

**STUDIES ON GENETIC
DIVERGENCE AND CHARACTER
ASSOCIATION FOR YIELD AND
DROUGHT RELATED TRAITS IN
FOXTAIL MILLET (*Setaria italica* L.)**

S. J. BHEEMESH

B.Sc. (Ag.)

**MASTER OF SCIENCE IN AGRICULTURE
(GENETICS AND PLANT BREEDING)**



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BY
S. J. BHEEMESH
B.Sc. (Ag.)

**THESIS SUBMITTED TO THE
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IN PARTIAL FULFILMENT OF THE REQUIREMENTS
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**MASTER OF SCIENCE IN AGRICULTURE
(GENETICS AND PLANT BREEDING)**

CHAIRPERSON: Dr. M. SUBBA RAO



**DEPARTMENT OF GENETICS AND PLANT BREEDING
SRI VENKATESWARA AGRICULTURAL COLLEGE, TIRUPATI
ACHARYA N.G. RANGA AGRICULTURAL UNIVERSITY
GUNTUR- 522002**

2017

DECLARATION

I **Mr. S. J. BHEEMESH**, hereby declare that the thesis entitled **“STUDIES ON GENETIC DIVERGENCE AND CHARACTER ASSOCIATION FOR YIELD AND DROUGHT RELATED TRAITS IN FOXTAIL MILLET (*Setaria italica* L.)”** submitted to the **Acharya N.G. Ranga Agricultural University**, for the degree of **Master of Science in Agriculture** is the result of original research work done by me.

I also declare that no material contained in this thesis has been published earlier in any manner.

Date :

S. J. BHEEMESH
I.D. No.: TAM/2015-35

CERTIFICATE

Mr. S. J. BHEEMESH has satisfactorily prosecuted the course of research and that the thesis entitled “**STUDIES ON GENETIC DIVERGENCE AND CHARACTER ASSOCIATION FOR YIELD AND DROUGHT RELATED TRAITS IN FOXTAIL MILLET (*Setaria italica* L.)**.” submitted is the result of original research work and is of sufficiently high standard to warrant its presentation to the examination.

I also certify that neither the thesis nor its part thereof has not been previously submitted by him for a degree of any university.

Place :
Date :

Dr. M. SUBBARAO
(Chairperson)

CERTIFICATE

This is to certify that the thesis entitled “**STUDIES ON GENETIC DIVERGENCE AND CHARACTER ASSOCIATION FOR YIELD AND DROUGHT RELATED TRAITS IN FOXTAIL MILLET (*Setaria italica* L.)**” submitted in partial fulfilment of the requirements for the degree of **MASTER OF SCIENCE IN AGRICULTURE** to the Acharya N. G. Ranga Agricultural University, Guntur, is a record of the bonafide original research work carried out by **Mr. S. J. BHEEMESH** under our guidance and supervision.

No part of the thesis has been submitted by the student for any other degree or diploma. The published part and all assistance received during the course of the investigations have been duly acknowledged by the author of the thesis.

Thesis approved by the Student’s Advisory Committee

- Chairperson** : **Dr. M. SUBBARAO** _____
Principal Scientist and Head
Dept. of Genetics and Plant Breeding
Agricultural Research Station,
Perumallapalle, Tirupati - 517502, A.P.
- Member** : **Dr. M. REDDI SEKHAR** _____
Professor
Dept. of Genetics and Plant Breeding
S. V. Agricultural College,
Tirupati – 517502, A.P.
- Member** : **Dr. V. RAJARAJESWARI** _____
Associate Dean
Department of Crop Physiology
S.V. Agricultural College,
Tirupati – 517 502, A.P.

Date of final viva-voce:

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Bhamesh.j... 

