when tested against pooled deviation and pooled error.

The estimation of environmental indices (Ij) revealed that environment E_1 (20th June) was favourable for all characters except days to 50 per cent flowering and days to maturity. Environment E_2 (10th July) was favourable for characters like plant height, harvest index, seed yield per plant and seed yield per ha. Third environment E_3 (30th July) was found to be unfavorable for all characters studied. Fourth environment E_4 (20th August) was found to be favourable for days to 50 per cent flowering and days to maturity.

The genotypes Vaghya (days to 50 per cent flowering), Phule Suyash and Varun (days to maturity), Varun (plant spread and pods per plant), GRB-902, GRB-9810, HPR-35 and Vaghya (seeds per pod), GRB-702 and GRB-9810 (plant height, primary branches per plant and harvest index), GRB-702 and HPR-35 (secondary branches per plant), HPR-35 and Varun (100-seed weight), GRB-701, GRB-702 and Vaghya (seed yield per plant) and GRB-702 (seed yield per ha), showed average stability, suitable for all environments.

The genotypes GRB-803 (days to 50 per cent flowering and days to maturity), GRB-701(pods per plant and secondary branches per plant), GRB-702 (plant spread and seeds per pod), HPR-35 (primary branches per plant) and Varun (seed yield per plant and seed yield per ha), showed stability for stress environments.

The genotypes, GRB-701 (days to 50 per cent flowering, seeds per pod and 100-seed weight), Varun (primary branches per plant), Vaghya (harvest index) and GRB-902 (plant height, plant spread, pods per plant, secondary branches per plant, seed yield per plant and seed yield per ha), showed stability for favourable environments.

1. INTRODUCTION

French bean is botanically known as *'Phaseolus vulgaris'* (2n = 2X = 22) and belongs to family Leguminosae. Rajmash or common bean is regarded as "Grain of Hope". However, in recent past, French bean is placed under the family *Fabaceae*. The genus, *Phaseolus* has over 50 species and Rajmash (*Phaseolus vulgaris* L.) is one of them accounting for 90 % of cultivated species worldwide. In India, both bushy and trailing types Rajmash are found. It is native of southern Mexico and Central America (Evans, 1979).

Rajmash is also known as haricot bean, salad bean, runner bean, snap bean, string bean, frijoles, kidney bean, common bean and navy bean (Singh, 2001). It has several vernacular names in several parts of the country *viz*. Rajmash (Hindi), Barigalu (Telugu), Shravanghevda (Marathi), Phansi (Gujarati) and Babri (Punjabi). The dry seed type varieties are known as 'Rajmash' in India. Among food legumes the French bean is the third most important worldwide famous crop, superseded by soybean and peanut.

French bean is a bisexual and self-pollinated pulse crop with simple type of pistil and diadelphous (9) + 1 condition of stamens. There has been considerable modification in growth habit during domestication and subsequent breeding of this crop. Thus the field evaluation of wild material and cultivars revealed that the plant type ranged from indeterminate climbers to determinate bush type (Evans, 1973). The most important changes, which have been taken place in the fruiting characteristics of these species, are pod and seed size, where up to nine seeds are found in wild form but rarely more than five in most of the cultivated cultivars. A remarkable range of testa colour occurs in the seeds of *Phaseolus* species, five main colour groups were identified, namely white, black, red, ochre, and brown super imposed on three ground colours may be various pattern of spots, flecks and strips.

Pod structure has also been altered in cultivars with reduction in dehiscence and fibre content. Three distinct pod textures are found in the common bean. The leathery types which are less dehiscent but split readily along the sutures and the flesh or stringless pods, which are indehiscent and do not split readily. Varieties with parchmented pods are used only for dry seed production, leathery poded varieties can be used for green pod production and fleshy poded or stringless types are usually grown for production of green vegetable pods.

Being a short duration crop French bean can be grown under different cropping patterns of hills and plains of India. In India, it is mainly grown in Himachal Pradesh, Punjab, Haryana, Uttar Pradesh, Bihar, Gujarat, Madhya Pradesh, Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu and Jammu and Kashmir. Brazil ranks first in production in the world. In Maharashtra, it is mainly grown in Satara, Pune, Sangali and Kolhapur districts.

Major Rajmash producing areas are located in tropical and temperate regions with a temperature around 21^0C. The optimum temperature for better growth is $16\text{-}24^0$C. Growth of plant ceases if temperature falls below 10^0C. A temperature above 35^0C causes dropping of buds and flowers resulting in poor yield. It is highly susceptible to frost. The crop is generally raised in areas receiving 50-150 cm annual rainfall. Water logging at any stage adversely affects its yield. Rains causes flower drop and spread of leaf spot diseases. French bean pods and mature and dry seeds are used for human consumption. In temperate countries it is grown for fresh pod consumption while, in tropical countries it is consumed as dry bean (Rajmash). It is also used as fodder for animals. It helps to increase the nitrogen level in the soil with *Rhizobium* bacteria. As dry bean, it is rich in nutrients as given below.

Sr. No.	Nutrient content	Quantity
1	Carbohydrates	56.90 g
2	Protein	20.80 g
3	Vitamin-A	0.21 RAE
4	Sodium	43.67 mg
5	Calcium	105.72 mg
6	Phosphorus	332.12 mg
7	Iron	6.21 mg
8	Vitamin C	8.93 mg
9	Thiamine	0.56 mg
10	Riboflavin	0.24 mg

(Anonymous, 2015)

Rajmash also possesses some medicinal properties which are useful in controlling diabetics and certain cardiac problems and it is a good natural cure for bladder burn. It has both carminative and reparative properties against constipation, diarrhoea, diuretic, dropsy, dysentery, emollient and kidney resolvent, respectively. French bean content nonnutritive bio-active compounds include saponins, phytic acid, plant sterols, phenolic compounds, enzyme inhibitors, and lectins. Saponin has anti-carcinogenic and anti-mutagenic properties and phytic acid has anti-cancer properties.

There is need to organized strong and efficient breeding programme to develop high yielding and good quality varieties of French bean, which comes under pulses crops. The yield of Rajmash in India remains at low level and production is either stagnant or dropping might be due to lack of high yielding varieties. Globally French bean is cultivated on about 28 m ha with a production of 19 million tonnes. Brazil is the leading producer of French beans. Columbia, USA, Canada, Ethiopia, China and Turkey are other leading countries producing French bean. In India, it is grown on an area of about 1.29 lakh ha mainly in the states of Maharashtra, Jammu and Kashmir, Himachal Pradesh, Uttar Pradesh, Tamil Nadu, Kerala, Karnataka and West Bengal.

Plant breeding is essentially consists of selection of plants among the variables. Thus, an insight into the magnitude of variability present in a crop species is important as, it allows effective selection. Total phenotypic variation, is made up of genetic and environmental components of variation. Genotypic variation, which arises due to the genotypic difference and the base for selection is the main concern of plant breeders. Hence, in selection for yield, more emphasis has to be placed on those attributes which have low environmental variability.

At present, development of strict ideotype as identified by the physiologist and adaptability to a wide range of environments is a major criterion for selection in French bean (Evans, 1979). The ability of individual populations or species to change in form or function in such a way to survive better under given environmental conditions is termed as adaptability (Allard, 1960). The genotypes possessing ability to do well in all the environments, are said to be 'general adaptable'. Some genotypes do well only under certain set of environmental conditions such as poor or rich environments. The adaptability of this kind is called *'specific adaptability*'. Thus, the predictability of performance *i.e.* ‘Stability’ depends upon the adaptability of the genotype. Stability in the yield and its components is, therefore, one of the most desirable characters for the adaptability of all genotypes, thus, is of great interest to the plant breeder.

There are some old varieties, which are good yielders, but are likely to succumb due to various pests and diseases or climatic variations or other biotic and abiotic stresses. Thus, over a period of time deterioration is noticed in established varieties. Hence, when varieties are compared across a series of environments, the relative ranking usually differs, which causes difficulty in proving or demonstrating the significant superiority of a particular variety. The 'stability of performance' or 'ability' to show minimum interaction with different environments, is one of the most desirable and important genetic characteristics.

There is a lot of scope for improvement of this crop for dry bean. The low yield of this crop in India is mainly attributed to the lack of stable high yielders and environmental variations. In recent years, stability analysis has become one of the important tools for plant breeders in predicting response of various genotypes over changing environments. The present investigation was, therefore, planned to identify such stable as well as 'well-buffered' genotypes.

The new concept of selecting varieties through evaluation of variety within the poor and difficult environments, where the farmer operates. The various environments would influence yield and make selection for a variety difficult due to genotypes by environments interaction. Genotypes x Environments (G x E) interaction is an important issue among plant breeders and agronomists. Yields are influenced by varied soil types among the farmers. Eberhart and Russell (1966) identified the rainfall pattern and dates of planting as a source of environmental influence which induce G x E interaction. Genotype cannot, therefore, be selected based on yield alone, but a method that combines yield and stability across a geographical area would be benefit to farmers. Yield stability statistics ensured the selection of consistently performing cultivars instead of high yield alone.

With this understanding the present investigation, “Evaluation of Adaptability of Rajmash (*Phaseolus vulgaris* L.) to different Environments” was undertaken with the following objectives.

1) To estimate stability for seed yield and its components.

2) To identify adaptable genotype suitable for *kharif* season.

2. REVIEW OF LITERATURE

The stability of productivity for characters of economic importance like yield and quality is of interest for the plant breeders. It is well known that some varieties of crop plant are widely adapted and others are not. Thus, adaptation is the property of individual genotype permitting its survival under selection and it is the property of genotypes permitting subsequent alteration of adaptation in response to changed selection pressure. Literature collected in the present investigation has been combined under following subheads.

2.1 Genotype and environment (G x E) interactions

2.2 Statistics and genetics of G x E interactions

2.3 Stability analysis in Rajmash

2.4 Stability in other pulses

2.1 Genotype and environment (G x E) interactions

G x E interactions are of major importance to plant breeders in developing improved varieties. A low level of interactions is useful for some characters so as to maximize the stability of performance over a number of environments. Environment is the sum of total of physical, chemical and biological factors.

Comstock and Moll (1963), has classified it in two categories.

i) Micro environment

ii) Macro environment

Micro environment is the environment of a single organism as opposed to that of another growing at the same time and same place where as macro environment which is associated with a general location and period of time and is a collection of micro environment and showed statistically, the effect of large genotype x environment interaction in reducing the process of selection.

Allard and Bradshaw (1964) coined the terms predictable and unpredictable environments. The predictable environment includes the permanent feature of the environment, such as climate, soil type, day length *etc*. It also includes controlled variables (Perkins and Jinks, 1968), for example, the level of fertilizer application, sowing dates, irrigated and unirrigated conditions, plant population densities *etc*. The unpredictable environment includes factors beyond the control of human beings *i.e.* amount and distribution of rainfall, the prevailing temperature.

2.2 Statistics and genetics of G x E interactions

Finlay and Wilkinson (1963), utilized technique to compare the performance of a set of cultivars grown at many sites for each variety. Varietal mean yield over environments and regression coefficients were used to classify the cultivars specially adapted to poor, better yielding environments and for general adaptability and indicated average phenotypic stability by a regression coefficient of unity (bi = 1.0). A cultivar with bi < 1.0 has above average stability, bi > 1.0 has below average stability and bi = 0 has absolute phenotypic stability, which means a constant grain yield in all environments. The ideal cultivar is one that possesses genetic potential in the highest yielding environment and maximum phenotypic stability.

Eberhart and Russell (1966) observed that the corn hybrids with a regression coefficient less than 1.0 usually had means yields that were below average and suggested that a desired variety should have high mean, regression coefficient equal to 1.0 and variance due to regression as small as possible. Thus they modified the regression techniques, which enables partitioning of genotype x environment interaction of each variety into two parts (bi), the variation due to response of variety to varying environmental indices (sum of squares due to regression) and the unexplainable deviation from the regression on the environmental index.

They defined both the linear (bi) and nonlinear (S^2di) components as stability parameters. They compared two types of crosses in maize and reported that hybrids x year interactions were significantly greater for single crosses than for three way or double crosses. They further stated that some single crosses may show as much or more phenotypic stability than most stable three way or double crosses.

The approaches of Finlay and Wilkinson (1963) and Eberhart and Russell (1966) are purely statistical and components of these analyses have not been related to the parameters in biometrical genetic model. Perkins and Jinks (1968) performed the second approach which was based on the fitting of models and specified the contribution of genetic, environmental and genotype x environmental interaction to generation means and variance allowing for the contribution of additive, dominance and epistatic gene effects to the genetic and interaction components of the model

Yijk = μ + di + Ej + BiEj + eij + eijk

Knight (1970) reviewed the regression analysis developed by Finlay and Wilkinson (1966) to investigate genotype x environment interactions and to assess genotypes for their adaptation to a range of environments.

Freeman and Perkins (1971) proposed independent estimate of environmental index in the following two ways (a) divide the replications into two groups, so that one group may be used for measuring the average performance of varieties, which will used for estimating environmental index (bi) use one or more varieties as check and assess environmental index on the basis of their performance. They proposed following model.

Yijk = m + di + eij + eijk

Bains and Gupta (1972) proposed that if the linear regression of above average genotypes upon the environmental mean is less than 1.0

with comparatively small deviation mean square, an agreeable compromise between the two definitions of Finlay and Wilkinson (1963) and Eberhart and Russell (1966) is essential. Singh and Singh (1980), studied stability of component characters in relation with the stability of yield. They analyzed how the component characters interact. The relationship among predictable behavior of G x E interaction of the component traits and yield revealed that linear response of yield was positively and significantly associated only with the linear response of maize tiller per plant whereas, that of yield per spike was positively associated with number of grains per spike and test weight.

Park (1987) studied stability analysis for genotype x environmental (G x E) interactions and yield-stability, the Cultivars (C) x Locations (L) and C x L x Year (Y) effects were highly significant with large variance components indicating importance of cultivar and test locations.

Dabholkar (1999) had given applicability of stability models. He suggests that the genotype is having the general adaptability if the 'bi' value (linear component) is at unity with pooled mean above the grand mean. Further, he also suggested that the performance of the particular genotype is predictable, if that genotype is having 'S^2di' value (non-linear component) non-significant.

Genotypes do not give the same phenotypic performance under changing environment and different genotypes respond differently to a specified environment. This variation arising from the lack of correspondence between genetic and no genetic effects, known as G x E interaction. In other words, the failure of a genotype to give the same phenotypic performance when grown under different environments is the reflection of G x E interactions. These are generally considered as an impediment in plant breeding as it baffles the breeder in judging the real potential of genotype when grown in different environments. Several workers considered G x E interactions as linear function of environment and proposed regression of yield of a genotype on the mean yield of all genotypes in each environment to evaluate stability of genotype. (Finlay and Wilkinson, 1963; Eberhart and Russell, 1966; Perkins and Jinks, 1968).

Eberhart and Russell (1966) redefined the technique of Finlay and Wilkinson (1963) and suggested that the interaction of genotype with environment is a function of linear and non-linear response of genotype to additive environmental variation. Thus, in addition to linear component (bi), they included a non-linear component (S^2di) also as a stability parameter. They defined stable variety as one, which has a high mean performance, unit regression coefficient (bi=1) and the least deviation from regression ($S^2di=0$).

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 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.

The stability in the productivity and the characters 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).

According to Eberhart and Russell (1966) linear (bi) and non-linear (S^2di) are residual mean squares (MS) of deviation from the regression and are the measures of the stability. Minimum G x E interactions are desirable 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 in the presence of G x E interaction reduces the correlation between phenotype and genotype and makes it difficult to judge the genetic potential of genotype.

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

A genotypes which maintains its deviation from the mean yield value when tested at all sides is considered as ecologically stable or in other words the genotype is considered as environmentally stable when a unit change in the genotype performance corresponds to unit changing 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 reacts strongly and quickly to improved conditions , but reacts less strongly to unfavorable environmental changes and are more suited to poor conditions. Their yield reduction in poor environment is less than that of unstable varieties (Rosochora, 1987).

2.3 Stability analysis in Rajmash

Chiriboga (1978) studied adaptability and stability of eight varieties of French bean in five locations of the Ecuadorian highlands. In one year trial, the best overall yields were obtained from the line 32 (1557 kg/ha) because of its adaptation to poor environments, Nima (1410 kg/ha) because of its specific adaptation to favourable environments and Uribe (1337 kg/ha) which had average adaptation.

Kelly *et al.* (1987) observed that Rajmash indeterminate cultivars gave higher yield than determinate cultivars and the 'short-vine' type - III determinate cultivar had above average yield and minimum deviation from regression. It was concluded that type - III growth habit offers the best opportunity for increasing seed yield with good stability.

Ayeh (1988) worked on yield stability in selected landraces of *Phaseolous vulgaris* L. and estimated yield stability by using genotypes x environment, variances, slope and deviation from regression and revealed that heterozygous F_2 and most complex synthetic mixtures were very stable and mean yields of most mixtures were significantly higher than mean of their components and there was linear relationship between magnitude of stability and diversity.

Guv (1988) analysed genotype x environment interactions of rust resistant dry bean lines in different locations and revealed that G x E interaction was found to be significant for pod yield, weight, length and width. Further he observed that Taichung 12 and 16 were most stable for pod length, 100 pod weights giving higher yield than control lines and three lines were highly resistant in both plains and mountain region.

Abreu *et al.* (1990) studied G x E interaction on estimation of genetic and phenotypic parameters of common bean and reported significant interactions of progeny and density.

Santos and Ramalho (1990) while selecting French bean progeny for autumn and winter conditions found some promising progenies with cold tolerance, marked quality and yield and concluded that ESAL-572 and ESAL-603 were well-adapted to favourable conditions.

Shellie and Hostfield (1991) found genotype x environment effects on food quality of common bean and reported that G x E interaction was significant for cooking time index and percentage water absorption while it was non-significant for seed protein content.

Sekhon *et al.* (1992) reported that last week of September was the optimum time for sowing (1386 kg/ha) in Punjab and found that genotype, HIM-V had good yield potential as well as being short-duration escape frost-injury at seed filling stage. In contrast, HUR-87 (medium-maturing) and PDR-14 (late-maturing) were the highest yielding genotypes but liable to frost-injury.

Sarma *et al*. (1993) studied phenotypic stability for grain yield of twelve genotypes of French bean under residual soil-moistures conditions; observed significant differences amongst genotype and substantial influence of G x E interaction effects on yield. Genotypes, DF-B1, DF-B6 and DF-B9, produced the highest mean yields over years and had high stable yields under fluctuating environmental conditions.

Wadan *et al*. (1993) reported that the varietal performance was affected markedly by environmental conditions, as they found the 'Swat Local' with the lowest number of days at Mingora indicating sensitivity of the genotype to the environment. The genotypes Reglex (2.0 t/ha) and Swat Local (1.0 t/ha), produced the highest fresh pod yield at Kalam and Mingora, respectively. .

Ramalho *et al.* (1993) studied G x E interaction of Rajmash cultivars with two sowing dates in 16 locations in Minas Gerais state during dry and winter season of 1989-90 and concluded that Eriparsa was most stable cultivar under unfavourable environments although it was the lowest yielding (1.1 t/ha). The highest yielding cultivar Pintado (1.6 t/ha) responded well to favourable environments.

Saindon and Schaalle (1993) recorded that in dry bean, partition of the G x E mean square demonstrated the possibility of reproducing the G x E structure of entire data sets with three sites; however, more locations may be needed to compare unpredictable environmental effects.

Singh *et al.* (1993) reported that the best performing genotypes in French bean were Sel-2 and Pusa Parvati for number of pods per plant and Contender and UL-1 for 100-seed weight. Arka Komal (Sel-9) was the earliest producing highest pod yield and was recommended as the most suitable variety for growing in central plateau of Orissa during *rabi* season.