LIST OF CONTENTS

CHAPTER NO.	TITLE	PAGE NO.
I	INTRODUCTION	1-4
II	REVIEW OF LITERATURE	5-44
III	MATERIAL AND METHODS	45-67
IV	RESULTS AND DISCUSSION	68-150
V	SUMMARY AND CONCLUSIONS	151-155
	LITERATURE CITED	156-180
	APPENDICES	181-182

LIST OF TABLES

Table No.	Title	Page No.
3.1	Details of 60 foxtail millet genotypes	46-47
3.2	Per cent mortality of foxtail seedlings at different lethal temperatures	55
3.3	Per cent survival of foxtail seedlings at different induction (sub lethal) temperature range	56
4.1	Analysis of variance for 19 quantitative characters in foxtail millet	69
4.2	Mean performance of sixty genotypes of foxtail millet for nine yield and yield attributing characters	70-71
4.3	Mean performance of 60 genotypes of foxtail millet for five physiological characters at 30 and 45 DAS	76-77
4.4	Mean performance of top ten high yielding genotypes of foxtail millet for grain yield attributing characters	81
4.5	Mean performance of top ten high yielding genotypes of foxtail millet for physiological characters	82
4.6	Thermo tolerance performance of top ten high yielding foxtail genotypes	88
4.7	Mean performance of Foxtail millet germplasm for Thermo Induction Response (TIR) characters	86-87
4.8	Identification of promising thermo tolerant and thermo sensitive foxtail genotypes using TIR technique	90
4.9	Effect of PEG induced drought stress on germination per cent of 60 foxtail millet genotypes under different concentrations	92-93
4.10	Stress tolerance performance of top ten high yielding foxtail millet genotypes	94
4.11	Identification of promising stress tolerant foxtail millet genotypes through PEG technique	94
4.12	Mean, coefficients of variation, heritability (broad sense) and genetic advance as per cent of mean for nineteen characters in 60 foxtail millet genotypes	98

Table No.	Title	Page No.
4.13	Analysis of variance for dispersion of 60 genotypes of foxtail millet	104
4.14	Cluster composition of 60 foxtail millet genotypes based on Tocher' s method	106
4.15	Intra cluster (diagonal) and inter-cluster distances of thirteen clusters in foxtail millet	107
4.16	Cluster means with respect to yield and yield component characters in Foxtail millet	109
4.17	Cluster means with respect to physiological characters in Foxtail millet	111
4.18	Contribution of different grain yield and physiological characters to diversity in foxtail millet	113
4.19	Canonical root values, percent of variation explained and cumulative variation explained for 60 genotypes in foxtail millet	116
4.20	Mean values of canonical vectors for 60 genotypes of foxtail millet	117-118
4.21	Canonical vectors for nineteen characters in 60 genotypes of foxtail millet	119
4.22	Phenotypic (r_p) and genotypic (r_g) correlation coefficients among grain yield per plant and other yield attributing characters in 60 genotypes of Foxtail millet	127
4.23	Phenotypic (r_p) and genotypic (r_g) correlation coefficients among grain yield per plant and physiological traits in 60 genotypes of foxtail millet	131
4.24	Phenotypic (P) and genotypic (G) path coefficients among grain yield per plant and other yield components in 60 genotypes of Foxtail millet	136
4.25	Phenotypic (P) and genotypic (G) path coefficients among grain yield per plant and physiological traits in 60 genotypes of foxtail millet	142

LIST OF ILLUSTRATIONS

Figure No.	Title	Page No.
3.1	Protocol of the technique: Temperature Induction Response (TIR)	55
4.1	Mean performance of top ten foxtail millet genotypes for yield, yield components and physiological traits	83
4.2	Effect of PEG induced drought stress on plumule length (cm) of stress tolerant and sensitive foxtail millet lines	95
4.3	Effect of PEG induced drought stress on radicle length (cm) of stress tolerant and sensitive foxtail millet lines	95
4.4	Intra-cluster (D) and inter-cluster distance (D2) among thirteen clusters of foxtail millet	108
4.5	Relative contribution of different grain yield and physiological characters to diversity in foxtail millet	114
4.6	Phenotypic path diagram of grain yield and yield and physiological components in 60 genotypes of foxtail millet	149
4.7	Genotypic path diagram of grain yield and yield and physiological components in 60 genotypes of foxtail millet	150

LIST OF PLATES

Plate. No.	Title	Page No.
1	Overall view of experimental field	49
2	Plant height of selected foxtail millet lines	73
3	Ear head length of selected foxtail millet lines	73
4	Thermo induction response of foxtail millet seedlings in tolerant and sensitive genotypes	89
5	An experimental view of polyethylene glycol screening technique in laboratory	96

LIST OF APPENDICES

Appendix No.	Title	Page No.
I	Meteorological data during crop growth period	181-182

LIST OF SYMBOLS AND ABBREVIATIONS

%	: Per cent
@	: At the rate of
°C	: Degree centigrade
ANOVA	: Analysis of Variance
CD	: Critical Difference
cm	: Centimetre
DAS	: Days after sowing
df	: Degrees of Freedom
<i>et al.</i> ,	: and others
etc	: and so on; and other people/ things
Fig.	: Figure
g	: Gram
g L ⁻¹	: Gram per litre
GA	: Genetic Advance
GCV	: Genetic Coefficient of Variation
h	: hour
h ² (b)	: Heritability in broad sense
ha	: Hectare
ha ⁻¹	: Per hectare
<i>i.e.</i>	: That is
Kg	: Kilogram
kg ha ⁻¹	: Kilogram per hectare
LT	: Leaf Temperature
m	: Metre
M	: Molarity
m ha	: Million hectares
m ²	: Square meter
Max temp.	: Maximum Temperature
Max.	: Maximum
mg	: Milligram
mg g ⁻¹	: Milligram per gram
MI	: Membrane Injury
Min.	: Minimum
ml	: Milli litre
ml L ⁻¹	: Millilitre per litre

mm	: Millimetre
No.	: Number
PCV	: Phenotypic Coefficient of Variation
PEG	: Polyethylene Glycol
<i>per se</i>	: As such with mean
R^2	: Regression coefficient
RARS	: Regional Agricultural Research Station
r_g	: Genetic correlation coefficient
r_p	: Phenotypic correlation coefficient
RWC	: Relative Water Content
SCMR	: SPAD Chlorophyll Meter Reading
SEd	: Standard Error of difference
SEm	: Standard Error of Mean
SLA	: Specific Leaf Area
TIR	: Temperature Induction Response
<i>viz.</i> ,	: Namely

ABSTRACT

Name of the Author : **S. J. BHEEMESH**

Title of the Thesis : **“STUDIES ON GENETIC DIVERGENCE AND CHARACTER ASSOCIATION FOR YIELD AND DROUGHT RELATED TRAITS IN FOXTAIL MILLET (*Setaria italica* L.).”**

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The present investigation was undertaken in Foxtail millet during *khari*, 2016 to study genetic variability, genetic divergence, character association and path analysis in sixty germplasm lines including seven checks for different morpho-physiological characters related to drought tolerance along with yield and yield components.

The genotypes SiA 3636, Sri Lakshmi, Narasimharaya, SiA 3598 and SiA 3604 recorded superiority for most of the traits. Five genotypes *viz.*, Prasad, SiA 3580, SiA 3604, SiA 3618 and SiA 3623 showed the highest thermo tolerance in terms of 75 to 100 per cent seedlings survival with minimal reduction in root and shoot growth. From the experiment using polyethylene glycol (PEG) induced drought stress technique, Suryanandi, Prasad, SiA 3551 and SiA 3615 showed the highest germination per cent, lower reduction of plumule and radicle length. These varieties are able to survive even when they were exposed to high drought conditions.

Higher GCV, PCV, heritability and genetic advance as per cent mean were recorded for test weight, membrane injury at 30 DAS, fodder yield, ear bearing tillers per hill and grains per ear head indicating that simple selection could be practiced for improving these traits under rainfed condition.

All the genotypes were grouped into 13 clusters based on D^2 analysis. The inter-cluster distance was maximum between cluster IX and IV followed by cluster II and I. Selection of parents from such clusters for hybridization programmes would result in novel recombinants. Relative membrane injury contributed maximum towards genetic divergence.