Tel and Fiorentito (1993) revealed that English varieties having good adaptability to local environmental condition with moderate to good virus-resistance. Among navy type varieties Edmund, Albion and among brown type Fe (6766 x 4238) with dark brown seeds have shown best performance at central Italy.

Piana *et al.* (1994) studied grain yield stability and adaptability analysis of bean genotypes were performed from data collected in the Bean Yield State Trial, over 23 locations in the state of Rio Grande do Sul from 1988 to 1993. Each year location combination characterized one environment, summing up to 72 environments. Adaptability and stability parameter estimates were determined for the genotypes, Rio Tibagi, Guateian 6662, EMPASC 201, FT 120, Macanudo, Pampa, Mnuano, Macotaço, CNF 5491, Carioca and Irai.

Zimmermann (1994) observed that, only 25% genotypes showed significantly different performance under favourable and unfavourable environmental conditions when analyzing adaptability and yield stability of 76 common bean genotypes in Brazillian environments and suggesting that in case of less responsive cultivars currently cultivated with high technological inputs, these inputs might have misspent, further they reported that highest stability and seed yield were observed in PVMX1638, Cornell-49242, LM-10402 and A-226 adopted to high yielding environments.

Panwar *et al.* (1995) studied a set of 24 genotypes of Rajmash *(Phaseolus vulgaris* L.) grown in 3 distinct environments (Sangla, Kukumseri and Leo) in dry temperate region for 2 years for stability in yield. Stability performance analysis in 6 environments revealed significant differences due to genotypes, environments and genotypes x environment (G X E) interactions. Both linear and non-linear components of G x E interaction were present, with predominance of the former component. The genotypes showing wide adaptability and specific adaptation were identified. KRC 5, KRC 8 and KRC 11 were observed high yielding genotypes, out of which KRC 8 proved widely adaptable.

Wortmann *et al.* (1996) studied the seed yield stability in French bean multilines in 14 environments and revealed that G x E effects were significant for cooking time but variation was primarily due to genotypic effects. It was concluded that release of multilines is a potentially useful strategy, especially if multilines can be further improved by testing for computability of components. The results also demonstrated the importance of considering variation in cooking time, implying that long-cooking lines be excluded from multilines.

Ram and Dhar (1999) studied twenty eight genotypes of French bean including pole/semipole and dwarf types, were evaluated under four fertility regimes for stability analysis of seed yield and its componants using Eberhart and Russell's (1966) and Perkins and Jinks (1968) models. Significant G x E interaction was observed for genotypes and environments for all the traits. The environment E_3 was found to be beneficial for realization of full genetic potential of genotypes. Genotype PI310706 (pole type), Pat Anupama and UPF 627(both dwarf type) were found to be desirable and stable for seed yield per plant over the fertility environments. Number of seeds per pod appeared to be an important trait for seed yield stability in all these three genotypes.

Harer *et al.*(2000) studied seven Rajmash (*Phaseolus vulgaris*) cultivars, namely, PDR-9, PDR-5, ACPR-5, Red claud, Jwala, HPR-35 and Vaghya, were evaluated for seed yield and number of pods per plant (NOPPP) in a field experiment conducted in Pune, Maharashtra, India during the *kharif* seasons of 1993-95. The cultivars with the most stable seed yield and number of pods per plant were PDR-5 and ACPR-5, respectively.

Islam and Newaz (2001) studied G x E interaction for seeds per pod including other yield components in Rajmash. The present research work was undertaken with a view to assess genotype-environment interaction and to identify stable and high yielding genotypes with greater pod and seed production under changing cultural environments.

Firew (2003) studied an experiment to determine the stability of seed yield in 21 common bean genotypes representing three growth habits. Seven genotypes in each growth habit (determinate bush, indeterminate bush and indeterminate prostrate) were evaluated in replicated trials at three locations for three years under rainfed conditions in Ethiopia. A combined analysis of variance, stability statistics and rank correlations among stability statistics and yield stability statistic were determined. Among the 21 genotypes, only 11 genotypes were selected for their high yielding and stable performance. Genotypes with growth habit III and I (indeterminate prostrate and determinate bush) were generally more stable than indeterminate bush.

Raffi *et al.* (2004) studied Genotype x Environment interaction for number of pods and seeds per plant in nine genotypes of dry bean under four cultural environments during *rabi* season of 2001-2002. There were significant variations due to genotypes (G), environments (E) and G x E interaction for both the characters, which were also highly correlated between themselves (r = 0.920**). On the basis of stability parameters (Pi, bi, S^2di), genotype, PB-S8, was found to be most desirable and stable.

Nimbalkar *et al.* (2004) reported on seed yield of French bean significant G x E interaction, influencing the relative ranking of genotypes across the locations ACPR 5, PDR 5 and Red cloud were identified as the stable genotypes and ACPR 94040 and ACPR 94039 suitable for favourable environments. Among the different locations, Karad was the best location followed by Pune to exploit high yielding potential of French bean.

Carbonell and Filho (2004) studied the adaptability and stability of grain yield of 18 common bean cultivars and lines in different environments. The experiment was set up in a randomized complete block design with four replications and plots consisting of two, central five meters rows flanked by border rows. Stability parameters were estimated by the methods Maximum Yield Deviations (MYD) and by the Additive Main Effects and Multiplicative Interaction Analysis (AMMI). For the identification of the most stable cultivars, the two methods led to consistent results, although by MYD the highest stability was always associated to the highest yield. MAC-733327 and LP 9637 were the most suitable cultivars and lines for the joint seasons, while LP 9637 and FT-Nobre were the most suitable for the dry season.

Pan *et al.* (2006) conducted an experiment to study the stability parameters, *viz.*, regression coefficient (bi) and mean square deviations (S^2di) from linear regression, along with *per-se* performance of 13 varieties of bush type French bean for nine yield related characters. The roundish and stringless podded line, EC 350949, was better performing, stable and suitable for favourable environment.

Singh *et al.* (2007) assessed twenty genotypes of French bean, selected on the basis of Eco - geographic and genetic divergence for stability of yield and its components under three nitrogen fertility regimes *viz.* N_1 (80 kg/ha), N_2 (120 kg/ha) and N_3 (160 kg/ha). Heterogeneity among regression coefficients accounted for a significant portion of the genotype-environment interaction. The environment N_3 was found to be beneficial for realization of full genetic potential of genotypes. According to stability criteria (high mean performance, b=1 and $S^2d=0$), four genotypes *viz.* HUR 137, CH 812, IIHR 909 and Arka Komal were found to be desirable and stable for pod yield per plot over the different fertility environments.

Helton and Leonardo (2009) were studied to identify 'Carioca' dry bean genotypes with high yield adaptability and stability in central South Brazil, based on different analysis methods. The value of cultivation and use (VCU) of 16 genotypes was evaluated in 26 trials in a randomized complete block design with three replications, in the states of Santa Catarina, Sao Paulo and Parana, in 2003 and 2004. Grain yield data were subjected to analysis of variance, of stability and adaptability, using the methodology of AMMI model, indicated the genotypes BRS Estilo and CNFC 9518 for high yield, high adaptability and high stability. The yield, stability and adaptability of cultivar Perola, widely grown in the country, were lower than of the new elite genotypes obtained by the breeding programs.

Razvi and Khan (2011) evaluated 17 local genotypes in three diverse locations during 2008-09 with observations recorded on maturity, morphological and yield parameters. Interaction of genotypes with the environment (G x E) were observed to be significant for all the traits except number of branches per plant and protein content. Based on the stability parameter of Eberhart and Russel model (1966), SAUAR 28 was considered as stable and average responsive to the environments for yield and most of the component traits.

Nigussie (2011) conducted an experiment to estimate the nature and magnitude of interaction of varieties with the environment, and to study the stability of common bean varieties for seed yield. Fifteen varieties were studied at five locations of Eastern Amhara namely Kobo, Sirinka, Jari, Chefa and Shewarobit using Randomized Complete Block Design with three replications in 2011 cropping season. There was highly significant difference among varieties, locations and variety by location interaction for days to flowering, seed filling period, number of pods per plant, number of seeds per pod, pod length, plant height, biological yield, seed weight and harvest index, indicating that varieties performed differently across location and the locations had different discriminating power.

Khalifa *et al.* (2013) evaluated nine Rajmash genotypes for yield stability under different sowing dates and watering regimes in three field experiments conducted in the River Nile State-Sudan during 2003 to 2006. Ten test- environments were thus achieved, representing the combined effect of drought and heat stress. Stability analysis (Eberhart and Russel model, 1966) was performed to identify the most yield-stable bean lines under limited moisture and temperature stress. The genotypes Bellenber-1, COWU-3-94-9, S/Hashim/98 and the small seeded genotype DB 190-74-1 appeared to be the most stable. It was concluded that these genotypes can be used to improve common bean tolerance to drought and heat stress conditions in the Sudan.

Musaana *et al*. (2015) studied pod yield stability on fourteen Rajmash genotypes introduced or locally bred in Uganda. The study was carried out in three seasons using six agro-ecological zones. All the six non-commercial genotypes had been gene pyramided for rust, Angular leaf spot and common bacterial blight making them tolerant to the diseases. J 12 had the highest yield while the commercial variety Paulista had the lowest. Values of bi coefficient indicated that varieties had the highest positive influence on pod yields, while location and season had higher negative influence than rust. Varieties J 12 and SB001 had the most stable and heavy pod yields. Population dynamics showed that Paulista and Angela had the most unstable performance with lowest yields.

2.4 Stability in other pulses

Patil *et al.* (1984) evaluated six varieties of groundnut for stability of yield over four environments. The differences in stability were mainly due to linear regression. The variety M-13 had good stability and was second best in yielding ability, while TMV-10 had given the highest yield with moderate stability. Since both were observed to be ideal genotypes for yield.

Bhole *et al.* (1987) studied phenotypic stability for pod yield in summer groundnut in a set of eight promising varieties at seven locations. The environment and genotype x environment interactions were significant which revealed that genotypes were interacted with environment. While among the cultivars, TG-17, and EC-21103 had low regression value and comparatively stable performance as the values of deviation around the regression line (S^2di) were low. The variety, JL-12, was the most stable for pod yield having regression value near to unity and the least mean square deviation (S^2di).

Varman and Raveendran (1989) studied stability analysis in ten Virginia groundnut genotypes during three rainfed seasons for three character *viz.* dry yield (kg/ha), shelling percentage and hundred kernel weight. Genotype x environment interaction was significant only for pod yield and kernel weight. But the linear G x E interaction was significant only for pod yield. Among all genotypes, ICG-2272 had regression coefficient equal to unity, non-significant S^2di hence concluded as most stable genotype.

Varman *et al*. (1989) studied phenotypic stability under both stress and stress free environments for three consecutive years involving seven groundnut genotypes. Stability was estimated for productivity and kernel quality characters. The genotype RSHY-1 exhibited high mean performance for yield but stability was poor.

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 medium environments for grain yield per plant.

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

Varman and Manoharan (1993) derived stability parameters in groundnut for dry pod yield and three related traits in ten genotypes over four locations. The genotype, VG-77, exhibited high mean performance for all traits except harvest index, whereas JL-24, VG-55 and J-11 were stable for shelling percentage, 100-pod weight and 100-seed weight respectively.

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. ICCC-6 was the most stable genotype for yield and maturity.

Begum *et al.* (1998) studied genotype x environment interaction for six quantitative characters in groundnut. Analysis of variance indicated that a significant difference existed among varieties and environments. In is evident from stability parameter that the genotype 147 would be suitable in all environments for spread of the plant, dry pod yield. However, DG-2 considered suitable for good environments.

Senapati and Roy (1998) studied correlation coefficients among stability parameters of yield and yield contributing characters by growing 60 diverse genotypes of groundnut in two seasons at Kalyani, West Bengal. There were positive significant correlation coefficients between phenotypic mean performance (Xi) and regression coefficient (bi) for days to 50 per cent flowering, plant height, secondary branch number, peg number and 100-seed weight, while they were negative for days to maturity and primary branch number. There was a significant positive correlation between bi and S^2di for shelling percentage and 100-seed weight but a negative one with days to maturity.

Bhattacharya and Pande (1999) had grown ten physiologically different chickpea genotypes under normal and late sowing (30^{th} October and 28^{th} November respectively). Longer vegetative period (68 days) was observed under late sowing as compared to normal sowing (58 days) for

1st flowering. However, duration of subsequent phenological events was shorter under late seeding than normal seeding *i.e.* days to maturity (140 and 114 days, respectively) and 50 per cent flowering (98 and 87 days). Heat consumed by chickpea at flowering and maturity were higher in first sowing *i.e.* 10th October and showed declining trend for subsequent sowings.

Friere-Filho *et al.* (2001a) studied yield stability analysis in semi-erect brown testa cowpea by 15 genotypes in 13 environments, in the Brazilian middle-North region, from 1999 to 2001, using AMMI model. Genotypic effect was not significant but environment and genotype x environment interaction were highly significant ($P < 0.0$). Three first axes of the AMMI model main component analysis were highly significant ($p < 0.01$). These axes explained, 27.30 per cent, 25.18 per cent and 20.34 per cent, respectively in a total of 72.82 per cent of the genotype x environment interaction sum of squares.

Friere- Filho *et al*. (2001b) evaluated 16 cowpea genotypes in nine environments (local and year combination) for yield stability in cowpea climbing and ground testa genotypes using AMMI model. The effets of genotypes were not significant but environmental interaction G x E interaction effects were significant ($P < 0.01$). The first and second axes of the AMMI model main components of analysis were significant ($P < 0.01$). These two axes explained, 37.50 per cent and 23.75 per cent respectively in a total of 61.2 per cent of G x E interaction sum of squares.

Raje and Rao (2001) analyzed 200 lines of mung bean for stability for 100-seed weight. They reported that 17 genotypes had higher values than population mean, with above average stability ($bi<1$ and $S^2di=0$). Thirty one genotypes had lower mean values than the population mean with above average stability. They concluded that the genotypes with the lower mean values on one hand and genotypes with high mean values on the other represented two genotypically diverse groups of stable genotypes which can be used as genetically diverse and stable parents in hybridization programme to develop high yielding and stable varieties of mungbean.

Kent McKay *et al.* (2002) observed that chickpea matured latter than dry pea, lentil and preferred a longer warmer growing season. In Canada, Deshi chickpea averaged 1320 degree days for maturity. Deshi chickpea flowered one day to one week earlier than Kabuli types depending on the specific varieties being compared.

Kavitha *et al.* (2003) evaluated 21 genotypes in four environments for seed yield in cowpea and reported significant mean sum of squares due to genotypes, indicating presence of genetic variation among the genotypes for seed yield in cowpea. The linear component (59.96 per cent) of genotype x environment interaction was higher than the linear component. Ten genotypes had above average mean performance, average responsiveness and stable seed yield, hence their use in future breeding programme aimed at stable seed yield in cowpea was advocated.

Khatri *et al.* (2003) carried out stability analysis for test weight in 21 diverse genotypes of cowpea grown during *kharif,* 2000 in Hisar, Haryana. Both linear as well as non-linear components of genotypes x environment interaction were equally for test weight. Genotypes HC 98-40, HC 98-93 and GC 9732 had above average mean performance and average responsiveness coupled with better stability. The use of these genotypes as donor parents for stable test weight in further breeding programme in cowpea was suggested.

Pujari *et al*. (2003) studied phenotypic stability for pod characters in cow pea by growing 15 genotypes in summer and *kharif* seasons, reported G x E interaction for all the 6 characters. The genotypes Sel 2-1, IIHR 61-B, Sel 263, DCP-120 and Faizabadi L-1 were good performers and showed stability for a number of traits. These genotypes can be furthered utilized in cow pea breeding programmes.

Singh (2003) evaluated 15 genotypes of cow pea for stability during *kharif,* 1988 to 1991 and recorded significant differences among genotypes. The interaction sum of squares due to genotype x year was also highly significant, indicating the effect of environment on characters expression. Genotypes FTC-4, FTC-9 and FTC-27 had some potential of stability, and the use of their potential in future breeding programme is suggested to develop genotypes with high seed yield and stability in diverse environments. A comparison of yield data over the years with weather parameters indicated that the amount of rain distribution affected the relative ranking of phenotypes.

Singh *et al.* (2005) reported that heat units consumed by chickpea for 50 per cent flowering, 50 per cent pod formation and maturity were higher in first sowing *i.e*. 15th November (1100, 1187 and 1628 degree days, respectively) followed in second sowing *i.e.* 30th November (947, 1080 and 1512 degree days, respectively) and third sowing on 15th December (853, 1021 and 1493 degree days, respectively).

Thaware *et al.* (2006) conducted multi-location trial of DFC-1 (Local selection) and EC-4216 of cow pea at Dapoli, Palghar and Muldhe during 1987-88 to 1990-91. DEC-1 recorded high yield over check in all the trials. The per cent increase over check was 26.93. In the multi-location trials during *kharif* season the DFC-1 produced 25.90 q/ha green fodder producing 23.18 per cent higher yield over check. DFC-1 has been recommended for cultivation in *kharif* and *rabi* seasons in Konkan region of Maharashtra. It has been released in the name of Konkan fodder.

Shanti *et al.* (2007) evaluated 20 genotypes of black gram over three seasons from *rabi* 2001-2003 and *kharif* 2002, reported that genotype x environment interaction was significant, when tested against pooled error, components of genotypes x environment interaction, *i.e*. G x E (linear) and pooled deviation were significant when tested against pooled error. The genotypes GPB 89, GBN 4 and VBG 62 were average responsive to seasons, had high mean seed yield and stable in both approaches.

Patel *et al.* (2009) studied stability analysis in 36 genotypes of green gram in four differents environments (different sowing dates) to study G x E interaction components. Significant differences for all characters, indicated wide differences between environments and differential behavior of genotypes in different environments. The linear and non-linear components of G x E interaction were significant for all the characters. The genotypes *viz.,* GM 4, KM 5-122, KM 5-122 x KM 5-124, KM-5-122 x GM 3, KM 5-124 x GM 4, KM 5-124 x GM 3, KM 5-167 x KM 5-191, KM 5-167 x GM 3, KM 3-183 x GM 3, GM 4 x KM 851 were stable for seed yield under average environmental conditions, while KM 5-124 stable for poor environmental conditions.

Shyam *et al.* (2009) conducted experiment to understand genotype (G) x environment (E) interactions for quantitative traits in 108 diverse genotypes of chickpea *(Cicer arietinum),* in diverse environments and found that majority of genotypes showed a complete absence of G x E interactions while a limited number of genotypes showed their suitability for favourable planting environments having both a significant regression as well as high mean yield. A sizable number of genotypes showed stable yield performance over all the environments, indicating their high general adaptability.

Choudhary and Haque (2010) studied the stability of yield and its components, results of these studies revealed that environmental (linear) was found highly significant for all the characters which indicated variation in weather condition of location. The pooled deviation (non-linear portion of the variance) was found highly significant for all the characters. The GxE interaction were found highly significant, showing important role of environment and genotype x environment interaction to the characters.

Pillai *et al.* (2010) evaluated ten cultivars with two checks for yield stability in black gram during three different seasons and reported significant differences among genotypes, all genotypes with significant S^2di. The genotypes, KKB 05005 and KKB 05010 showed significant bi value greater than unity hence suitable for favourable environments.

3. MATERIAL AND METHODS

The present investigation entitled, “Evaluation of Adaptability of Rajmash (*Phaseolus vulgaris* L.) to different Environments” was conducted at the field of Division of Agricultural Botany, College of Agriculture, Pune during *kharif*, 2015.

3.1 Experimental material

The experimental material for the present study consists of ten genotypes along with one check of Rajmash (*Phaseolus vulgaris* L.). The source of the genotypes is given in table No. 3.1

Table 3.1: Source of Rajmash genotypes

Sr. No.	Genotypes	Source
1.	GRB- 701	NARP, Ganeshkhind, Pune-07
2.	GRB-702	NARP, Ganeshkhind, Pune-07
3.	GRB-803	NARP, Ganeshkhind, Pune-07
4.	GRB-804	NARP, Ganeshkhind, Pune-07
5.	GRB-902	NARP, Ganeshkhind, Pune-07
6.	GRB-9810	NARP, Ganeshkhind, Pune-07
7.	HPR-35	NARP, Ganeshkhind, Pune-07
8.	Phule Suyash	NARP, Ganeshkhind, Pune-07
9.	Vaghya	NARP, Ganeshkhind, Pune-07
10.	Varun (check)	NARP, Ganeshkhind, Pune-07

3.2 Experimental Methods

The experiment comprised of ten varieties of Rajmash evaluated in Randomized Block Design with three replications over four environments in the field. Each genotype was planted in four rows of 30 x 10 cm spacing. The field experiment was conducted at normal fertile soil. The details of the field experiment are given below:

A) Material	:	10 genotypes GRB-701, GRB-702, GRB-803, GRB 804, GRB-902, GRB-9810, HPR-35, Phule Suyash, Vaghya and Varun (c)
B) Date of sowing	:	20th June 2015, 10th July 2015, 30th July 2015 and 20th August 2015.
C) Design	:	Randomized Block Design
D) No. of replications	:	3
E) Spacing	:	30 x 10 cm
F) Plot Size	:	4 x 1.20m^2
G) Fertilizer dose	:	60:80:00 NPK Kg ha^{-1}
H) Season	:	*Kharif*, 2015

3.2.1 Season

The crop was grown during *kharif*, 2015 season under four different sowing dates (environments) as follow: (Table 3.2)

Table 3.2 Environments with different sowing dates

Environments	Date of sowing
E_1	20th June, 2015
E_2	10th July, 2015
E_3	30th July, 2015
E_4	20th August, 2015

3.2.2. Cultural practices

The land was prepared by ploughing followed by two cross harrowing. The basal dose 60 kg N, 80 kg P_2O_5 per hectare was applied at all four sowings. The four different environments required were created by undertaking sowings in different meteorological weeks.

3.2.3 Harvesting

When the pods attained physiological maturity, harvesting was carried out by pulling the crop and seeds were separated by threshing after sun drying.

3.3 Observations recorded

(a) Days to 50% flowering (No.)

(b) Days to maturity (No.)

(c) Plant height (cm)

(d) Plant spread (cm)

(e) Primary branches per plant (No.)

(f) Secondary branches per plant (No.)

(g) Pods per plant (No.)

(h) Seeds per pod (No.)

(j) 100-seed weight (g)

(i) Harvest index (%)

(k) Seed yield per plant (g)

(l) Seed yield (kg/ha)

3.4 Method of recording observations

The following pre and post-harvest observations were recorded on five randomly selected plants from each treatment in each replication in all the four environments and averages were worked out separately for each of the environments.

3.4.1 Days to 50 per cent flowering (No.)

Number of days required from sowing to the day on which 50 per cent of the plants in plot flowered was recorded as days to 50 per cent flowering.

3.4.2 Days to maturity (No.)

Number of days required from sowing till the physiological maturity was considered as days to maturity.

3.4.3 Plant height (cm)

The plant height is measured from the ground to top of the main axis in centimeters at maturity.

3.4.4 Plant spread (cm)

The plant spread recorded by the horizontal space occupied by plant between tips of two extreme leaves at harvest.

3.4.5 Primary branches per plant (No.)

The branches directly emerging from the base of the main shoot counted on five randomly selected plants during harvest.

3.4.6 Secondary branches per plant (No.)

The branches arising from primary branches are counted on five randomly selected plants during harvest.

3.4.7 Pods per plant (No.)

The total number of dry pods present on the plant at maturity were counted and recorded from randomly selected plants.

3.4.8 Seeds per pod (No.)

The total number of seeds was counted from twenty five pods which were taken from five randomly selected plants *i.e.*, five pods from each plant.

3.4.9 100-seed weight (g)

A representative random sample of 100 seeds per treatment weighed in grams.

3.4.10 Harvest index (%)

Harvest index is the ratio of economic yield to the total biological yield and expressed in percentage.

$$\text{Harvest index (HI) (\%)} = \frac{\text{Economic yield}}{\text{Total biological yield}} \times 100$$

3.4.11 Seed yield per plant (g)

The weight of seeds from each of the randomly selected plants was recorded after threshing from each plant separately and the average was worked out to represent the yield per plant.

3.4.12 Seed yield (kg/ha)

The seed yield per hectare was calculated after calculating seed yield per plant.

3.5 Statistical analysis

3.5.1 Environment wise analysis of variance

Mean sum of squares for individual environments were calculated as suggested by Panse and Sukhatme (1985) in the following form.

Table 3.3 Environment wise analysis of variance

Sr.No.	Source of Variation	Degree of freedom	Expected mean sum of squares
1	Replication	r-1	$\sigma^2 e^2 + t\ \sigma^2 r$
2	Treatment	t-1	$\sigma e^2 + r.\ \sigma^2 t$
3	Error	(r-1)(t-1)	$\sum^2 e$
	Total	(rt-1)	

Where,

r = number of replications

t = number of treatments.

The mean sums of squares due to genotypes over each environment for all characters were studied.

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 (Panse and Sukhatme, 1967).

Stability analysis was performed by model proposed by Eberhart and Russell (1966). They proposed the 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 (X), regression coefficient (bi) and the squared deviation from the regression (S^2di).

These parameters are defined using the following model.

$Yij = \mu i + biIj + \delta ij$

Where,

Yij = Mean of i^{th} genotype in j^{th} environment.

(i = 1, 2 …v, and j = 1, 2……,…….n)

µi = Mean of all genotypes over all Environments.

bi = The regression coefficient of i^{th} genotype on the environmental index, which measures response of genotype to varying environments.

Ij = The environmental index which is defined as deviation of the mean of all the genotypes at a given environment from the overall mean.

$$\frac{\sum_{i} Yij}{v} - \frac{\sum_{i}\sum_{j} Yij}{n} \quad \text{With } \sum Ij = 0$$

δij =The deviation from regression of the i^{th} genotype at j^{th} environment.

3.5.2 The stability parameters

a) The regression coefficient (bi) is described as under

$$bi = \sum YijIj / \sum I^2j$$

where,

$\sum YijIj$ = The sum of the products.

$\sum I^2j$ = The sum of squares of environmental index.

b) Mean square deviation (S^2di) from linear regression

$$S^2d = \frac{\sum_j \delta^2 ij}{(s-2)} - \frac{S^2e}{r}$$

Where,

$$\sum_j \delta^2 ij = \left(\sum_i Yj^2 ij - \frac{Yi^2}{v} \right) - \frac{(\sum Yij^2 Ij)^2}{\sum_j I^2 j}$$

S^2e = Estimate of pooled error.

v = Number of genotypes.

s = Number of environments.

1) Computation of environmental index (lj)

We know that I_j is defined as,

$$I_j = \frac{\sum_j Yij}{v} - \frac{\sum_i \sum_j Yij}{n}$$

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

2) Computation of regression coefficient (bi)

For each genotypes,

$$= \frac{\sum_j Yij \;\; Ij}{\sum_j I^2 j}$$

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

$$\sum I^2j = (I^2_1 + I^2_2 + \ldots\ldots\ldots\ldots\ldots + I^2j)$$

i The $\sum$ YijIj for each genotype of environmental index (Ij) with corresponding mean (X) of that genotype at each environment.

These values were obtained in the following manner

$$(\bar{X})\ (Ij) = (\sum_{j} YijIj) = S$$

Where,

$(\bar{X})$ = Matrix of the means

(Ij) = Vector for environmental index

(S) = Vector for sum of products i.e. $\sum$ YijIj

ii The bi value for each genotype was thus calculated by dividing $\sum$ YijIj as calculated above in (ii) by $\sum I^2$ obtained above under (i)

$$\text{Thus, } bi = \sum_{j} YijIj / \sum I^2j$$

3) Computation of S^2di

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,

$\sigma^2y = \sigma^2$ regression + σ^2 deviation from regression

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

$$\sigma^2vi = \sum_j Y^2ij - (Yi^2/S)$$

Where,

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

Yi = Sum of means of i^{th} genotype over j^{th} environment.

The variance due to deviation from regression,

$\sum_j \delta^2ij$ for a genotype being

$$\sum \delta^2ij = (\sum Yij^2 - Yi^2 / s) - \frac{(\sum_j YijIj)^2}{\sum_j I^2j}$$

Where,

$(\sum_j Yij^2 - Yi^2 / s)$ = The variance due to dependant variable

$(\sum_j YijIj)^2 / \sum_j I^2j$ = The variance due to regression

Because,

$$\frac{(\sum_j YijIj)^2}{\sum_j I^2j} = \frac{(\sum_j Yij)(\sum_j YijIj)}{\sum_j I^2j} = bi \sum_j YijIj$$

Where,

bi, values have been calculated in (2) and $\sum YijIj$ values in 2 (ii)

The $\sum\delta^2 ij$ values may be completed as

$$\sum_j \delta^2 ij = \sum_j \delta^2 vi - bi \sum_j YijIj$$

From $\sum\delta^2 ij$, the stability parameter S^2di for each genotype was calculated as follows

$S^2di = [\sum\delta^2 ij / (s - 2)] - (S^2\ e/r)$

3.5.3 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 environments + (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 in fact S.S due to regression.

ii) S.S due to deviation from linearity of response (*i.e.*, S.S due to pooled deviation).

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

Table 3.4 ANOVA for stability

Source	d.f.	S.S.	M.S.S.
Genotype	(t-1)	$1/S \sum_i Yi^2$ – C.F.	MS_1
Environments	(s-1)	$1/t \sum_j Yi^2$ – C.F.	MS_2
Genotype x environments	(t-1) (s-1)	$\sum\sum Yij^2$ – C.F.– G.S.S - E.S.S.	MS_3
Environment + (Genotype x environment)	t (s-1)	$\sum_i\sum_j Y^2ij - Yi^2/s$	MS_4
Environment (linear)	1	$1/t\ (\sum_j Yijlj)^2 / \sum_j l^2j$	
Genotype x environment (linear)	(t-1)	$\sum_i(\sum_j Yijlj)^2/\sum_j l^2j$-E(1) S.S.	MS_5
Pooled deviation	t (s-2)	$\sum_i\sum_j {}^2ji$	MS_6
Pooled error	st (r-1)		MS_7

Where,

t = Number of genotypes

s = Number of environments

r = Number of replications

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,

$$= \frac{(n_1 - 1)(\text{M.S. error } L_1) + \ldots\ldots\ldots + (n_5 - 1)(\text{M.S. errors})}{(n_1 - 1) + (n_2 - 1) + \ldots\ldots\ldots + (n_1 - 1)}$$

Where,

M.S. error L_5 = Mean sum of squares due to error for 5th environment

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

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

The S.S. due to remaining sources were calculated as follows S.S. due to environment (Genotype x Environment)

$$= \sum_i \sum_j Yij - \sum_i Yi^2 / t$$

In fact,

S.S. (E = G X E)

= S.S.E. + S.S. (G x E)

Where,

$$\text{S.S.E.} = 1/t \left(\sum_j YiIj\right)^2 / \sum_j I^2j$$

The Yi and Ij 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)

$$= t \times \sum Ij^2$$

In fact,

S.S. G x E (linear)

$$= \sum_j \left[\sum_j (YijIj)^2 / \left(\sum_j Ij\right)^2\right] - \text{S.S.E. (linear)}$$

$$= bi \sum_j YijIj \text{ for each genotype}$$

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.

3.5.4 Test of significance

a) The significance of differences among genotypes and environments were tested against the M.S.S. due to G x E interaction (MS_3). The fore more was 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) and G x E (linear) were 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 follow.

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

e) Stable genotype *i.e.* tests of significance for regression coefficient.

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

$$\text{SE bi} = \sqrt{\frac{\text{MSS due to pooled deviation}}{\sum j\ I^2 j}}$$

The significance of bi values was tested by‘t’ test as (against unity).

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

Mean of bi = Σi bi/t

Population mean and standard error are calculated as,

$$\text{Population mean } (\mu) = \frac{\text{Grand total}}{\text{Number of observations}}$$

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

4. EXPERIMENTAL RESULTS

The present investigation entitled “Evaluation of Adaptability of Rajmash (*Phaseolus vulgaris* L.) to different Environments” was undertaken with a view to estimate stability parameters for seed yield and its important components and to identify most stable genotypes under different environmental conditions for *kharif* season.

4.1 Response of various Rajmash genotypes to changing environments

The mean values of the genotypes for different characters studied under four sowing dates are presented in Tables 4.1.1 to 4.1.12.

4.1.1: Mean performance of Rajmash genotypes for days to 50 per cent flowering over environments

In first environment (E_1) days to 50 per cent flowering ranged from 32.00 days (GRB-803 and Phule Suyash) to 37.00 days (GRB-804) with a population mean 34.48 days (Table 4.1.1). The genotype, GRB-803, as well as Phule Suyash (32.00 days) was the earliest to flower which was at par with the Vaghya (33.00 days), while GRB- 804 was late in flowering followed by GRB-702 (36.33 days).

In second environment (E_2) days to 50 per cent flowering ranged from 32.00 days (GRB-803 and Phule Suyash) to 36.53 days (GRB-804) with a population mean 34.34 days. The genotype GRB-803 as well as Phule Suyash (32.00 days) was the earliest to flower, followed by the Vaghya (33.00 days), while GRB- 804 (36.53 days) was late in flowering followed by GRB-702 (35.66 days).

Table 4.1.1 Mean performance of Rajmash genotypes for days to 50 per cent flowering over environments

Sr. No.	Genotypes	Days to 50% flowering (No.)				
		E_1	E_2	E_3	E_4	Mean
1	GRB - 701	35.46	35.26	34.00	30.00	33.68
2	GRB - 702	36.33	35.66	35.00	33.00	35.00
3	GRB - 803	32.00	32.00	31.46	30.53	31.50
4	GRB - 804	37.00	36.53	36.20	34.93	36.16
5	GRB - 902	35.00	34.46	33.00	32.53	33.75
6	GRB - 9810	34.00	34.00	33.40	32.33	33.43
7	HPR - 35	35.00	35.00	33.66	32.40	34.01
8	Phule Suyash	32.00	32.00	31.20	30.73	31.48
9	Vaghya	33.00	33.00	32.20	31.13	32.33
10	Varun (check)	35.00	34.46	33.33	32.40	33.80
11	Mean	34.48	34.34	33.44	32.00	33.54
12	S.E +/-	0.88	0.10	0.23	0.27	0.25
13	CD@5%	1.86	0.22	0.50	0.57	

In third environment (E_3), days to 50 per cent flowering ranged from 31.20 days (Phule Suyash) to 36.20 days (GRB-804) with a population mean 33.44 days. The genotype, Phule Suyash (31.20 days), was the earliest to flower, followed by GRB-803 (31.46 days), while GRB- 804 (36.20 days) late in flowering followed by GRB-702 (35.00 days).

In fourth environment (E_4), days to 50 per cent flowering ranged from 30.00 days (GRB-701) to 34.93 days (GRB-804) with a population mean 32.00 days. The genotype, GRB-701 (30.00 days) was the earliest to flower followed by GRB-803 (30.53 days), while GRB- 804 was late in flowering followed by GRB-702 (33.00 days).

Means over four environments ranged from 31.48 days (Phule Suyash) to 36.16 days (GRB-804) days with population mean 33.54 days. The genotype Phule Suyash and GRB-803 consistently recorded early flowering in each of the environments.

4.1.2: Mean performance of Rajmash genotypes for days to maturity over environments

In first environment (E_1) days to maturity ranged from 72.00 days (GRB-803, Phule Suyash and Varun) to 75.80 days (GRB-9810) with a population mean 74.12 days (Table 4.1.2). The genotypes GRB-803, Phule Suyash and Varun (72.00 days) was the earliest to mature, while GRB-9810 was late in maturity followed by GRB-702 (75.73 days).

In second environment (E_2) days to maturity varied from 71.40 days (Varun) to 75.46 days (GRB-9810) with a population mean 73.76 days. The genotype Varun (71.40 days) was the earliest to mature followed by GRB-803 (71.60 days), while GRB-9810 (75.46 days) was late in maturity followed by GRB-702 (75.33 days).

Table 4.1.2 Mean performance of Rajmash genotypes for days to maturity over environments

Sr. No.	Genotypes	Days to maturity (No.)				
		E_1	E_2	E_3	E_4	Mean
1	GRB - 701	75.40	75.06	74.40	72.26	74.28
2	GRB - 702	75.73	75.33	74.73	72.66	74.61
3	GRB - 803	72.00	71.60	70.93	70.40	71.23
4	GRB - 804	73.33	72.33	70.80	70.46	71.73
5	GRB - 902	75.00	75.00	74.46	72.86	74.33
6	GRB - 9810	75.80	75.46	74.33	73.00	74.65
7	HPR - 35	75.00	74.46	73.33	72.60	73.85
8	Phule Suyash	72.00	72.00	70.73	69.86	71.15
9	Vaghya	75.00	75.00	73.73	72.26	74.00
10	Varun (check)	72.00	71.40	70.26	69.13	70.70
11	Mean	74.12	73.76	72.77	71.55	73.05
12	S.E +/-	0.33	0.10	0.26	0.29	0.17
13	CD@5%	0.70	0.22	0.55	0.61	

The performance of third environment (E_3) for days to maturity ranged from 70.26 days (Varun) to 74.73 days (GRB-702) with a population mean 72.77 days. The genotype Varun was the earliest to mature (70.26 days) followed by the 70.73 days (Phule Suyash) while GRB- 702 (74.73 days) was late in maturity followed by GRB-9810 (74.33 days).

In fourth environment (E_4) days to maturity ranged from 69.13 days (Varun) to 73.00 (GRB-9810) with a population mean 71.55 days. The genotype Varun (69.13 days) was the earliest to mature, which was followed by Phule Suyash (69.86 days), while GRB-9810 (73.00 days) was late in maturity followed by GRB-902 (72.86 days).

Mean performance over four environments ranged from 70.70 days (Varun) to 74.65 days (GRB-9810) with population mean 73.05 days. The genotype Varun as well as Phule Suyash consistently recorded early maturity in each of the environments.

4.1.3: Mean performance of Rajmash genotypes for plant height over environments

In first environment (E_1) plant height ranged from 52.00 cm (Phule Suyash) to 58.13 cm (GRB-902) with a population mean 55.15 cm (Table 4.1.3). The genotype GRB-902 (58.13 cm) showed highest plant height followed by Varun (57.20 cm), GRB-702 (56.86 cm) and Phule Suyash showed lowest (52.00 cm) plant height.

In second environment (E_2) population mean was 53.80 cm for plant height, which ranged from 50.53 cm (Phule Suyash) to 57.86 cm (GRB-902). The genotype GRB-902 (57.86 cm) showed highest plant height followed by Varun (56.33 cm), GRB-702 (55.20 cm) and Phule Suyash (50.53 cm) showed lowest plant height.