Fodder yield per plant, number of grains per ear head, test weight, ear bearing tillers per hill, days to maturity, SPAD chlorophyll meter reading and relative water content exhibited highly significant positive association with grain yield per plant. Fodder yield per plant, test weight, number of grains/ ear head, SPAD chlorophyll meter reading and relative water content exerted maximum positive direct effect on grain yield besides other traits. Hence, emphasis should be made on these traits in the selection programme to evolve high yielding genotypes in foxtail millet under rainfed condition.

Chapter - I

INTRODUCTION

Foxtail millet is one of the oldest cultivated small millets grown both for food and fodder. It ranks second in the total world production of millets and continues to have an important place in world agriculture providing food for millions of people in arid and semiarid regions. It is native to China, India and Pakistan grown under rainfall ranging from 150-700 mm and is regarded as an elite drought-tolerant crop. Andhra Pradesh, Karnataka and Tamil Nadu are the major foxtail millet growing states in India contributing about 79 per cent of the total area (Munirathnam *et al.*, 2006).

In India, foxtail millet is cultivated in 98,000 ha. area with a production of 56 t ha⁻¹ and productivity of 565 kg ha⁻¹ and in Andhra Pradesh, it is cultivated in an area of 23,005 hectares with a production of 28,348 tonnes and productivity of 1232 kg ha⁻¹ (www.apdes.ap.gov.in). In India, it is cultivated in Andhra Pradesh, Karnataka, Maharashtra, Tamilnadu, Odissa, Rajasthan and Madhya Pradesh for staple food as well as fodder.

Foxtail millet has an excellent nutritional profile and is ahead of rice and wheat in terms of protein, fiber, minerals and vitamins. It is rich in dietary fibre (6.7 %), protein (11 %) and low in fat (4 %). The grain is a good source of Beta-carotene, which is the precursor of Vitamin A (Murugan and Nirmalakumari, 2006). About 8-14 % oil is being extracted from the bran of foxtail millet, which can be used as oil after refinement (Munirathnam *et al.* 2006). Unlike rice, foxtail millet releases glucose steadily without affecting the metabolism of the human body with low glycemic index (Thathola *et al.* 2010). Hence, the demand for foxtail millet

is increasing during the recent years on account of its higher nutritive value especially by the people suffering from diabetes.

In foxtail millet, seedling, early tillering and flowering stages are the most critical ones, susceptible to moisture stress in the life cycle of plant. Drought at seedling stage affects the initial plant stand and ultimately results in reduced grain yield. Drought during early tillering stage decreases vegetative growth, affects the development of reproductive structures and ultimately decreases grain yield. Drought stress during flowering results in greatest yield loss due to large reductions in grain number.

Evolving varieties tolerant to drought offers low cost technology and is one of the most efficient methods of reducing crop loss for stabilizing the production and economic returns. As foxtail millet is often produced in the areas of sub-optimal rainfall, additional yield increases may be achieved by selecting genotypes with greater plant productivity under limited soil moisture.

In breeding programme for drought resistance, it is expected that genetic gains would be more rapid and predictable, if desirable morphological and physiological attributes could be identified and selected for the parents and their progenies.

In areas where drought stress is recurrent, it is necessary to select varieties tolerant to stress conditions. This is feasible because of considerable variability for drought tolerance is available in foxtail millet germplasm.

Drought itself is a complex phenomenon and several parameters influencing it were found to be under genetic control. Hence, a better understanding of the genetic principles controlling the various parameters is still needed. Information on the genetics of parameters related to drought tolerance in foxtail millet is very limited.

The phenotypic expression of a character is resultant of the interactions between genotype and environment. Hence, the total variation needs to be partitioned into variance due to genotype (heritable) and variance due to environment (non heritable) for assessing the true breeding behaviour of the phenotype. Heritability is an important parameter which determines the extent of expressivity of a trait in a setup of environment or agro-climatic conditions. Therefore, heritability estimates are useful in predicting genetic advance under different intensities of selection. High heritability estimates together with high genetic advance are more valid for selection than heritability estimates alone (Johnson *et al.* 1955). Estimation of genetic variability in conjunction with heritability and genetic advance gives an idea of the possible improvement of the character through selection.