Table 4.1.3 Mean performance of Rajmash genotypes for plant height over environments

Sr. No.	Genotypes	Plant height (cm)				
		E_1	E_2	E_3	E_4	Mean
1	GRB - 701	55.06	53.66	52.13	50.86	52.93
2	GRB - 702	56.86	55.20	54.53	52.86	54.86
3	GRB - 803	53.00	52.13	50.33	49.53	51.25
4	GRB - 804	54.06	53.40	52.46	50.93	52.71
5	GRB - 902	58.13	57.86	54.60	52.13	55.68
6	GRB - 9810	55.00	53.26	52.80	50.46	52.88
7	HPR - 35	54.06	51.78	50.80	50.20	51.71
8	Phule Suyash	52.00	50.53	50.33	49.26	50.53
9	Vaghya	56.13	53.86	52.26	51.80	53.51
10	Varun (check)	57.20	56.33	53.20	51.46	54.55
11	Mean	55.15	53.80	52.34	50.95	53.06
12	S.E +/-	0.88	1.00	0.73	0.65	0.30
13	CD@5%	1.86	2.11	1.53	1.36	

In third environment (E_3) plant height ranged from 50.33 cm (GRB-803 and Phule Suyash) to 54.60 cm (GRB-902) with a population mean 52.34 cm. The genotype GRB-803 and Phule Suyash (50.33 cm) showed lowest plant height, while GRB-902 (54.60 cm) showed highest plant height followed by GRB-702 (54.53 cm) and Varun (53.20 cm).

In fourth environment (E_4) plant height ranged from 49.26 cm (Phule Suyash) to 52.86 cm (GRB-702) with a population mean 50.95 cm. The genotype GRB-803 and Phule Suyash (49.53 cm and 49.26 cm respectively) recorded lowest plant height, while GRB-702 (52.86 cm) showed highest plant height followed by GRB-902 (52.13 cm) and Vaghya (51.80 cm).

Mean performance over four environments ranged from 50.53 cm (Phule Suyash) to 55.68 cm (GRB-902) with population mean 53.06 cm. Among the genotypes GRB-902 consistently recorded maximum plant height in each of the environments.

4.1.4: Mean performance of Rajmash genotypes for plant spread over environments.

In first environment (E_1) plant spread ranged from 13.60 cm (Phule Suyash) to 16.86 cm (GRB-902) with a population mean 14.94 cm (Table 4.1.4). Genotype Phule Suyash (13.60 cm) showed lowest while GRB-902 (16.86 cm) showed highest plant spread followed by Varun (15.86 cm) and Vaghya (15.26 cm).

In second environment (E_2) for plant spread ranged from 13.06 cm (Phule Suyash) to 16.06 cm (GRB-902) with a population mean 14.30 cm. Phule Suyash (13.06 cm) showed lowest, while GRB-902 (16.06 cm) showed highest plant spread followed by Varun (15.20 cm) and Vaghya (15.00 cm).

Table 4.1.4 Mean performance of Rajmash genotypes for plant spread over environments.

Sr. No	Genotypes	Plant spread (cm)				
		E_1	E_2	E_3	E_4	Mean
1	GRB - 701	14.40	14.20	12.93	13.06	13.65
2	GRB - 702	15.20	14.40	14.26	13.60	14.36
3	GRB - 803	14.00	13.26	12.26	11.46	12.75
4	GRB - 804	14.26	13.33	12.80	11.73	13.03
5	GRB - 902	16.86	16.06	15.06	14.00	15.50
6	GRB - 9810	14.73	14.46	12.66	11.40	13.31
7	HPR - 35	15.20	14.00	13.40	12.26	13.71
8	Phule Suyash	13.60	13.06	12.46	12.00	12.78
9	Vaghya	15.26	15.00	13.26	12.73	14.06
10	Varun (check)	15.86	15.20	14.40	13.73	14.80
11	Mean	14.94	14.30	13.35	12.60	13.79
12	S.E +/-	0.38	0.24	0.36	0.53	0.13
13	CD@5%	0.80	0.50	0.76	1.12	

In third environment (E_3) population mean for plant spread was 13.35 cm, which ranged from 12.26 cm (GRB-803) to 15.06 cm (GRB-902). The genotype GRB-803 (12.26 cm) showed lowest, while GRB-902 (15.06 cm) showed highest plant spread followed by Varun (14.40 cm) and GRB-702 (14.26 cm)

In fourth environment (E_4) plant spread ranged from 11.40 cm (GRB-9810) to 14.00 cm (GRB-902) with a population mean 12.60 cm. Genotypes GRB-9810 (11.40 cm) and GRB-803 (11.46 cm) showed lowest, while GRB-902 (14.00 cm) showed highest plant spread followed by Varun (13.73 cm) and GRB-702 (13.60 cm).

Mean performance over four environments ranged from 12.75 cm (GRB-803) to 15.50 cm (GRB-902) with population mean 13.79 cm. Among the genotypes GRB-902 consistently recorded maximum plant spread in each of the environments.

4.1.5: Mean performance of Rajmash genotypes for primary branches per plant over environments.

In first environment (E_1**)** primary branches per plant ranged from 2.80 (HPR-35) to 3.00 (GRB-902) with a population mean 2.88 (Table 4.1.5) .The genotype HPR-35 (2.80) showed lowest primary branches per plant, while GRB-902 (3.00) showed highest primary branches per plant followed by GRB-9810 (2.93) and Varun (2.93).

In second environment (E_2) primary branches per plant ranged from 2.40 (GRB-804) to 2.93 (GRB-902) with a population mean 2.76. The genotype GRB-804 (2.40) showed lowest, while GRB-902 (2.93) showed highest primary branches per plant followed by GRB-803 (2.86).

In third environment (E_3) primary branches per plant ranged from 2.46 (GRB-701) to 2.73 (GRB-902, HPR-35, Phule Suyash and Varun) with a population mean 2.66. The genotype GRB-701 (2.46) showed

Table 4.1.5 Mean performance of Rajmash genotypes for primary branches per plant over environments.

Sr. No.	Genotypes	Primary branches per plant (No.)				
		E_1	E_2	E_3	E_4	Mean
1	GRB - 701	2.86	2.73	2.46	2.40	2.61
2	GRB - 702	2.86	2.80	2.66	2.53	2.71
3	GRB - 803	2.86	2.86	2.66	2.60	2.75
4	GRB - 804	2.86	2.40	2.60	2.40	2.56
5	GRB - 902	3.00	2.93	2.73	2.73	2.85
6	GRB - 9810	2.93	2.80	2.66	2.66	2.76
7	HPR - 35	2.80	2.80	2.73	2.60	2.73
8	Phule Suyash	2.86	2.80	2.73	2.46	2.71
9	Vaghya	2.86	2.66	2.60	2.53	2.66
10	Varun (check)	2.93	2.80	2.73	2.40	2.71
11	Mean	2.88	2.76	2.66	2.53	2.71
12	S.E +/-	0.13	0.10	0.10	0.05	0.04
13	CD@5%	-	0.21	-	0.11	

lowest, while GRB-902, HPR-35, Phule Suyash and Varun (2.73) showed highest primary branches per plant.

The performance of fourth environment (E_4) for primary branches per plant ranged from 2.40 (GRB-701, GRB-804 and Varun) to 2.73 (GRB-902) with a population mean 2.53. The genotypes GRB-701, GRB-804 and Varun (2.40) showed lowest primary branches per plant, while GRB-902 (2.73) showed highest primary branches per plant followed by GRB-9810 (2.66).

Mean performance over four environments ranged from 2.56 (GRB-804) to 2.85 (GRB-902) with population mean 2.71. Among the genotypes GRB-902 consistently recorded maximum primary branches per plant than rest of the genotypes in each of the environments.

4.1.6: Mean performance of Rajmash genotypes for secondary branches per plant over environments.

In first environment (E_1), secondary branches per plant ranged from 4.66 (GRB-803) to 5.06 (GRB-702 and Varun) with a population mean 4.89 (Table 4.1.6). Genotype GRB-803 (4.66) showed lowest, while GRB-702 and Varun (5.06) showed highest secondary branches per plant followed by GRB-902 (5.03).

In second environment (E_2) secondary branches per plant ranged from 4.53 (GRB-803) to 5.06 (GRB-902) with a population mean 4.82. The genotype GRB-803 (4.53) showed lowest, while GRB-902 (5.06) showed highest secondary branches per plant followed by GRB-701, GRB-702 and Varun (4.93).

Secondary branches per plant in third environment (E_3) ranged from 4.60 (GRB-803) to 4.80 (GRB-702 and Phule Suyash) with a population mean 4.70. The genotype GRB-803 (4.60) showed lowest, while GRB-702 and Phule Suyash (4.80) showed highest secondary branches per plant.

Table 4.1.6 Mean performance of Rajmash genotypes for secondary branches per plant over environments.

Sr. No.	Genotypes	Secondary branches per plant (No.)				
		E_1	E_2	E_3	E_4	Mean
1	GRB - 701	4.73	4.93	4.66	4.60	4.73
2	GRB - 702	5.06	4.93	4.80	4.73	4.88
3	GRB - 803	4.66	4.53	4.60	4.46	4.56
4	GRB - 804	4.73	4.66	4.73	4.40	4.63
5	GRB - 902	5.03	5.06	4.73	4.60	4.85
6	GRB - 9810	4.86	4.66	4.73	4.53	4.70
7	HPR - 35	5.00	4.86	4.66	4.53	4.76
8	Phule Suyash	4.93	4.73	4.80	4.46	4.73
9	Vaghya	4.86	4.86	4.66	4.46	4.71
10	Varun (check)	5.06	4.93	4.66	4.60	4.81
11	Mean	4.89	4.82	4.70	4.54	4.74
12	S.E +/-	0.14	0.11	0.09	0.07	0.05
13	CD@5%	0.30	0.24	-	0.15	

In fourth environment (E_4) secondary branches per plant ranged from 4.40 (GRB-804) to 4.73 (GRB-702) with a population mean 4.54. The genotype GRB-804 (4.40) showed lowest while GRB-702 (4.73) showed highest secondary branches per plant followed by GRB-701, GRB-902, and Varun (4.60).

Mean performance over four environments ranged from 4.56 (GRB-803) to 4.88 (GRB-702) with population mean 4.74. Among the genotypes GRB-902 and GRB-702 consistently recorded maximum secondary branches per plant in each of the environments.

4.1.7: Mean performance of Rajmash genotypes for number of pods per plant over environments.

In first environment (E_1**)** pods per plant ranged from 10.93 (Phule Suyash) to 17.26 (GRB-902) with a population mean 14.37 (Table 4.1.7). The genotype Phule Suyash (10.93) showed least pods per plant, while GRB-902 (17.26) showed highest pods per plant followed by GRB-9810 (15.73) and Varun (15.26).

In second environment (E_2**)** pods per plant ranged from 11.80 (Phule Suyash) to 15.76 (GRB-902) with a population mean 13.59. The genotype Phule Suyash (11.80) showed least pods per plant, while GRB-902 (15.76) showed highest pods per plant followed by Varun (14.86) and GRB-702 (14.53).

The performance of third environment (E_3) for pods per plant ranged from 11.46 (HPR-35) to 14.33 (GRB-902) with a population mean 12.55. The genotype HPR-35 (11.46) showed least pods per plant, while GRB-902 (14.33) showed highest pods per plant followed by GRB-702 (13.53) and Varun (13.26).

Table 4.1.7 Mean performance of Rajmash genotypes for number of pods per plant over environments.

Sr. No.	Genotypes	Pods per plant (No.)				
		E_1	E_2	E_3	E_4	Mean
1	GRB - 701	14.00	14.00	12.73	12.33	13.26
2	GRB - 702	15.06	14.53	13.53	13.26	14.10
3	GRB - 803	13.46	12.86	11.73	11.73	12.45
4	GRB - 804	13.80	12.53	12.20	11.80	12.58
5	GRB - 902	17.26	15.76	14.33	12.73	15.02
6	GRB - 9810	15.73	13.50	12.60	11.53	13.34
7	HPR - 35	13.60	12.26	11.46	11.53	12.21
8	Phule Suyash	10.93	11.80	11.66	10.40	11.20
9	Vaghya	14.60	13.80	12.00	11.46	12.96
10	Varun (check)	15.26	14.86	13.26	12.53	13.98
11	Mean	14.37	13.59	12.55	11.93	13.13
12	S.E +/-	0.45	0.51	0.57	0.61	0.22
13	CD@5%	0.96	1.07	1.21	1.29	

In fourth environment (E_4) pods per plant ranged from 10.40 (Phule Suyash) to 13.26 (GRB-702) with a population mean 11.93. The genotype Phule Suyash (10.40) showed least pods per plant, while GRB-702 (13.26) showed highest pods per plant followed by GRB-902 (12.73) and Varun(12.53)

Mean performance over four environments ranged from 11.20 (Phule Suyash) to 15.02 (GRB-902) with population mean 13.13. Among the genotypes GRB-902 and GRB-702 consistently recorded maximum pods per plant than rest of the genotypes in each of the environments.

4.1.8: Mean performance of Rajmash genotypes for number of seeds per pod over environments.

First environment (E_1) for seeds per pod ranged from 4.06 (GRB-803 and GRB-804) to 4.26 (GRB-702 and Phule Suyash) with a population mean 4.16 (Table 4.1.8). The genotypes GRB-803 and GRB-804 (4.06) showed lowest seeds per pod, while GRB-702 and Phule Suyash (4.26) showed highest seeds per pod.

In second environment (E_2) seeds per pod ranged from 4.00 (GRB-9810 and Varun) to 4.20 (GRB-701 and Vaghya) with a population mean 4.09. The genotype GRB-9810 and Varun (4.00) showed lowest seeds per pod, while GRB-701 and Vaghya (4.20) showed highest seeds per pod followed by HPR-35 and Phule Suyash (4.13).

In third environment (E_3) seeds per pod ranged from 3.93 (GRB-701, GRB-803 and GRB-804) to 4.20 (GRB-902 and Vaghya) with a population mean 4.04. The genotypes GRB-701, GRB-803 and GRB-804 (3.93) showed lowest seeds per pod, while GRB-902 and Vaghya (4.20) showed highest seeds per pod followed by GRB-702 (4.13).

Table 4.1.8: Mean performance of Rajmash genotypes for number of seeds per pod over environments.

Sr. No.	Genotypes	Seeds per pod (No.)				
		E_1	E_2	E_3	E_4	Mean
1	GRB - 701	4.20	4.20	3.93	3.66	4.00
2	GRB - 702	4.26	4.06	4.13	4.20	4.16
3	GRB - 803	4.06	4.06	3.93	4.00	4.01
4	GRB - 804	4.06	4.06	3.93	3.93	4.00
5	GRB - 902	4.20	4.06	4.20	4.00	4.11
6	GRB - 9810	4.20	4.00	4.06	4.00	4.06
7	HPR - 35	4.13	4.13	4.00	4.00	4.06
8	Phule Suyash	4.26	4.13	4.00	3.53	3.98
9	Vaghya	4.13	4.20	4.20	3.86	4.10
10	Varun (check)	4.13	4.00	4.06	3.93	4.03
11	Mean	4.16	4.09	4.04	3.91	4.05
12	S.E +/-	0.14	0.11	0.11	0.14	0.04
13	CD@5%	-	-	0.24	0.30	

In fourth environment (E_4) seeds per pod ranged from 3.53 (Phule Suyash) to 4.20 (GRB-702) with a population mean 3.91. The genotype Phule Suyash (3.53) showed lowest pods per plant, while GRB-702 (4.20) showed highest seeds per pod followed by GRB-803, GRB-902, GRB-9810 and HPR-35 (4.00).

Mean performance over four environments ranged from 3.98 (Phule Suyash) to 4.16 (GRB-702) with population mean 4.05. Among the genotypes GRB-702 and GRB-902 consistently recorded maximum seeds per pod in each of the environments.

4.1.9: Mean performance of Rajmash genotypes for 100-seed weight over environments.

In first environment (E_1) 100-seed weight ranged from 31.93 g (GRB-9810) to 35.00 g (GRB-803 and GRB-902) with a population mean 33.56 g (Table 4.1.9).The genotype GRB-9810 (31.93 g) showed lowest, while GRB-803 and GRB-902 (35.00 g) showed highest 100-seed weight followed by HPR-35 (34.60 g).

The performance of second environment (E_2) for 100-seed weight ranged from 32.00 g (GRB-9810) to 35.20 g (GRB-803) with a population mean 33.51 g. The genotype GRB-9810 (32.00) showed lowest, while GRB-803 (35.20) showed highest 100-seed weight followed by HPR-35 (34.66 g).

In third environment (E_3) a population mean was 33.21 g for 100-seed weight which ranged from 31.86 g (GRB-9810) to 34.86 g (GRB-803). The genotype GRB-9810 (31.86 g) showed lowest, while GRB-803 (34.86 g) showed highest 100-seed weight followed by HPR-35 (34.70 g).

Table 4.1.9: Mean performance of Rajmash genotypes for 100- seed weight over environments.

Sr. No.	Genotypes	100-seed weight (g)				
		E_1	E_2	E_3	E_4	Mean
1	GRB - 701	34.00	33.60	33.23	33.00	33.45
2	GRB - 702	32.33	32.73	32.00	32.26	32.33
3	GRB - 803	35.00	35.20	34.86	34.13	34.80
4	GRB - 804	34.33	33.40	33.00	32.80	33.38
5	GRB - 902	35.00	34.50	34.00	34.00	34.37
6	GRB - 9810	31.93	32.00	31.86	31.93	31.93
7	HPR - 35	34.60	34.66	34.70	34.30	34.56
8	Phule Suyash	32.13	32.23	31.90	32.16	32.10
9	Vaghya	32.26	33.00	32.86	33.00	32.78
10	Varun (check)	34.00	33.83	33.73	33.60	33.79
11	Mean	33.56	33.51	33.21	33.12	33.35
12	S.E +/-	0.18	0.22	0.17	0.15	0.14
13	CD@5%	0.37	0.46	0.37	0.32	

In fourth environment (E_4) 100-seed weight ranged from 31.93 g. (GRB-9810) to 34.30 g (HPR-35) with a population mean 33.12 g. The genotypes GRB-9810 (31.93 g) showed lowest, while HPR-35 (34.30 g) showed highest 100-seed weight followed by GRB-803 (34.13 g)

Mean performance over four environments ranged from 31.93 g. (GRB-9810) to 34.80 g (GRB-803) with a population mean 33.35 g. Among the genotypes GRB-9810 consistently recorded maximum 100-seed weight in each of the environments.

4.1.10: Mean performance of Rajmash genotypes for harvest index over environments.

In first environment (E_1) harvest index ranged from 25.19 % (Phule Suyash) to 55.61 % (GRB-902) with a population mean 47.02 % (Table 4.1.10). The genotype Phule Suyash (25.13 %) showed lowest harvest index followed by HPR-35 (37.94 %), while genotype GRB-902 (55.61%) showed highest harvest index followed by GRB-702 (52.98 %).

In second environment (E_2) harvest index ranged from 23.04 % (Phule Suyash) to 53.95 % (GRB-902) with a population mean 45.40 %. The genotype Phule Suyash (23.04 %) showed lowest harvest index followed by HPR-35 (36.39 %), while GRB-902 (53.95 %) showed highest harvest index followed by GRB-702 (52.87 %).

In third environment (E_3) harvest index ranged from 20.46 % (Phule Suyash) to 52.50 % (GRB-902) with a population mean 44.12 %. The genotype Phule Suyash (20.46 %) showed lowest harvest index followed by HPR-35 (36.10 %), while GRB-902 (52.50 %) showed highest harvest index followed by GRB-702 (49.73 %).

Table 4.1.10 Mean performance of Rajmash genotypes for harvest index over environments.

Sr. No.	Genotypes	Harvest Index (%)				
		E_1	E_2	E_3	E_4	Mean
1	GRB - 701	52.26	50.84	49.62	48.99	50.43
2	GRB - 702	52.98	52.87	49.73	48.68	51.07
3	GRB - 803	48.26	46.26	46.96	44.67	46.53
4	GRB - 804	43.60	42.02	41.39	40.96	42.00
5	GRB - 902	55.61	53.95	52.50	51.70	53.44
6	GRB - 9810	50.41	49.21	47.45	46.87	48.48
7	HPR - 35	37.94	36.39	36.10	33.53	36.00
8	Phule Suyash	25.19	23.04	20.46	18.70	21.85
9	Vaghya	51.33	48.85	48.00	45.39	48.39
10	Varun (check)	52.66	50.63	49.04	47.90	50.06
11	Mean	47.02	45.40	44.12	42.73	44.82
12	S.E +/-	2.48	1.62	2.14	1.66	0.39
13	CD@5%	5.22	3.40	4.51	3.48	

In fourth environment (E_4) harvest index ranged from 18.70 % (Phule Suyash) to 51.70 % (GRB-902) with a population mean 42.73 %. The genotype Phule Suyash (18.70 %) showed lowest harvest index followed by HPR-35 (33.53 %), while GRB-902 (51.70 %) showed highest harvest index followed by GRB-701 (48.99 %).

Mean performance over four environments ranged from 21.85 % (Phule Suyash) to 53.44 % (GRB-902) with population mean 44.82 %. Among the genotypes GRB-902 consistently recorded maximum harvest index in each of the environments, while Phule Suyash consistently recorded minimum harvest index in each of the environments.

4.1.11: Mean performance of Rajmash genotypes for seed yield per plant over environments.

In first environment (E_1) seed yield per plant ranged from 14.46 g (Phule Suyash) to 23.53 g (GRB-902) with a population mean 19.56 g (Table 4.1.11). The genotype Phule Suyash (14.46 g) showed lowest yield per plant, while GRB-902 (23.53 g) showed highest seed yield per plant followed by GRB-702 (22.90 g) and GRB-701 (20.80 g).

In second environment (E_2) seed yield per plant ranged from 10.80 g (Phule Suyash) to 20.80 g (GRB-902) with a population mean 17.60 g The genotype Phule Suyash (10.80 g) showed lowest seed yield per plant, while GRB-902 (20.80 g) showed highest seed yield per plant followed by GRB-701 (20.10 g) and GRB-702 (20.03 g).

In third environment (E_3) seed yield per plant ranged from 9.26 g (Phule Suyash) to 17.56 g (GRB-902) with a population mean 15.40 g The genotype Phule Suyash (9.26) showed lowest seed yield per plant, while GRB-902 (17.56) showed highest seed yield per plant followed by GRB-702 (18.23 g).

Table 4.1.11 Mean performance of Rajmash genotypes for seed yield per plant over environments.

Sr. No.	Genotypes	Seed yield per plant (g)				
		E_1	E_2	E_3	E_4	Mean
1	GRB - 701	20.80	20.10	16.93	14.33	18.04
2	GRB - 702	22.90	20.03	18.23	16.36	19.38
3	GRB - 803	17.96	17.06	15.60	13.83	16.11
4	GRB - 804	16.90	16.80	15.53	13.20	15.60
5	GRB - 902	23.53	20.80	17.56	16.53	19.60
6	GRB - 9810	19.80	17.00	14.50	12.83	16.03
7	HPR - 35	19.10	16.40	14.20	12.63	15.58
8	Phule Suyash	14.46	10.80	9.26	7.33	10.46
9	Vaghya	19.73	17.40	14.86	13.76	16.44
10	Varun (check)	20.46	19.60	17.33	15.60	18.25
11	Mean	19.56	17.60	15.40	13.64	16.55
12	S.E +/-	0.87	1.20	0.74	0.65	0.32
13	CD@5%	1.83	2.53	1.55	1.38	

In fourth environment (E_4) seed yield per plant ranged from 7.33 g. (Phule Suyash) to 16.53 g (GRB-902) with a population mean 13.64 g. The genotype Phule Suyash (7.33 g) showed lowest seed yield per plant, while GRB-902 (16.53) showed highest seed yield per plant followed by GRB-702 (16.36 g).

Mean performance over four environments ranged from 10.46 g (Phule Suyash) to 19.60 g (GRB-902) with population mean 16.55 g. Among the genotypes GRB-902 and GRB-702 consistently recorded maximum seed yield per plant in each of the environments.

4.1.12: Mean performance of Rajmash genotypes for seed yield per hectare over environments.

In first environment (E_1) seed yield per hectare ranged from 1380.66 kg/ha (Phule Suyash) to 2345.00 kg/ha (GRB-902) with a population mean 1940.60 kg/ha (Table 4.1.12). The genotype Phule Suyash (1380.66 kg/ha) showed lowest yield per ha, while GRB-902 (2345.00 kg/ha) showed highest seed yield per ha followed by GRB-702 (2226.00 kg/ha).

In second environment (E_2) seed yield per hectare ranged from 1044.66 kg/ha (Phule Suyash) to 2238.66 kg/ha (GRB-902) with a population mean 1784.83 kg/ha. The genotype Phule Suyash (1044.66 kg /ha) showed lowest seed yield per plant, while GRB-902 (2238.66 kg/ha) showed highest seed yield per hectare followed by GRB-702 (2034.66 kg/ha).

In third environment (E_3**)** seed yield per hectare ranged from 937.33 kg/ha (Phule Suyash) to 1903.33 kg/ha (GRB-902) with a population mean 1584.70 kg/ha. The genotype Phule Suyash (937.33 kg/ha) showed lowest seed yield, while GRB-902 (1903.33 kg/ha) showed highest seed yield followed by GRB-702 (1875.33 kg/ha).

In fourth environment (E_4) seed yield per hectare ranged from 751.66 kg/ha (Phule Suyash) to 1676.66 kg/ha (GRB-902) with a population mean 1363.33 kg/ha. The genotype Phule Suyash (751.66 kg/ha) showed lowest seed yield per ha, while GRB-902 (1676.66 kg/ha) showed highest seed yield per hectare followed by GRB-702 (1670.00 kg/ha).

Mean performance over four environments ranged from 1028.58 kg/ha (Phule Suyash) to 2040.91 kg/ha (GRB-902) with population mean 1668.40 kg/ha. Among the genotypes GRB-902 and GRB-702 consistently recorded maximum seed yield per ha. in each of the environments.

Table 4.1.12: Mean performance of Rajmash genotypes for seed yield per hectare over environments.

Sr. No.	Genotypes	Seed yield (kg/ha)				
		E_1	E_2	E_3	E_4	Mean
1	GRB - 701	2126.66	2034.66	1723.33	1496.00	1845.16
2	GRB - 702	2226.00	2034.66	1875.33	1670.00	1951.50
3	GRB - 803	1773.33	1612.00	1518.66	1309.33	1553.33
4	GRB - 804	1683.33	1647.00	1540.33	1309.33	1545.00
5	GRB - 902	2345.00	2238.66	1903.33	1676.66	2040.91
6	GRB - 9810	2051.33	1832.66	1553.33	1278.33	1678.91
7	HPR - 35	1876.66	1745.66	1487.33	1238.00	1586.91
8	Phule Suyash	1380.66	1044.66	937.33	751.66	1028.58
9	Vaghya	1908.66	1712.66	1544.00	1352.66	1629.50
10	Varun (check)	2034.33	1945.66	1764.00	1551.33	1823.83
11	Mean	1940.60	1784.83	1584.70	1363.33	1668.40
12	S.E +/-	47.06	56.03	39.97	43.19	26.00
13	CD@5%	98.87	117.71	83.98	90.75	

4.2 Season wise mean sum of squares

The mean sum of squares due to treatments under each environment for all characters studied in E_1, E_2, E_3 and E_4 are given in table 4.2. The difference due to treatments were highly significant for all characters except primary branches per plant (E_1, E_2 and E_3), secondary branches per plant (E_1, E_2 and E_4) and seeds per pod (E_1, E_2 and E_3).

4.3 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, primary branches per plant, secondary branches per plant, pods per plant, seeds per pod, 100-seed weight, harvest index, seed yield per plant and seed yield per ha was done. The analysis revealed that genotypes exhibited highly significant differences for all the characters under study (Table 4.3).

Pooled analysis of variance over four different environment showed that, genotypic variance and E + (G x E) were significant for all the characters *viz.*, days to 50 per cent 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, yield per hectare and harvest index, when tested against pooled deviation, pooled error and G x E interaction. Environmental variances were found significant for the characters *viz.,* plant height, secondary branches per plant, seeds per pod and harvest index against pooled error.

Partitioning of G x E interaction showed that, G x E (linear) effect were significant for the characters *viz*., days to 50 per cent flowering, plant height, plant spread, pods per plant, seeds per pod, 100-seed weight, seed yield per plant and seed yield per ha, 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 (Ij) are presented in Table 4.4 which revealed that environment E_1 (20th June) was favourable for all characters *viz.*, plant height (2.08), plant spread (1.14), pods per plant (1.26), 100-seed weight (0.20), harvest index (2.13), seed yield per plant (3.01) and seed yield per hectare (272.23), except days to 50 per cent flowering and days to maturity.

Environment E_2 (10th July) was also favourable for characters *viz.*, plant height (0.74), harvest index (0.74), seed yield per plant (1.04) and seed yield per hectare (116.46), except days to 50 per cent flowering and days to maturity.

Third environment E_3 (30th July) was favourable for none of the character. Environment E_4 (20th August) was favourable for characters only for days to 50 per cent flowering (-1.54) and days to maturity (-1.50) showed minimum deviation for fourth environment.

In general environment E_1 was most favourable for yield and yield contributing characters.

Table 4.2: Analysis of variance (MSS) for twelve characters at four different environments

Sr. No.	Characters	Mean Sum of squares due to											
		E1			E2			E3			E4		
		Rep	Treat	Error	Rep	Treat	Error	Rep	Treat	Error	Rep	Treat	Error
1	Days to 50% flowering (No.)	1.45	7.38**	1.18	0.02	8.71**	0.01	0.14	9.19**	0.08	0.11	6.27**	0.11
2	Days to maturity (No.)	0.10	7.82**	0.16	0.02	8.67**	0.01	0.28	10.24**	0.10	0.02	6.12**	0.12
3	Plant height (cm)	0.80	11.31**	1.17	5.15**	14.30**	1.52	1.96	7.11**	0.79	0.66	3.90**	0.63
4	Plant spread (cm)	0.24	2.75**	0.22	0.07	2.69**	0.08	0.02	2.59**	0.19	0.02	2.80**	0.42
5	Pri. branches per plant (No.)	0.01	0.01	0.028	0.03	0.06**	0.01	0.02	0.02	0.01	0.02**	0.04**	0.01
6	Sec. branches per plant (No.)	0.20**	0.06	0.03	0.07**	0.08**	0.01	0.01	0.01	0.01	0.01	0.02	0.01
7	Pods per plant (No.)	0.58	8.42**	0.31	0.08	4.69**	0.39	0.24	2.58**	0.49	1.23**	1.96	0.57
8	Seeds per pod (No.)	0.20**	0.01	0.03	0.03	0.01	0.01	0.01	0.03	0.02	0.02	0.10**	0.03
9	100-seed weight (g)	0.02	4.69**	0.04	0.11	3.35**	0.07	0.02	3.66**	0.04	0.10**	2.20**	0.03
10	Harvest index (%)	8.54	256.50**	9.29	0.62	271.61**	3.94	4.73	271.16**	6.91	2.12	295.24**	4.13
11	Seed yield per plant (g))	3.43**	21.71**	1.13	0.83	25.13**	2.18	2.47	19.67**	0.82	0.32	20.60**	0.64
12	Seed yield (kg/ha)	4963	23781**	3322	1795	320803**	4709	5962	224965**	2396	12297**	216060**	2798

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

Table 4.4 Estimation of environmental index for all twelve characters

Sr. No.	Characters	Environmental index (Ij)			
		E_1	E_2	E_3	E_4
1.	Days to 50 % flowering (No.)	0.83	0.79	-0.09	-1.54
2.	Day to maturity (No.)	1.07	0.71	-0.28	-1.50
3.	Plant height (cm)	2.08	0.74	-0.71	-2.11
4.	Plant spread (cm)	1.14	0.50	-0.44	-1.19
5.	Primary branches per plant (No.)	0.17	0.05	-0.05	-0.17
6.	Secondary branches per plant (No.)	0.15	0.07	-0.03	-0.20
7.	Pods per plant (No.)	1.26	0.48	-0.56	-1.18
8.	Seeds per pod (No.)	0.11	0.03	-0.00	-0.14
9.	100-seed weight (g)	0.20	0.16	-0.13	-0.23
10.	Harvest index (%)	2.13	0.74	-0.90	-1.98
11.	Seed yield per plant (g)	3.01	1.04	-1.15	-2.91
12.	Seed yield (kg/ha)	272.23	116.46	-83.66	-305.03

4.5 Stability Parameters

Since G x E interaction was detected, the stability parameters were estimated and are presented in Tables 4.5.1 to 4.5.12. High mean across environments (beyond + SE values), bi around unity and S^2di values as small as possible were considered for selecting stable and promising genotypes. The range of variation for mean performance over four environments (Xi), linear regression coefficient (bi) and deviation from regression (S^2di) for the characters studied are presented given below.

4.5.1 Days to 50 per cent flowering (No.)

The means for days to 50 per cent flowering varied from 31.48 days (Phule Suyash) to 36.41 days (GRB-804) with an average of 33.54 days over four environments. The genotypes GRB-803 (31.50 days), Phule Suyash (31.48 days), Vaghya (32.33 days) and GRB-9810 (33.43 days), were early in flowering across the four environments (Table 4.5.1).

Estimate of stability parameters for days to 50 per cent flowering revealed that the genotype Vaghya had more stabilizing across the environments and identified as early flower genotype was low mean value (32.33 days), significant regression coefficient (bi=0.79*) nearer to unity and non-significant deviation from regression (S^2di = -0.120). The estimates of regression coefficient ranged from 0.54 to 2.26 (bi<1) for genotypes GRB-803 and Phule Suyash with low mean values significant regression coefficient (bi=0.62* and 0.54* respectively), and non-significant deviation from regression (S^2di= -0.120 and -0.083 respectively) indicating their stability under poor environments.

The genotype, GRB-701, showed lower mean than population mean (33.68) S.E. (0.88), regression coefficient (bi=2.26*) greater than unity and non-significant deviation from regression (S^2di = 0.073) indicating its stability under rich environments.

The genotype, GRB-804, had significant deviation from regression (S^2di =0.980**) indicating unpredictable genotype for that trait.

4.5.2 Days to maturity (No.)

The data on stability for days to maturity showed range from 70.70 days (Varun) to 74.65 days (GRB-9810) with a population mean of 73.05 days over four environments (Table 4.5.2).

The genotypes, Phule Suyash (71.15 days) and Varun (70.70 days), exhibited lower mean, non-significant regression coefficient (bi= 0.89 and 1.09 respectively) close to unity and non-significant deviation from regression (S^2di = 0.010 and -0.012 respectively) indicating general adaptability with early maturity *i.e.,* suitable for all environments.

The genotype, GRB-803, showed lower mean (71.23), regression coefficient (bi=0.61*) significantly lower than unity and non-significant deviation from regression (S^2di = -0.014), indicating its stability for poor environments *i.e.* above average stability.

None of the genotypes showed lower mean than population mean with bi>1 and non-significant deviation from regression (S^2di).

The genotypes, GRB-701, GRB-702, GRB-804 and GRB-902 had significant deviation from regression (S^2di =0.110*, 0.101*, 0.340** and 0.090* respectively) indicating the unpredictable nature of genotypes for days to maturity.

Table 4.5.1 Stability parameters (mean, bi and S^2di) for days to 50 per cent flowering

Sr. No	Genotypes	Days to 50 % flowering (No.)		
		Xi	bi	S^2di
1	GRB - 701	33.68	2.26*	0.073
2	GRB - 702	35.00	1.27	-0.015
3	GRB- 803	31.50	0.62*	-0.120
4	GRB – 804	36.41	0.74	0.980*
5	GRB- 902	33.75	0.96	0.233
6	GRB- 9810	33.43	0.70*	-0.120
7	HPR - 35	34.01	1.11	-0.080
8	Phule Suyash	31.48	0.54*	-0.083
9	Vaghya	32.33	0.79*	-0.120
10	Varun (check)	33.80	1.00	0.034
	Mean	33.54		

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

Table 4.5.2 Stability parameters (mean, bi and S^2di) for days to maturity

Sr. No.	Genotypes	Days to maturity (No.)		
		Xi	bi	S^2di
1	GRB - 701	74.28	1.19	0.110*
2	GRB - 702	74.61	1.15	0.101*
3	GRB- 803	71.23	0.61*	-0.014
4	GRB – 804	71.73	1.08	0.340**
5	GRB- 902	74.33	0.84	0.090*
6	GRB- 9810	74.65	1.10	-0.032
7	HPR - 35	73.85	0.93	0.022
8	Phule Suyash	71.15	0.89	0.010
9	Vaghya	74.00	1.12	0.010
10	Varun (check)	70.70	1.09	-0.012
	Mean	73.05		

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

4.5.3 Plant height (cm)

Mean plant height ranged from 50.53 cm (Phule Suyash) to 55.68 cm (GRB-902) with the population mean of 53.06 cm. (Table 4.5.3).

The genotypes GRB-9810 (52.88 cm), GRB-701 (52.93), Vaghya (53.51 cm) and GRB-702 (54.86 cm), exhibited higher mean non-significant regression coefficient (bi= 1.00, 1.01, 1.04 and 0.90 respectively) close to unity and non-significant deviation from regression (S^2di= -0.070, -0.380, 0.050 and -0.270, respectively), indicates average stability *i.e*. suitable for all environments.

The genotypes GRB-902 and Varun exhibited higher mean (55.68 cm and 54.55 cm respectively) non-significant regression coefficient (bi=1.52, 1.45 respectively) greater than unity and non-significant deviation from regression (S^2di= 0.500 and -0.010 respectively) indicating below average stability. *i.e.* suitable only for favourable environment and none of the genotypes showed higher mean than population mean with (bi<1) and non-significant deviation from regression (S^2di).

4.5.4 Plant spread (cm)

Plant spread ranged from 12.75 cm (GRB-803) to 15.50 cm (GRB-902) with a population mean of 13.79 cm (Table 4.5.4).

An estimate of regression coefficient ranged from 0.61 to 1.50. The regression coefficient was less than unity (bi=0.61) for genotype GRB-702 exhibited higher mean (14.36 cm) and non-significant deviation from regression (S^2di = -0.011) indicates its stability for stress environment *i.e.* above average stability.

Table 4.5.3 Stability parameters (mean, bi and S^2di) for plant height

Sr. No.	Genotypes	Plant height (cm)		
		Xi	bi	S^2di
1	GRB - 701	52.93	1.01	-0.380
2	GRB - 702	54.86	0.90	-0.270
3	GRB- 803	51.25	0.87	-0.301
4	GRB – 804	52.71	0.74	-0.290
5	GRB- 902	55.68	1.52	0.500
6	GRB- 9810	52.88	1.00	-0.070
7	HPR - 35	51.71	0.89	0.020
8	Phule Suyash	50.53	0.60	-0.234
9	Vaghya	53.51	1.04	0.050
10	Varun (check)	54.55	1.45	-0.010
	Mean	53.06		

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

Table 4.5.4 Stability parameters (mean, bi and S^2di) for plant spread

Sr. No.	Genotypes	Plant spread (cm)		
		Xi	bi	S^2di
1	GRB - 701	13.65	0.67	0.061
2	GRB - 702	14.36	0.61	-0.011
3	GRB- 803	12.75	1.08*	-0.073
4	GRB – 804	13.03	1.01	-0.021
5	GRB- 902	15.50	1.20	-0.070
6	GRB- 9810	13.31	1.50	0.060
7	HPR - 35	13.71	1.16	0.010
8	Phule Suyash	12.78	0.68*	-0.070
9	Vaghya	14.06	1.19	0.040
10	Varun (check)	14.80	0.90	-0.071
	Mean	13.79		

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

The regression coefficient was more than unity (bi=1.20 and 1.19 respectively) for genotypes GRB-902 (15.50 cm) and Vaghya (14.06 cm). They showed high mean, regression coefficient more than unity and minimum deviation from regression (S^2di = - 0.070 and 0.040 respectively) indicating below average stability suitable for favourable environments.