Further, a clear understanding of the association of plant characters with yield is necessary for successful crop improvement programme. Correlation coefficient reveals magnitude and direction of association of yield components while path analysis identifies components that directly or indirectly influences yield. Both character association and path analysis helps in formulating an effective selection strategy to develop drought tolerant and productive genotypes.

The importance of genetic diversity in plant breeding is obvious from results obtained in different crops. The recognition and measurement of such diversity, its nature and magnitude are beneficial, perhaps crucial, to any breeding programme. Exploitation of heterosis and chances of obtaining desirable segregants depends to a great extent on the degree of genetic divergence between parents chosen. Precise information on the nature and degree of genetic divergence would help the plant breeder in choosing the right type of parents for hybridization.

Various methods have been advocated by several workers, to estimate genetic divergence in crop plants (Murthy and Quadri, 1966). Of the several

methods available, Mahalanobis's D^2 statistics (Rao, 1952) has been followed by several workers on a wide range of crop species, including small millets, to measure the genetic distance among the breeding lines and to identify characters responsible for such divergence.

The present investigation aims to determine the genetic diversity among 60 lines including checks of foxtail millet of indigenous origin using cluster analysis based on morphological traits.

Keeping these points in view, the present investigation has been proposed with the following objectives:

1. To evaluate performance of germplasm lines for yield and yield components.
2. To estimate the variability and genetic parameters for drought related traits, yield and yield contributing traits.
3. To study the genetic diversity among the lines using D^2 – statistics.
4. To study the nature and magnitude of association among different yield components and their relation with yield in foxtail millet lines.
5. To identify the yield attributes contributing to grain yield based on path coefficient analysis.

Chapter - II

REVIEW OF LITERATURE

Water stress is one of the variables affecting plant growth and development. Conversely, plants are exposed to periods of mild or severe drought during the crop growth. The literature pertaining to the objectives of the present study in foxtail millet (*Setaria italica* L.) is reviewed here under the following heads.

2.1 Defining drought and drought tolerance

2.2 Drought situations

2.3 Mechanisms of drought tolerance

2.4 Morphological, biochemical and physiological basis of drought tolerance

2.5 Yield and yield components under drought stress

2.6 Genetic variability

2.7 Correlations

2.8 Path coefficient analysis

2.9 D² analysis

2.1 DEFINING DROUGHT AND DROUGHT TOLERANCE

Linsley *et al.* (1959) defined drought as a sustained period of time without significant rainfall. The term 'drought' describes a condition in which available soil moisture is reduced to the point where the plant cannot absorb it rapidly enough to compensate for transpiration (Osmanzai *et al.*, 1987).

Drought is a meteorological and environmental event which can be defined as absence of rainfall for a period of time, long enough to cause moisture depletion in soil and water deficit with a decrease of water potential in the plant tissues of the maize plant (Slayter, 1967; Kramer, 1980).

Drought, from the point of view of a crop, is the state when an adequate amount of water in quantity and distribution, is not available to allow the crop to express its full genetic yield potential. Thus, a working definition of drought would be water availability, including rainfall and soil moisture capacity, in quantity and distribution during the life cycle of the crop, inadequate for realization of its full yield potential (Sinha, 1987).

Drought resistance in plants is the ability to obtain and retain water, as well as continue its metabolic functions during a period of low water potential in its tissue (Osmanzai *et al.*, 1987). Arnon (1972) defined drought resistance as the ability to survive drought conditions without injury. To plant breeders, drought resistance is the ability of one genotype to be more productive with a given amount of soil moisture than another (Quizenberry, 1982).

Sinha (1986) is of the opinion that scientists belonging to different disciplines have different perceptions of drought resistance and therefore their definitions vary accordingly. For a molecular biologist, drought resistance is the survival of individual cell or unicellular organism by adaptation to osmoregulation. For a physiologist, it is maintenance of growth during water stress and its accelerated resumption on termination of water stress. Drought tolerance for an agronomist would mean stability in yield performance of a crop or a variety in water deficit environment. Thus, the perception of individual scientists forms the basis for defining drought tolerance. It might thus be useful, to define drought resistance as the mechanism(s) causing minimum loss of yield in a water deficit environment relative to the maximum yield in a water constraint free management of the crop.