The genotype Varun (14.80 cm) had high mean, regression coefficient close to unity (bi=0.90) and minimum deviation from regression (S^2di =-0.071) indicating their stability for all environments.

4.5.5 Primary branches per plant (No.)

Primary branches per plant ranged from 2.56 (GRB-804) to 2.85 (GRB-902) with a population mean of 2.71 (Table 4.5.5).

The genotypes Phule Suyash, GRB-803, GRB-9810 and GRB-902exhibited higher mean (2.71, 2.75, 2.76 and 2.85, respectively) non-significant regression coefficient (bi= 1.10, 0.85, 0.85 and 0.80 respectively) close to unity and non-significant deviation from regression (S^2di= -0.001, -0.002, -0.003 and -0.002, respectively.) indicating its stability for all environments.

The genotype Varun exhibited higher mean (2.71), non-significant regression coefficient (bi=1.45) greater than unity and non-significant deviation from regression (S^2di= 0.001), indicating their stability for favourable environment *i.e.* below average stability.

The genotype HPR-35 exhibited higher mean (2.73), non-significant regression coefficient (bi=0.57) lower than unity and non-significant deviation from regression (S^2di= -0.004), indicating their stability for stress environment *i.e.* above average stability.

Table 4.5.5 Stability parameters (mean, bi and S^2di) for primary branches per plant

Sr. No.	Genotypes	Primary branches per plant (No.)		
		Xi	bi	S^2di
1	GRB - 701	2.61	1.42	-0.001
2	GRB - 702	2.71	0.97	-0.005
3	GRB- 803	2.75	0.85	-0.002
4	GRB – 804	2.56	1.07	0.030**
5	GRB- 902	2.85	0.85	-0.002
6	GRB- 9810	2.76	0.80	-0.003
7	HPR - 35	2.73	0.57	-0.004
8	Phule Suyash	2.71	1.10	-0.001
9	Vaghya	2.66	0.92	-0.003
10	Varun (check)	2.71	1.45	0.001
	Mean	2.71		

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

The genotype GRB-804 exhibited lower mean non-significant regression coefficient and significant deviation from regression (S^2di= 0.030**), indicating unpredictable genotypes over all the environments for the character primary branches per plant.

4.5.6 Secondary branches per plant (No.)

Secondary branches per plant ranged from 4.56 (GRB-803) to 4.88 (GRB-702) with a mean of 4.74 (Table 4.5.6).

The genotype GRB-701 exhibited higher mean (4.73) non-significant regression coefficient (bi=0.62) significantly lower than unity and non-significant deviation from regression (S^2di = -0.010) indicates its stability for poor environment *i.e.* above average stability.

The genotype Varun and GRB-902 exhibited higher mean (4.81 and 4.85 respectively), non-significant regression coefficient (bi=1.34 and 1.39 respectively), greater than unity and non-significant deviation from regression (S^2di= -0.002 and 0.001 respectively) indicating their stability for favourable environment *i.e*. below average stability.

The genotype Phule Suyash, HPR-35 and GRB-702 exhibited higher mean (4.73, 4.76 and 4.88 respectively) non-significant regression coefficient (bi = 1.14, 1.31 and 0.91), close to unity and non-significant deviation from regression (S^2di= 0.003, -0.006 and -0.005), indicating average stability *i.e*. suitable for all environments.

4.5.7 Pods per plant (No.)

The number of pods per plant ranged from 11.20 (Phule Suyash) to 15.02 (GRB-902) with a mean of 13.11. The genotype Varun exhibited higher mean (13.98) and non-significant regression coefficient (bi=1.18) close to unity and non-significant deviation from regression (S^2di= -0.080) values indicates average stability *i.e.* suitable for all environments.

Table 4.5.6 Stability parameters (mean, bi and S^2di) for secondary branches per plant

Sr. No.	Genotypes	Secondary branches per plant (No.)		
		Xi	bi	S^2di
1	GRB - 701	4.73	0.62	0.010
2	GRB - 702	4.88	0.91	-0.005
3	GRB- 803	4.56	0.44	-0.004
4	GRB – 804	4.63	0.86	0.003
5	GRB- 902	4.85	1.39	0.001
6	GRB- 9810	4.70	0.77	-0.001
7	HPR - 35	4.76	1.31	-0.006
8	Phule Suyash	4.73	1.14	0.003
9	Vaghya	4.71	1.21	-0.006
10	Varun (check)	4.81	1.34	-0.002
	Mean	4.74		

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

Table 4.5.7 Stability parameters (mean, bi and S^2di) for pods per plant

Sr. No.	Genotypes	Pods per plant (No.)		
		Xi	bi	S^2di
1	GRB - 701	13.26	0.76	-0.051
2	GRB - 702	14.10	0.77	-0.140
3	GRB- 803	12.45	0.77	-0.090
4	GRB – 804	12.58	0.75	-0.024
5	GRB- 902	15.02	1.78*	-0.080
6	GRB- 9810	13.34	1.60	0.120
7	HPR - 35	12.21	0.85	0.050
8	Phule Suyash	11.20	0.18	0.440*
9	Vaghya	12.96	1.35	-0.110
10	Varun (check)	13.98	1.18	-0.080
	Mean	13.11		

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

The genotype GRB-701 and GRB-702 exhibited higher mean (13.26 and 14.10 respectively) and non-significant regression coefficient (bi= 0.76 and 0.77 respectively) significantly lower than unity and non-significant deviation from regression (S^2di= -0.051 and -0.140 respectively) indicating its stability for poor environment *i.e.* above average stability.

The genotype GRB-902 (15.02) and GRB-9810 (13.34) exhibited higher mean, regression coefficient (bi = 1.78* and 1.60 respectively) significantly higher than unity and non-significant deviation from regression (S^2di = -0.080 and 0.120), indicating their stability for favourable environment *i.e.* below average stability.

The genotype Phule Suyash exhibited significant deviation from regression (S^2di = 0.440*) showed unpredictable genotypes over all the environments for the character pods per plant.

4.5.8 Seeds per pod (No.)

The number of seeds per pod ranged from 3.98 (Phule Suyash) to 4.16 (GRB-702) with a population mean of 4.05 (Table 4.5.8).

The genotype GRB-9810 (4.06), HPR-35 (4.06), Vaghya (4.10) and GRB-902 (4.11), exhibited higher mean and non-significant regression coefficient (bi = 0.64, 0.59, 1.17 and 0.68 respectively) close to unity and non-significant deviation from regression (S^2di= -0.004, -0.010, 0.005 and -0.003) values indicates average stability *i.e.* suitable for all environments.

The genotype GRB-702 exhibited higher mean (4.16) non-significant regression coefficient (bi = 0.09), significantly lower than unity and non-significant deviation from regression (S^2di= 0.001) indicating its stability for poor environment *i.e.* above average stability.

Table 4.5.8 Stability parameters (mean, bi and S^2di) for seeds per pod

Sr. No.	Genotypes	Seeds per pod (No.)		
		Xi	bi	S^2di
1	GRB - 701	4.00	2.28	-0.001
2	GRB - 702	4.16	0.09	0.001
3	GRB- 803	4.01	0.31	-0.006
4	GRB – 804	4.00	0.59	-0.010
5	GRB- 902	4.11	0.68	-0.003
6	GRB- 9810	4.06	0.64	-0.004
7	HPR - 35	4.06	0.59	-0.010
8	Phule Suyash	3.98	2.96*	-0.010
9	Vaghya	4.10	1.17	0.005
10	Varun (check)	4.03	0.70	-0.010
	Mean	4.05		

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

The genotypes GRB-701 showed higher mean than population mean (4.00), higher regression coefficient, more than unity (bi=2.28) and non-significant deviation from regression (S^2di = -0.001), indicating their stability under rich environment.

4.5.9 100-seed weight (g)

100-seed weight ranged from 31.93 g (GRB-9810) to 34.80 g (GRB-803) with a population mean of 33.35 g (Table 4.5.9).

Estimates of regression coefficient ranged from 0.14 to 2.72. The regression coefficient was more than unity (bi=1.92 and 2.03 respectively) for genotypes GRB-701 (33.45) and GRB-902 (34.37) had high mean, and minimum deviation from regression (S^2di = 0.010 and 0.033 respectively) indicating below average stability suitable for favourable environments.

The genotype Varun (33.79) and HPR-35 (34.56) had high mean, regression coefficient close to unity (bi = 0.72 and 0.48 respectively), and minimum deviation from regression (S^2di = -0.013 and 0.020 respectively) indicating their stability for all environments.

The genotypes GRB-702, GRB-803, GRB-804 and Vaghya exhibited significant deviation from regression (S^2di= 0.063*, 0.081**, 0.150** and 0.104**) showed unpredictable over all the environments for the character 100-seed weight.

None of the genotypes showed higher mean than population mean with (bi<1) and non-significant deviation from regression (S^2di).

Table 4.5.9 Stability parameters (mean, bi and S^2di) for 100-seed weight

Sr. No	Genotypes	100-seed weight (g)		
		Xi	bi	S^2di
1	GRB - 701	33.45	1.92	0.010
2	GRB - 702	32.33	0.89	0.063*
3	GRB- 803	34.80	1.78	0.081**
4	GRB – 804	33.38	2.72	0.150**
5	GRB- 902	34.37	2.03	0.033
6	GRB- 9810	31.93	0.14*	-0.015
7	HPR - 35	34.56	0.48	0.016
8	Phule Suyash	32.10	0.29	0.010
9	Vaghya	32.78	-0.93	0.104**
10	Varun (check)	33.79	0.72	-0.013
	Mean	33.35		

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

Table 4.5.10 Stability parameters (mean, bi and S^2di) for harvest index

Sr. No	Genotypes	Harvest index (%)		
		Xi	bi	S^2di
1	GRB - 701	50.43	0.79	-1.913
2	GRB - 702	51.07	1.02	0.120
3	GRB- 803	46.53	0.85	-1.091
4	GRB – 804	42.00	0.56	-1.530
5	GRB- 902	53.44	0.94	-1.910
6	GRB- 9810	48.48	0.89	-1.913
7	HPR - 35	36.00	0.92	-1.303
8	Phule Suyash	21.85	1.57*	-1.951
9	Vaghya	48.39	1.31	-1.420
10	Varun (check)	50.06	1.13	-1.892
	Mean	44.82		

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

4.5.10 Harvest index (%)

Harvest index ranged from 21.85 % (Phule Suyash) to 53.44 % (GRB-902) with a population mean of 44.82% (Table 4.5.10).

An estimate of regression coefficient ranged from 0.56 to 1.57. The regression coefficient was more than unity (bi=1.31) for a genotype Vaghya, which had high mean (48.39 %) than population mean and minimum deviation from regression (S^2di= -1.420) indicating below average stability suitable for favourable environments.

The genotypes, GRB-803, GRB-9810, Varun, GRB-701, GRB-702 and GRB-902, had high mean (46.53%, 48.48%, 50.06 %, 50.43%, 51.07% and 53.44% respectively), regression coefficient close to unity (bi=0.85, 0.89, 1.13, 0.79, 1.02 and 0.94 respectively) and minimum deviation from regression (S^2di = -1.091, -1.913, -1.892, -1.913, 0.120 and -1.910 respectively) indicating their stability over environments.

None of the genotypes showed higher mean than population mean with (bi<1) and non-significant deviation from regression (S^2di).

4.5.11 Seed yield per plant (g)

Seed yield per plant ranged from 10.46 g (Phule Suyash) to 19.60 g (GRB-902) with a population mean of 16.55 g (Table 4.5.11).

The regression coefficient values ranged from 0.61 to 1.22. The genotype Varun had regression coefficient value less than unity (bi = 0.84) with high mean (18.25 g) and minimum deviation from regression (S^2di = - 0.240) indicating above average stability and is suitable for stress environments.

The regression coefficient was more than unity (bi = 1.22) for the genotype GRB-902 and had high mean (19.60 g) and minimum deviation from regression (S^2di = -0.070) indicating below average stability and is suitable for favourable environments.

Table 4.5.11 Stability parameters (mean, bi and S^2di) for yield per plant

Sr. No.	Genotypes	Seed yield per plant (g)		
		Xi	bi	S^2di
1	GRB - 701	18.04	1.13	0.280
2	GRB - 702	19.38	1.07	-0.260
3	GRB- 803	16.11	0.69	-0.290
4	GRB – 804	15.60	0.61	0.281
5	GRB- 902	19.60	1.22	-0.070
6	GRB- 9810	16.03	1.17	-0.320
7	HPR - 35	15.58	1.08	-0.310
8	Phule Suyash	10.46	1.15	0.133
9	Vaghya	16.44	1.03	-0.265
10	Varun (check)	18.25	0.84	-0.240
	Mean	16.55		

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

The genotypes, Vaghya (16.44 g), GRB-701 (18.04 g) and GRB-702 (19.38 g) and had high mean, regression coefficient close to unity (bi = 1.03 1.13 and 1.07 respectively) and minimum deviation from regression (S^2di = -0.265, 0.280 and -0.260 respectively), indicating their stability over environments.

4.5.12 Seed yield (kg/ha)

Seed yield per hectare ranged between 1028.58 kg/ha (Phule Suyash) to 2040.91 kg/ha (GRB-902) with a population mean of 1668.36 kg/ha (Table 4.5.12).

The regression coefficient values ranged from 0.65 to 1.34. The genotype Varun had regression coefficient values less than unity (bi = 0.85) with high mean (1823.83 kg/ha) and minimum deviation from regression (S^2di = -570) indicating above average stability and are suitable for stress environments.

The regression coefficient was more than unity (bi = 1.34*, 1.22 and 1.15 respectively) for genotypes GRB-9810, GRB-701 and GRB-902 and had high mean (1678.91 kg/ha, 1845.16 kg/ha and 2040.91 kg/ha respectively), regression coefficient more than one and minimum deviation from regression (S^2di = -1045, 1170 and 1403 respectively) indicating below average stability and are suitable for favourable environments.

The genotype GRB-702 (1951.50 kg/ha) had high mean, regression coefficient close to unity (bi = 0.94) and minimum deviation from regression (S^2di = -665) indicating its stability for all environments.

The genotype Phule Suyash exhibited significant deviation from regression (S^2di= 7438**) indicating unpredictable performance over all the environments for the character seed yield per hectare.

Table 4.5.12 Stability parameters (mean, bi and S^2di) for seed yield per hectare

Sr. No.	Genotypes	Seed yield (kg/ha)		
		Xi	bi	S^2di
1	GRB – 701	1845.16	1.15	1170
2	GRB – 702	1951.50	0.94	-665
3	GRB- 803	1553.33	0.77	-182
4	GRB – 804	1545.00	0.65	1826
5	GRB- 902	2040.91	1.22	1403
6	GRB- 9810	1678.91	1.34*	-1045
7	HPR – 35	1586.91	1.13	-651
8	Phule Suyash	1028.58	1.01	7438**
9	Vaghya	1629.50	0.94	-513
10	Varun (check)	1823.83	0.85	-570
	Mean	1668.36		

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

5. DISCUSSION

There is considerable variation in French bean (*Phaseolus vulgaris* L.) in respect of quantitative characters. At present development of genotypes with wider adaptability is the major objective in French bean. Thus, varietal adaptability is one of the important parameters for stability in production. Therefore, for wide adaptation of a variety, its stability in performance is one of the most desirable properties.

In the present investigation ten genotypes of Rajmash along with one check were evaluated for their stability across the environments through genotype x environment interaction analysis by estimating stability parameters. The results obtained are discussed in this chapter.

5.1 Pooled analysis of variance

Analysis of variance for stability parameters was done (Table 4.3) by following model of Eberhart and Rusell (1966), which revealed the presence of significant variation due to environment (E) for all the characters indicating considerable additive environmental variance. Genotypic variance (G) was significant for all the traits, indicated prevalence of the genetic variability among the Rajmash genotypes under study.

Partitioning of G x E interaction showed that G x E (linear) effects were significant for the characters *viz*., days to 50 per cent flowering, plant height, plant spread, pods per plant, seeds per pod, 100-seed weight, seed yield per plant and seed yield per ha, 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.

Park (1987) and Panwar *et al.* (1995) revealed significant differences due to genotypes, environments and genotype x environment interactions in Rajmash.

Baisakh and Nayak (1991) reported significant differences for G, E and G x E interaction for grain yield in chickpea.

5.2 Genotype x Environment interaction

G x E interaction has been an important and challenging issue for plant breeders and geneticists. When varieties were compared over a series of environments the relative ranking was usually different. This causes difficulty in demonstrating the superiority of any variety. The present experiment was conducted to find out the influence of environmental condition on seed yield per plant and its component characters in newly developed lines of Rajmash.

It has been shown that presence of G x E interaction contributes substantially to the non-realization of expected seeds from selection (Comstock and Moll, 1963). The population which adjust its genotypic or way that it gives high and economic returns can be termed as "well buffered" (Allard and Bradshaw, 1964). The mechanism of stability falls into four general categories.

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

The most widely used approach for statistical analysis of genotypes, environments and interaction is the regression technique in which partitioning of the genotype x environment interaction components of variability into its genotypes over a range of environments is complied.

In the present study, the same approach as outlined by Eberhart and Russell (1966) has been applied.

5.3 Environmental indices (Ij)

Estimates of environmental indices (Ij) are presented in (Table 4.4) which revealed that environment E_1 (20th June) was favourable for all characters *viz.*, plant height, plant spread, pods per plant, 100-seed weight, harvest index, seed yield per plant, seed yield per ha. except days to 50 per cent flowering and days to maturity.

Environment E_2 (10th July) was also favourable for characters *viz.*, plant height, harvest index, yield per plant and yield per ha. except days to 50 per cent flowering and days to maturity.

Third environment E_3 (30th July) was favourable for none of the characters and environment E_4 (20th August) was favourable for characters only for days to 50 per cent flowering and days to maturity which showed minimum deviation for fourth environment.

In general, environment E_1 was the most favourable for yield and yield contributing characters.

5.4 Stability Parameters

5.4.1 Days to 50 per cent flowering (No.)

The means for days to 50 per cent flowering varied between 31.48 days (Phule Suyash) and 36.41 days (GRB-804) with an average of 33.54 days over four environments. The genotypes, GRB-803, GRB-9810, Phule Suyash and Vaghya were early flowering across the four environments.

The estimates of regression coefficient ranged from 0.54 to 2.26. The regression coefficient was less than unity ($bi < 1$) for GRB-803 and Phule Suyash.

The genotype GRB-701 had regression coefficient greater than unity (bi > 1) and was suitable for favourable environment. The genotype, Vaghya, had more stablity across the environment and identified as early maturity genotype with low mean days to 50 per cent value, significant regression coefficient nearer to unity and non-significant deviation from regression indicating average stability over all the environments (Fig.1).

The linear and non-linear components of G x E interaction were found to be significant. Similar results were reported for character days to 50 per cent flowering by Singh *et al.* (1993) and Panwar *et al.* (1995) in Rajmash.

Sharma and Maloo (1989) recorded significant linear interaction in chickpea in three diverse environments for days to 50 per cent flowering.

Kavitha *et al.* (2003) recorded early days to 50 per cent flowering and maturity in cowpea genotypes.

5.4.2 Days to maturity (No.)

The data on stability for days to maturity showed the range between 70.70 days (Varun) to 74.65 days (GRB-9810) with a population mean of 73.05 days over four locations.

The genotypes, Phule Suyash and Varun exhibited lower mean, non-significant regression coefficient close to unity and non-significant deviation from regression indicating general adaptability with early maturity *i.e.* suitable for all environments. (Fig.2).The genotype, GRB-803, showed lower mean, regression coefficient significantly lower than unity and non-significant deviation from regression, indicating its suitability for poor environment. The genotype, GRB-9810, had regression coefficient greater than unity and non-significant deviation from regression indicating its suitability suitable to grow only in favourable environments.

The genotypes, GRB-701, GRB-702, GRB-804 and GRB-902 had significant deviation from regression indicates unpredictable genotypes with early maturity.

The linear and non-linear components of G x E interaction was significant for days to maturity. Similar results also reported by Singh *et al*. (1993), Panwar *et al.* (1995), Razvi and Khan (2011) and Nigussie (2011) in Rajmash.

Sekhon *et al.* (1992) reported early, medium and late maturing varieties in Rajmash. Baisakh and Nayak (1991) reported linear and non-linear component of G x E interaction were significant for days to maturity in chickpea.

5.4.3 Plant height (cm)

Mean plant height ranged from 50.53 cm (Phule Suyash) and 55.68 cm (GRB-902) with the population mean of 53.06 cm.

The genotypes, GRB-701, GRB-702, GRB-9810 and Vaghya exhibited higher mean non-significant regression coefficient, close to unity and non-significant deviation from regression indicating average stability *i.e.*, suitable for all environments (Fig.3). The genotypes GRB-902 and Varun exhibited higher mean, non-significant regression coefficient greater than unity and non-significant deviation from regression indicating below average stability. *i.e.*, suitable only for favourable environments and none of the genotypes showed higher mean than population mean with ($bi<1$) and non-significant deviation from regression (S^2di).

G x E interaction with environment (linear) and G x E (linear) components were significant revealing their role in expression of plant height. Similar results were also reported by Nigussie (2011) in French bean at five locations of Eastern Amhara.

Kelly *et al.* (1987) reported that determinate and short vines of French bean had good stability for increasing yield.

Positive significant correlation coefficient between phenotypic mean performance (xi) and regression coefficient (bi) in respect to plant height was reported by Senapati and Roy (1998) in groundnut.

5.4.4 Plant spread (cm)

Plant spread values ranged between 12.75 cm (GRB-803) and 15.50 cm (GRB-902) with a population mean of 13.79 cm.

An estimate of regression coefficient ranged from 0.61 to 1.50. The regression coefficient was less than unity (bi < 1) for genotype, GRB-702, exhibited higher mean regression coefficient significantly lower than unity and non-significant deviation from regression indicating its suitability for poor environment (Fig.4). The regression coefficient was more than unity (bi > 1) for genotypes GRB-GRB-902 and Vaghya with high mean and minimum deviation from regression indicating below average stability and are suitable for favourable environments.

The genotype, Varun, had high mean, regression coefficient close to unity and minimum deviation from regression, indicating its stability for all environments.

Ram and Dhar (1999) in French bean reported that pole type and dwarf type plant spread was found to be favourable for increasing yield.

G x E interaction with environment (linear) and G x E (linear) components was significant and showed their role in expression of plant spread. This is in agreement with the results of Begum *et al.* (1998) in groundnut.

5.4.5 Primary branches per plant (No.)

Primary branches per plant ranged between 2.56 (GRB-804) to 2.85 (GRB-902) with a mean of 2.71. The genotype GRB-803, GRB-902, GRB-9810 and Phule Suyash exhibited higher mean, non-significant regression coefficient, close to unity and non-significant deviation from regression, indicating its stability for all environments (Fig.5).

The genotype Varun exhibited higher mean, non-significant regression coefficient, greater than unity and non-significant deviation from regression indicating their stability for favourable environments.

The genotype GRB-804 exhibited lower mean, non-significant regression coefficient and significant deviation from regression, indicates unpredictable genotypes over all the environments.

Genotype x Environment interaction was observed to be absent for this trait, indicating that this character was not influenced by changing environments. Similar observations were reported by Razvi and Khan (2011) in Rajmash and by Senapati and Roy (1998) in groundnut.

Environmental (linear) was found highly significant for primary branches per plant. Similar results were reported by Chaudhary and Haque (2010) in chickpea.

5.4.6 Secondary branches per plant (No.)

Secondary branches per plant ranged between 4.56 (GRB-803) to 4.88 (GRB-702) with a mean of 4.74.

The genotype GRB-701 exhibited higher mean, non-significant regression coefficient significantly lower than unity and non-significant deviation from regression indicates its stability for poor environment. The genotype GRB-902 and Varun exhibited higher mean, non-significant regression coefficient, greater than unity and non-significant deviation from regression indicating their stability for favourable environment

(Fig.6). The genotype GRB-702, HPR-35 and Phule Suyash exhibited higher mean, non-significant regression coefficient, close to unity and non-significant deviation from regression indicating average stability *i.e.* suitable for all environments.

Present investigation showed non-significant G x E interaction for the trait secondary branches per plant, similar results observed by Razvi and Khan (2011) in Rajmash and by Senapati and Roy (1998) in groundnut. Environmental (linear) was found highly significant for secondary branches per plant. Similar results were reported by Chaudhary and Haque (2010) in chickpea.

5.4.7 Pods per plant (No.)

As per data, projected range of pods per plant ranged from 11.20 (Phule Suyash) to 15.02 (GRB-902) with a mean of 13.11. The genotype Varun exhibited higher mean and non-significant regression coefficient close to unity and non-significant deviation from regression values indicating average stability (Fig.7).The genotype GRB-701 and GRB-702 exhibited higher mean and non-significant regression coefficient significantly lower than unity and non-significant deviation from regression indicating its stability for poor environment.

The genotype GRB-902 and GRB-9810 exhibited higher mean and non-significant regression coefficient significantly higher than unity and non-significant deviation from regression indicating their stability for favourable environment. The genotype Phule Suyash exhibited significant deviation from regression showed unpredictable genotypes over all the environments for the character pods per plant.

The variances for linear and non-linear G x E interaction were found to be significant which confirmed the results of Guv *et al.* (1988), Singh *et al.* (1993) and Harer *et al.* (2000) in Rajmash.

Similar results were obtained by Sharma and Maloo (1989) in chickpea, Thaware *et al.* (2006) and Pujari *et al.* (2003) in cowpea.

5.4.8 Seeds per pod (No.)

The number of seeds per pod ranged from 3.98 (Phule Suyash) to 4.16 (GRB-702) with a mean of 4.05. The genotype GRB-902, GRB-9810, HPR-35 and Vaghya exhibited higher mean and non-significant regression coefficient close to unity and non-significant deviation from regression values indicating average stability (Fig.8).

The genotype GRB-702 exhibited higher mean, non-significant regression coefficient, significantly lower than unity and non-significant deviation from regression indicating its stability for poor environment. The genotypes GRB-701 showed higher mean than population mean and non-significant deviation from regression indicates their stability under rich environment.

Both linear components (environment and G x E) were highly significant with their major contribution in expression of this trait. Ram and Dhar (1999), Islam and Newaz (2001), Raffi *et al.* (2004) found significant for (E and G x E) interactions in Rajmash.

5.4.9 100-seed weight (g)

100-seed weight ranged between 31.93 g (GRB-9810) to 34.80 g (GRB-702) with a mean of 33.35 g.

An estimate of regression coefficient ranged from 0.14 to 2.72. The regression coefficient was more than unity (bi > 1) for genotypes GRB-701 and GRB-902 had high mean and minimum deviation from regression, indicating below average stability, suitable for favourable environments (Fig.9). The genotype HPR-35 and Varun had high mean, regression coefficient, close to unity and minimum deviation from regression indicating their stability for all environments. The genotypes GRB-702, GRB-803, GRB-804 and Vaghya exhibited significant deviation from regression showed unpredictable over all the environments for the character 100-seed weight.

None of the genotypes showed higher mean than population mean with (bi<1) and non-significant deviation from regression (S^2di).

G x E interaction and its linear component of environment were found to be highly significant indicating its role in expressing the character. Singh *et al.* (1993), Nigussie (2011) reported significant G x E interaction for 100-seed weight in French bean.

Bouslama *et al.* (1990) in chickpea and Varman and Manoharan (1993) in groundnut reported linear and non-linear components were found significant for 100-seed weight.

Khatri *et al.* (2003) reported stability for the trait 100-seed weight in 21 diverse genotypes of cowpea in Hisar, Haryana.

5.4.10 Harvest index (%)

Harvest index ranged between 21.85 % (Phule Suyash) to 53.44 % (GRB-902) with a mean of 44.82%.

An estimate of regression coefficient ranged from 0.56 to 1.57. The regression coefficient was more than unity (bi > 1) for genotype Vaghya, which had high mean and minimum deviation from regression indicating below average stability, suitable for favourable environments (Fig.10). The genotypes GRB-701, GRB-702, GRB-803, GRB-902, GRB-9810 and HPR-35 had high mean regression coefficient close to unity and minimum deviation from regression indicating their stability for all environments

None of the genotypes showed higher mean than population mean with (bi<1) and non-significant deviation from regression (S^2di).

Genotype x Environment interaction was observed to be absent for this trait, indicating that this character was not influenced by changing environments. Similar observations were reported by Nigussie (2011) in

Rajmash and similar results were obtained by Varman and Manoharan (1993) in groundnut.

5.4.11 Seed yield per plant (g)

Yield per plant ranged between 10.46 g (Phule Suyash) to 19.60 g (GRB-902) with a population mean of 16.55 g.

The regression coefficient values ranged from 0.61 to 1.22. The genotype Varun had regression coefficient values less than unity with high mean and minimum deviation from regression indicating their above average stability suitable for stress environments (Fig.11). The regression coefficient was more than unity (bi > 1) for genotype GRB-902 had high mean and minimum deviation from regression indicating below average stability suitable for favourable environments. The genotype GRB-701, GRB-702 and Vaghya had high mean, regression coefficient close to unity and minimum deviation from regression indicating their stability for all environments.

Both linear components of G x E interactions (environment and G x E) were highly significant proving their contribution in the expression of seed yield per plant. These results are in conformity with those of Chiriboga (1978), Guv (1988), Ramalho *et al.* (1988), Ram and Dhar (1999) and Harer *et al*. (2000) in Rajmash.

Similar results to this finding were obtained by Pillai *et al*. (2010) after evaluating ten cultivars of black gram during three different seasons.

5.4.12 Seed yield (Kg/ha)

Yield per ha ranged between 1028.58 kg (Phule Suyash) to 2040.91 kg (GRB-902) with a population mean of 1668.36 kg.

The regression coefficient values ranged from 0.65 to 1.34. The genotype, Varun, had regression coefficient values less than unity (bi < 0.85) and had high mean and minimum deviation from regression, indicating its above average stability and suitability for stress environments (Fig.12).

The regression coefficient was more than unity for genotypes GRB-701, GRB-902 and GRB-9810 and had high mean and minimum deviation from regression indicating below average stability and suitability for favourable environments. The genotype GRB-702 had high mean, regression coefficient close to unity and minimum deviation from regression indicating its stability over environments.

The genotype Phule Suyash exhibited significant deviation from regression indicating unpredictable performance over the environments.

The G x E interaction and its linear portion (environment) showed significant mean sum of squares, revealing that it played an important role in building-up of total G x E and expressing the seed yield.

Similar findings for different cultivars of Rajmash were reported by Wadan *et al.* (1993), Singh *et al.* (1993), Zimmermann (1994) and Nimbalkar *et al*. (2004) and found the highest performance for different genotypes studied.

Kavitha *et al.* (2003) reported significant mean sum of square due to genotypes indicating presence of genetic variation among the genotypes for seed yield in cowpea. Patel *et al.* (2009) in mung bean showed that G x E interactions was highly significant for seed yield.

6. SUMMARY AND CONCLUSIONS

6.1 Summary

In the present investigation ten genotypes of Rajmash (*Phaseolus vulgaris* L.) along with one check were evaluated in a Randomized Block Design with three replications at Botany Farm, College of Agriculture, Pune (Maharashtra) to know the stability for seed yield and its components. These genotypes were grown in four environments *i.e.,* 25^{th} meteorological week (E_1), 28^{th} meteorological week (E_2), 31^{st} meteorological week (E_3) and 34^{th} meteorological week (E_4) during *kharif,* 2015.

The observations were recorded on 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, number of pods per plant, number of seeds per pod, 100-seed weight, harvest index, seed yield per plant and seed yield per ha.

The stability analysis as per Eberhart and Russell (1966) model showed significant genotypic differences for almost all the characters. Similarly, environmental variations were significant for all the characters. G x E interactions were significant for days to 50 per cent flowering, plant spread, number of seeds per pod and yield per ha, when tested against pooled deviation.

The linear component of G x E interactions was significant for days to 50 per cent flowering, plant height, plant spread, pods per plant, seeds per pod, 100-seed weight, yield per plant and yield per hectare when tested against pooled deviation and pooled error.

The estimation of environmental indices (Ij) revealed that environment E_1 (20^{th} June) was favourable for all characters *viz*., plant height, plant spread, primary branches per plant, secondary branches per plant, pods per plant, seeds per pod, 100-seed weight, harvest index, seed yield per plant, seed yield per ha except days to 50 per cent flowering and days to maturity. Environment E_2 (10^{th} July) was favourable for characters like *viz.*, plant height, harvest index, yield per plant and yield per ha. Third environment E_3 (30^{th} July) was found to be totally unfavorable for all characters studied. Fourth environment E_4 (20^{th} August) was found to be favourable for days to 50 per cent flowering and days to maturity.

Different genotypes showed differential reaction to the various environments studied. Some of them exhibited average or general, above average or below average stability for different component characters as shown in table 6.1.

The genotypes, Vaghya (days to 50 per cent flowering), Phule Suyash and Varun (days to maturity), GRB-701, GRB-702, GRB-9810 and Vaghya (plant height), Varun (plant spread and pods per plant), GRB-702, GRB-803, GRB-902 and GRB-9810 (primary branches per plant) GRB-702, HPR-35 and Phule Suyash (secondary branches per plant) GRB-902, GRB-9810, HPR-35 and Vaghya (seeds per pod) HPR-35 and Varun (100-seed weight), GRB-701, GRB-702, GRB-902, GRB-9810 and HPR-35 (harvest index) , GRB-701, GRB-702 and Vaghya (seed yield per plant) and GRB-702 (seed yield per ha) exhibited average stability indicating their suitability for all the environments.

The genotypes, GRB-803, Phule Suyash (days to 50 per cent flowering), GRB-803 (days to maturity), GRB-702 (plant spread), HPR-35 (primary branches per plant), GRB-701 (secondary branches per plant and pods per plant), GRB-702 (seeds per pod), Varun (seed yield per plant and seed yield per ha) exhibited above average stability indicating their suitability for poor environments.

The genotypes, GRB-701 (days to 50 per cent flowering and seeds per pod), GRB-902, Varun (plant height and secondary branches per plant), GRB-902, Vaghya (plant spread), Varun (primary branches per plant), GRB-902 and GRB-9810 (pods per plant), GRB-701 and GRB-902 (100-seed weight), Vaghya (harvest index) GRB-902 (seed yield per plant) and GRB-701, GRB-902 and GRB-9810 (seed yield per ha) had below average stability indicating their suitability for normal environments.

Table 6.1 Nature of stability of the genotypes studied

Sr. No.	Characters	Genotypes showing stability		
		Average wider stability (bi=1)	Above average Stability (bi<1)	Below average stability (bi>1)
1	Days to 50% flowering (No.)	Vaghya	GRB-803, P. Suyash,	GRB-701
2	Days to maturity (No.)	Phule Suyash, Varun	GRB-803	-
3	Plant height (cm)	GRB-701, GRB-702, GRB-9810, Vaghya	-	GRB-902, Varun
4	Plant spread (cm)	Varun	GRB-702	GRB-902, Vaghya
5	Primary branches per plant (No.)	GRB-702, GRB-803, GRB-902, GRB-9810	HPR-35	Varun
6	Secondary branches per plant (No.)	GRB-702, HPR-35, Phule Suyash	GRB-701	GRB-902, Varun
7	Pods per plant (No.)	Varun	GRB-701	GRB-902, GRB-9810
8	Seeds per pod (No.)	GRB-902, GRB-9810, HPR-35, Vaghya	GRB-702,	GRB-701
9	100-seed weight (g)	HPR-35, Varun	-	GRB-701, GRB-902
10	Harvest index (%)	GRB-701, GRB-702, GRB-803, GRB-902, GRB-9810, Varun	-	Vaghya
11	Seed yield per plant (g)	GRB-701, GRB-702, Vaghya	Varun	GRB-902
12	Seed yield (kg/ha)	GRB-702	Varun	GRB-701, GRB-902, GRB-9810

6.2 Conclusion

On the basis of present studies the following main conclusions are drawn.

1. Genotype x Environment interactions were significant for days to 50 per cent flowering, plant spread, number of seeds per pod, seed yield per hectare.
2. The genotypes, Vaghya (days to 50 per cent flowering), Phule Suyash and Varun (days to maturity), Varun (plant spread and pods per plant), GRB-902, GRB-9810, Vaghya (seeds per pod) GRB-701, GRB-702 and Vaghya (seed yield per plant and seed yield per hectare), showed average stability and are suitable for all environments.
3. The genotypes, GRB-701 (pods per plant), Varun (seed yield per plant and seed yield per ha) showed above average stability and are suitable for stress environments.
4. The genotype, GRB-902 (plant height, pods per plant, secondary branches per plant, seed yield per plant and seed yield per hectare), GRB-701 (days to 50 per cent flowering and seeds per pod), showed below average stability and are suitable for favourable environments.
5. None of the genotypes was found to be stable for all the characters studied.
6. Stability analysis indicated that, the environment E_1 (20^{th} June) was found to be most suitable for better expression of yield and yield contributing characters.

Table 4.2: Analysis of variance (MSS) for twelve char acters at four different environments.