2.2 DROUGHT SITUATIONS

The frequency of drought tends to increase with variability in rainfall. In India, highest drought (once in 3 years) occurs in arid areas like eastern Rajasthan and the least (once in six years) in Madhya Pradesh. For semi-arid India as a whole, the chance of occurrence of drought is once in four years. Though arid areas tend to be more prone to drought, they are of less importance for food-crop production. Tropical semi-arid regions are characterised by high-evapotranspirative demand and low water holding capacity of soils making them more drought susceptible than semi-arid areas of temperate regions (Swindale and Bidinger, 1981).

The type of drought situations, in which a crop is grown, greatly determines the type of mechanisms that should be developed and decide the appropriate breeding methodology that should be used. In general, three types of environments can be associated with drought stress in plants; however, numerous combinations of these environments occur.

2.2.1 Stored moisture environment

In this environment, the crop completes its entire life cycle on soil moisture that is stored in the soil during the previous season. Distinct seasonal dry and wet periods occur and the degree or intensity of drought is determined by the amount of water that is stored in the soil during the period. Breeding strategies to exploit this type of environment cover a broad spectrum of traits like phenological, morphological, functional and metabolic traits. The potential for genetic improvement of drought resistance in this environment should have a high probability of success.

2.2.2 Variable moisture environment

In this environment, crop is grown during the portion of the year when precipitation is expected to occur. Alternate dry and wet periods of

varying lengths can be expected during crop growth. Plants grown in this environment must be able to take advantage of the rainfall when it occurs and are in constant competition with atmospheric evaporation for the available soil moisture. In this environment, plants need to have high photosynthetic rates, stomatal responses sensitive to moisture deficits, dense but not necessarily deep roots, rapid osmotic adjustments and indeterminate growth habits (Turner, 1979). Probability of success of breeding efforts is less in this environment because of variability in seasonal precipitation which hinders the development of crop varieties. Maize growing Regions of western and central India represent this type of environment.

2.2.3 Optimal moisture environment

In this environment, crop is grown with adequate soil moisture during most of its cycle but occasional periods of drought occur during the growing season. Drought in such areas is highly unpredictable. This environment is considered to be optimal for crop production. Extensive root development, rapid osmotic adjustment to maintain cell turgor, and indeterminate growth habits are some mechanisms of value to the plant breeder for this environment (Turner, 1979). Stomata that close quickly at a relatively high water content to maintain the plant water balance during drought should be useful (Raschke, 1975)

2.3 MECHANISMS OF DROUGHT RESISTANCE

In agriculture, the ability of a crop plant to produce its economic product with limited availability of water can be referred to as drought resistance, whereas in evolutionary context, it is the ability of a plant to survive and eventually reproduce under limited moisture.

Levitt (1972) and Turner (1979) described three primary types of drought resistance and these are drought escape, drought avoidance and drought tolerance. Drought escape mechanisms enable crop plants to resist

drought by early maturity, developmental plasticity and re-mobilization of stem reserves before anthesis to grain (Turner, 1979). In drought avoidance, plants avoid low tissue water potentials by one or more discrete mechanisms such as change in rooting pattern or an adjustment in leaf area. Leaf area adjustment has been suggested as one of the most powerful mechanisms of avoiding stress (Passioura, 1976). Drought tolerance gives the ability to produce despite loss of plant water status (O'Tootle and Chang, 1979). Unlike most xerophytes, crop plants use more than one mechanism to resist moisture stress (Gaff, 1980). Gupta and O'Tootle (1986) added one more term 'drought recovery' as the ability of a plant to resume growth and yield after stress with a minimum irreversible yield loss.

May and Milthrope (1962) identified three primary types of drought resistance.