Sr. No.	Characters	Mean Sum of squares due to											
		E1			E2			E3			E4		
		Rep	Treat	Error	Rep	Treat	Error	Rep	Treat	Error	Rep	Treat	Error
1	Days to 50% flowering (No.)	1.45	7.38**	1.18	0.02	8.71**	0.01	0.14	9.19**	0.08	0.11	6.27**	0.11
2	Days to maturity (No.)	0.10	7.82**	0.16	0.02	8.67**	0.01	0.28	10.24**	0.10	0.02	6.12**	0.12
3	Plant height (cm)	0.80	11.31**	1.17	5.15**	14.30**	1.52	1.96	7.11**	0.79	0.66	3.90**	0.63
4	Plant spread (cm)	0.24	2.75**	0.22	0.07	2.69**	0.08	0.02	2.59**	0.19	0.02	2.80**	0.42
5	Pri. branches per plant (No.)	0.01	0.01	0.028	0.03	0.06**	0.01	0.02	0.02	0.01	0.02**	0.04**	0.01
6	Sec. branches per plant (No.)	0.20**	0.06	0.03	0.07**	0.08**	0.01	0.01	0.01	0.01	0.01	0.02	0.01
7	Pods per plant (No.)	0.58	8.42**	0.31	0.08	4.69**	0.39	0.24	2.58**	0.49	1.23**	1.96	0.57
8	Seeds per pod (No.)	0.20**	0.01	0.03	0.03	0.01	0.01	0.01	0.03	0.02	0.02	0.10**	0.03
9	100-seed weight (g)	0.02	4.69**	0.04	0.11	3.35**	0.07	0.02	3.66**	0.04	0.10**	2.20**	0.03
10	Harvest index (%)	8.54	256.50**	9.29	0.62	271.61**	3.94	4.73	271.16**	6.91	2.12	295.24**	4.13
11	Seed yield per plant (g))	3.43**	21.71**	1.13	0.83	25.13**	2.18	2.47	19.67**	0.82	0.32	20.60**	0.64
12	Seed yield (kg/ha)	4963	23781**	3322	1795	320803**	4709	5962	224965**	2396	12297**	216060**	2798

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

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

Table 4.3 ANOVA for stability as per Eberhart and Russell Model (1966) for seed yield and yield components in Rajmash

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 (No.)	9.167 ++**##	0.145	0.452 * ##	1.649++ ** ##	37.257 ** ##	0.917 **##	0.198	0.117
2	Days to maturity (No.)	10.618 ++**##	0.037	0.115##	1.433 ++**##	39.877 **##	0.130##	0.097 ##	0.035
3	Plant height (cm)	10.763 ++**##	0.716 *	0.483	3.729 ++**##	98.833 **##	0.819*#	0.284	0.345
4	Plant spread (cm)	3.231 ++**##	0.031	0.130 *	1.180 ++**##	31.891 **##	0.261 **#	0.058	0.078
5	Primary branches per plant (No.)	0.025 ++**##	0.008	0.007	0.029 ++**##	0.674 **##	0.005	0.007	0.006
6	Secondary branches per plant (No.)	0.038 ++**##	0.024 +*#	0.008	0.031 ++**##	0.720 **##	0.008	0.008	0.006
7	Pods per plant (No.)	4.741 ++**##	0.178	0.382 *#	1.518 ++**##	35.240 **##	0.799 **##	0.155	0.148
8	Seeds per pod (No.)	0.014	0.024 **#	0.014 *	0.024 **##	0.341 **##	0.028 **##	0.006	0.008
9	100 seed weight (g)	4.331 ++**##	0.023	0.103##	0.140 *##	1.431 **##	0.172 *##	0.061 ##	0.017
10	Harvest index (%)	363.002 ++**##	1.306 *	0.613	3.840++ **#	98.638 **##	0.790	0.472	2.024
11	Seed yield per plant (g))	27.463 ++**##	0.588	0.528	7.130 ++**##	199.663 **##	0.885 * #	0.314	0.400
12	Yield(kg/ha)	320185.200 ++**##	2084.914	4343.761 *##	66482.960 ++**##	1877207.000 **##	8538.602 **##	2021.706 #	1102.235

+ , ++ = Significant at 5 and 1 % level of significance, respectively against the G x E interaction
*, ** = Significant at 5 and 1 % level of significance, respectively against the pooled deviation
#, ## = Significant at 5 and 1 % level of significance, respectively against the pooled error

7. LITERATURE CITED

Abreu, A., Ramalho, M. A. P., Santos, J. B. Dos and Pereira Filho I. A. 1990. Effect of genotype x environment interaction on estimation of genetic and phenotypic parameter of common bean. *Revista Brasileria de Genetica J.*13(1): 75-82.

Ayeh, E. 1988. Evidence for yield stability in selected landraces of bean *(Phaseolus vulgaris* L.). *Exper. Agric.* 24(3): 367-383.

Allard, R. W. 1960. Principles of Plant Breeding, John Willey and Sons, Inc. New York and London.

Allard, R. W. and Bradshaw, A. O. 1964. Implication of genotype x environment interaction in applied plant breeding. *Crop Sci.* 4:503-507.

Anonymous. 2015. Indian Institute of Pulses Research, Govt. of. India.

Bains, K. S. and Gupta, P. V. 1972. Stability of yield and yield components in bread wheat. *Indian J. Genet.* 32: 306-312.

Baisakh, B. and Nayak, B. K.1991. Phenotypic stability of seed yield and maturity in Chickpea (*Cicer arietinum* L.). *Indian J. Agril. Sci.* 61(11):826-828.

Begum, S., Samad, A., Khaleda, S. and Alam, A. K. M. S. 1998. Gentoype x Environment interaction for some quantitative characters in groundnut. *Bangladesh J. Sci. Indust. Res*. 33(1): 13-16.

Bhattacharya, A. and Pandey, P. S.1999. Physiological studies in chickpea varieties *i.e.* effect of temperature and time of sowing. *Indian Pulses Res.* 12(1): 56-64.

Bhole, G. R., Narkhede, B. N., Patil, S. S. and Deokar, A. B. 1987. Phenotypic stability of pod yield and in summer groundnut. *J. Oilseed Res.* 4: 108-110.

Bouslama, M. A., Garoi, G. and Harrabi, M. 1990. Stability analysis of some chickpea genotypes in Tunisia. *Agril. Mediterranea*. 120(1): 74-78.

Carbonell, S. A. M and Filho, J. A. 2004. Common bean cultivars and lines interactions with environments. *Sci. Agric*. (Piracicaba, Braz.), 61(2):169-177.

Chiriboga V. C. E. 1978. Adaptability and stability of eight varieties of French bean in five locations of the Ecuadoria high lands. Ph.D.thesis. The Universidad Central del Ecuador, Quito, Ecuador.

Choudhary, R. N., Haque, M. F. 2010. Stability of yield and its components in chickpea. Legume research *Inter. J.* 33(3).

Comstock, R. E. and Moll, R.H. 1963. genotype x environment interaction. Statistical Genetics and Plant Breeding, *NAS NRG-Publ.* 982: 174-196.

Dabholkar, A. R. 1999. Elements of biometrical Genetics. Concept Publishing Company, New Delhi, pp. 379-421.

Eberhart, S. A. and Russell, W. A., 1966. Stability parameters for comparing varieties. Crop Sci., 6: 36-40.

Evans, A. M. 1973. Genetic improvement of *Phaseolus vulgaris* in nutrients. Improvement of food legume by breeding. P. A. G. symposium, F. A. O. Rome (1972). 107-115.

Evans, A. M. 1979. Beans (*Phaseolus* spp.) in evolution of crop plants. Longman, London, and New York. pp. 168-172.

Finlay, K. W. and Wilkinson, G. N. 1963. Analysis of adaptation in a plant breeding programme. *Australian J. Agric. Res.* 14: 742-754.

Firew M, 2003. Yield stability in common bean (*Phaseolus vulgaris* L.) genotypes. *Euphytica* 130: 147-153.

Freeman, G. M. and Perkins, J. M. 1971. Environmental components of variability VIII. Relation between genotypes grown in different environment and measure of these environments. *Heredity* 27:15-24.

Freire-Filho, F. R., Ribeiro,V. Q., Rocha, M. M. and Lopes, A. A. 2001a. Yield stability analysis in semi erect brown testa cowpea employing AMMI model. Documents Embrapa-Meio-Novt.56: 219-224.

Freire-Filho, F. R., Ribeiro, V. Q., Rocha, M.M. and Lopes, A. A. 2001b. Evaluation of yield stability in cowpea climbing and brown testa genotypes using AMMI model. Documents Embrapa-Meio-Novt.56: 225-230.

Frey, K. N. 1964. Adaption reaction of a strain selected under stress and non- stress environmental conditions. *Crop Sci*. 4: 55-58.

Guv, J. W. 1988. Studies on stability of rust resistant bean lines in different locations. Bull. Toichung district. *Agril. Improv. Stn. No.* 19:3-10.

Harer, P. N., Bhor, T. J. and Lad, D. B. 2000. Stability for seed yield and numbers of pods in Rajmash varieties. *J. Maharashtra Agric. Univ.,* 25: 88-99.

Helton, P. and Leonardo, C. M. 2009. Stability and adaptability of carioca common bean genotypes in states of the central South Region of Brazil. Crop Breeding and Applied Biotechnology. 9: 181-188.

Islam, A. K. and Newaz, M. A. 2001. Genotype-environment interaction for seed yield and yield contributing characters in dry bean (*P. vulgaris* L.). *Bangladesh J. Plant Breed. Genet.* 14: 43-48.

Kavitha, R., Khatri, R. S. and Sargawan, R.S. 2003. Stability analysis for grain yield in cowpea. Adv. *Arid Legume Res.* 379-382.

Kelly, J. D., Adams, M. W. and Varner, G. V. 1987. Yield stability of determinate and indeterminate dry bean cultivars. Theor. And Appl. Genet., 74(4)

*Kent Mckay, Perry Miller, Brian jenks, Jack Riesselman, Karness Neill, Dave Bushena and Bussan, A.J. 2002. Growing chickpea in Northern Ghat Plain. A-1236, Nov. 2002. North Dekota State Univarsity, NDSU Extension service pp. 147-151.

Khalifa, G. E., Eljack, A. E. and Mohammed, M. I. 2013. Yield stability in common bean genotypes. *J. of Plant Breed. and crop Sci*. 5(10). 203-208.

Khatri, R. S., Kavitha, R. and Sangwan, R. S. 2003. Stability analysis for test weight in cowpea. *Adv. Arid Legumes Res*. 376-378.

Knight, R. 1970. The measurement and interpretation of genotype-environment interactions. *Euphytica*. 19: 225- 233.

*Lerner, I. M. 1954. Genetic Homeostasis, Oliver and Boyd. London. Edinburg.

Mahil, J. F., Jekins, J. N., McCarty Jr-1 and Parrott, W. L. 1984. Performance and stability of double haploid lines of upland cotton derived via semi genny. *Crop Sci*. 24: 271-277.

Musaana S., Ugen-Adrogu, M. and Mawejje, D. 2015.Yield stability of some bush snap bean genotypes in Uganda. Direct Research *Journal of Agricultural and Food Science* (DRJAFS) Vol.3 (4), 74-82.

Nedelia, G., Moisue, A., Parachioiu, R. and Sonea, V. 1984. Interaction between stability and yield components in winter wheat, Agronomie. 19: 65-75.

Nigussie, K. 2011. Genotype x Environment interaction of released common bean (*Phaseolus vulgaris* L.) varieties, in Eastern

Amhara region, Ethiopia. M.Sc. (Agri.) thesis submitted to Haramaya University, Ethiopia.

Nimbalkar, C. A., Baviskar, A. P. and Desai, V. T. 2004 Selection strategy for yield improvement in French bean (*Phaseolus vulgaris* L.) *Indian. J. Genet.,* 62(4): 349-351.

Pan, R. S., Prasad, V.S.R.K. and Rai, M. 2006 Yield stability in pole bean (*Phaseolous vulgaris* L.). *Vegetable Sci.,* 28: 65-66.

Panse, V. G. and. Sukhatme, P. G. 1985. Statistical methods for agricultural workers ICAR, New Delhi, India.

Panse, V.G. and Sukhatme, P. G. 1967. Statistical method for agriculture workers. ICAR, New Delhi, India.

Panwar, K. S., Chaudhary, H. K. and Thakur, S.R.1995. Stability in seed yield of French bean genotypes in high hill, dry temperature region of North Western Himalayas. *Indian J. Agri. Sci.* 65(5): 341-345.

Park, S. J. 1987. Cultivar by environment interactions, yield stability and grouping of test locations for field bean cultivar trial in Ontario. *Canadian J. of Plant Sci.* 67(3): 653-659.

Patel, J. D., Naik, M. R., Chaudhari, S.B., Vaghela, K. O. and Kodapully, V. C. 2009. Stability analysis for seed yield in green gram (*Vigna radiate* L. Wilczenk) *Agric.Sci. Digest.* 29(1): 67-71.

Patil, P. S., Patil, S. S. and Deokar, A. B. 1984. Stability of yield in groundnut. *Madras agric. J.* 71 (2): 78-80.

Perkins, J. M. and Jinks, J. L. 1968. Specificity of the interaction of genotype with environments. *Heredity,* 26: 463-474.

Piana C. F. B., Silva L. G. C. and Barreto, J. N.1994. An application of segmented linear regression to the study of genotype x environment interaction. *Biometrics,* 41(4): 1093.

Pillai, M. A. Anandhi, K. and Selvi, B. 2010. Stability analysis for yield in blackgram. *Legume Res.* 33(2): 152-153.

Pujari, M. V. Tiwari, V. and Singh, B. B. 2003. Phenotypic stability for pod characters in cowpea. *Ann. Agric. Res.* 24(1): 358-361.

Raffi, S. A. Newaz, M. A. and Khan, N. 2004. Stability analysis for pod and seed production in dry beans *(Phaseolus vulgaris* L.*) Asian J. Plant Sci.*3(2): 239-242.

Raje, R. S. and Rao, S. K. 2001. Stability analysis for hundred seed weight in Mung bean (*Vigna raidata* L. Wikzek). *Legume Res*. 24 (4): 222-230.

Ram, H. H. and Dhar, S. 1999. Stability analysis for yield and its components under different fertility regimes in French bean (*Phaseolus vulgaris* L.). *Vegetable Sci.*, 26: 6-11.

*Ramalho, M. A. P., Abreu, A. F. B. and Righetto, G.V. 1993. Interaction of common bean cultivars with sowing date in different location in Minas State. Pesquisa Agropecuaria Brasileira. 28(10): 1183-1189.

Razvi, S. M. and Khan, M. N. 2011. Stability analysis in common bean (P*haseolus vulgaris* L.) genotypes of Kashmir. *Elec. J. Plant Breed*. 2(3): 342-347.

*Rosochora, M. 1987. Influence of external conditions on the traits and characteristics of potato varieties N. E. Foldo, E Hansen, M.K. Niel sen and R. Rasmussen (Eds.): 133-134.

Saindon, G. and Schaalle, G. B. 1993. Evaluation of location for testing dry bean cultivars in Western Canada using statistical procedures, biological interpretation and multiple traits. *Canadian J. Pl. Sci.,* 73(4): 985-994.

*Santos, J. B. and Ramalho, M. A. P. 1990. Selection of French bean progenies adapted to autumn and winter conditions in South of Minas Gerais. *Pesquisa Agropecuria Brasileira J.* 25(11): 1655-1661.

Sarma, R.N., Roy, A., Borthakur, A. and Sarma, S.K. 1993. Genotypic stability for grain yield in Rajmash ***(****Phaseolus valgaris* L.). *Annals of Agric. Res.* 14(3): 339-341.

Sekhon, H.S., Singh, B.,Verma, M. M.and Brar, G. S., 1992. Growth and seed yield performance of some promising varieties of Rajmah *bean* in Punjab. Crop. *Improv.,* 19(2) : 139-145.

Senapati, B. K. and Roy, K. 1998. Correlation coefficients among stability parameters of yield and yield contributing characters in groundnut (*Arachis hypogaea* L.). *Legume Res.* 21 (1): 37-40.

Shanti, P. S., Jebaraj and Murugan, E. 2007. Stability analysis in black gram (*Vigna mungo* L. Hepper). *Legume Res.* 30 (20): 154-156.

Sharma, P. P. and Maloo, S. R. 1989. Phenotypic stability in chickpea *(Cicer arietinum* L.). *Madras Agric. J.* 76(7): 400-405.

Shellie, K. C. and Hostfield, G. L. 1991. G x E effect on food quality of common bean resources efficient testing procedure. Amer. Soc. *Hort. Sci. J.* 116(4): 732-736.

Shyam, S., Yadav, Verma, A. K. Rizvi, A. H., Singh, D., Kumar. J and Mitchell Andrews. 2009. Impact of Genotype x Environment interactions on the relative performance of diverse groups of chickpea *(Cicer arietinum* L.). *Archives of Agronomy and Soil Science* 56(1).

Singh, S. V. and Singh, R. B. 1980. Stability of component characters in relation with the stability of yield. *Indian. J. Genet.* 40: 93-98.

Singh, D. N., Nandi, A. and Tripathy, P. 1993. Performance of French bean (*Phaseolus valgaris* L.) cultivars in North Central Plateau zone of Orisa. *Indian J. Agric. Sci.* 63(10): 658-659.

Singh, S. P. 2001. Common bean: Improvement in the twenty first century. Kluwer Academic Publishers, London: 2-7.

Singh, R. C. 2003. Stability of cowpea lines under weather conditions of semiarid region. *Adv. Agric. Legume Res:* 383-386.

Singh, T. P., Deshmukh, P. S., Shrivasthava, G. C., Kushawaha, S. R. and Mishra, S. K. 2005. Growth rate of Chickpea genotypes under different planting dates. *Indian J. Plant Physiol.* 10(3): 245-259.

Singh, A. K., Tomer, A. K., Tyagi Kuldip. 2007. Stability analysis for yield and its components in French bean (*Phaseolus vulgaris* L.) *Legume Res.,* 30 (3): 166-172.

Tel, F. and Fiorentito, S. 1993. Adaptability and yield potential of some English varieties of French bean in central Italy. *Erabacec Univ. Agra. Generate.* 39(6): 29-35.

Thaware, B. L., Bendale V. W. and Toro, V. A. 2006. Konkan fodder cowpea a new fodder cowpea variety for Konkan region of *Maharashtra J. Maharashtra Agric. Univ.* 31(1): 127.

Varman, P. V. and Raveendran, T. S. 1989. Stability analysis in certain Virginia groundnut genotypes. *J. Oilseed Res.* 6: 165-167.

Varman, P. V., Rathinaswamy, R., Sethupthi, Ramalingam, R. and Vaman Bhat, M. 1989. Phenotypic stability for yield and quality characters in groundnut. *Madras Agric. J.* 76 (5): 247-251.

Varman, P.V. and Monoharan, V. 1993. Stability analysis in bunch groundnut. *Madras Agric. J.* 83 (12): 665-667.

Wadan, D., Khan, S., Gul, F., Majeed A. and Khan, H. 1993. Performance of seven bush bean *(Phaseolus vulgaris* L.) genotype in different environmental conditions of Swat Sarhad *J. Agric.* 9 (1): 5-9.

Wortmann, C. S., Gridley, H. F. and Musaana, S.M. 1996. Seed yield stability of bean multiline. Field Crop Research. 46(1/3):153-159.

Zimmermann, M. J. O. 1994. Adaptability and yield stability in common bean genotype. *Pesquisa Agropecuaria Brasileira.* 29(1): 25-32.

* Originals not seen

8. *VITA*

Mr. Thakare Pratik Ashok

A candidate for the Degree

of

MASTER OF SCIENCE (AGRICULTURE)

in

AGRICULTURAL BOTANY

(GENETICS AND PLANT BREEDING)

2016

Title of thesis : **"EVALUATION OF ADAPTABILITY OF RAJMASH (*Phaseolus vulgaris* L.) TO DIFFERENT ENVIRONMENTS"**

Major field : **Genetics and Plant Breeding**

Biographical information

Personal : Borned on 7th January 1992 at Bopane, Taluka Chandwad, District Nashik, Maharashtra.

Son of Mrs. Fulabai and Mr. Ashok Karbhari Thakare.

Education : Passed S.S.C. from Swami Vivekananda Vidyalaya, Dighwad. Tal Chandwad Dist Nashik with first class with distinction (86.92%) in 2008.

	:	Passed H.S.C. from K. K. Wagh Junior College of Arts, Science & MCVC, Bhausahebnagar. Tal Niphad Dist Nashik with first class (70.67%) in 2010.
	:	Completed B.Sc. (Agri.) from K. K. Wagh College of Agriculture, Nashik affiliated to Mahatma Phule Krishi Vidyapeeth, Rahuri with CGPA (8.34) in 2014.
Achievements	**:**	Received third prize in essay competition held in Nashik (International *Krishi Pradarshan*-2013).
Permanent address	**:**	At Bopane, Post Dighwad, Taluka Chandwad District Nashik, Maharashtra, Pincode - 423101
Contact details	**:**	Mobile – 9822593379 e-mail – pratikthakare107@gmail.com