- a) **Drought escape:** The ability of a plant to complete its life cycle before a serious plant water deficit develops. Plants can achieve this by rapid phenological development and developmental plasticity.
- b) **Drought tolerance with high tissue water potential:** The ability of a plant to endure periods of rainfall deficit, while maintaining high tissue water potential.
- c) **Drought tolerance with low tissue water potential:** The ability of a crop plant to endure rainfall deficits at low tissue water potential achieved by maintenance of turgor and desiccation tolerance. Jones *et al.* (1970) listed several mechanisms that enable plants to resist drought which are listed below.

Mechanisms of drought tolerance and Drought escape

- a) Rapid phenological development
- b) Developmental plasticity

Drought tolerance with high tissue water potential

- a) Maintenance of water uptake
 - i) Increased rooting
 - ii) Increased hydraulic conductance
- b) Reduction of water loss
 - i) Reduction in epidermal conductance
 - ii) Reduction in absorbed radiation
- iii) Reduction in evaporative surface

Drought tolerance with low tissue water potential can be obtained by

- a) Maintenance of turgor
 - i) Solute accumulation
 - ii) Increase in elasticity
- b) Desiccation tolerance
 - i) Protoplasmic resistance

2.4 Morphological basis for drought tolerance

Drought induced damage symptoms manifested by plants appeared to be complex. Attempts have been made by some authors to subdivide the general symptoms into components and have studied the various responses individually. Pre-flowering drought stress traits include leaf firing, leaf

shedding, leaf rolling, angle changes, height reduction and changes in root factors. Symptoms frequently observed under drought stress are: stunted plants, top firing, tassel blast, leaf firing in lower leaves, both mild and extreme wilting and rolling of leaves, silk delay, poor seed set, barrenness, root systems and dead plants.

2.4.1 Stunted plants

Reduction in plant height under drought Conditions was reported earlier by several workers (Gu *et al.*, 1989; Abellandsa and Canny, 1991; Mwambula and Myer, 1991; Denmead and Shaw, 1960; and Clasen and Shaw, 1970). Prolonged drought stress in the vegetative stage mainly affects the length of the internodes (Robins and Domingo, 1953; Jurgens *et al.*, 1978).

2.4.2 Changes in root characters

Wiersum (1967) and Hurd (1973) concluded that cultivars of corn penetrated roots upto 70 cm deep into the soil. Deep rooting in comparison to total number of roots is an advantage in crops where water supply is limited.

A large root weight gave superior root type. Strains with more root branches, high root weight and deep root system will impose the plants to absorb more moisture and withstand water stress; however, root volume has little effect because of seminal roots (Sharp and Davies, 1985; Tan and Fulton, 1985).

Drought commonly increases the ratio of root to shoot (Mooney, 1972; Larcher, 1975) and there are several reports of the absolute size of the root system actually increasing during drought (Bennett and Doss, 1960; Schultz, 1974). The reasons for good growth of roots of drought plants have been discussed by Hsaio and Acavedo (1974) and Itai and Benzioni (1976). The most likely explanation is that drought affects growth of the shoot more

than it does photosynthesis, so that the amount of assimilates available for root growth is thereby increased the difference between species, with respect to drought to their root and shoot ratios is enormous.

Mwambula and Myers (1991) studied the behaviour of maize genotypes under irrigated and rainfed conditions and concluded that number of barren plants were significantly reduced under irrigated conditions. Some of the other symptoms observed under drought include wilting, leaf firing in lower leaves and poor seed set.

2.4.3 Biochemical basis of drought tolerance

Water deficit results in disturbance to normal pattern of protein synthesis. Protein synthesis was adversely affected by the drought (Younis *et al.*, 1965). One of the effects of water stress on protein synthesis was blockage of amino acid metabolism at different points in their biosynthetic pathways (Naylor, 1982). Total protein and amino acid levels in stressed seedlings dropped by more than 40 per cent, while free amino acid content increased 2.5 folds in maize. Among the total protein amino acids, alanine, aspartic acid, glycine, leucine, serine and valine were found in high quantities in maize and sunflower (Navari-Izzo *et al.*, 1990).

Free proline accumulates under water stress (Routley, 1966 and Waldren *et al.*, 1974). Singh *et al.* (1972) proposed proline accumulation as a mechanism conferring adaptive value to plants under water deficits. Singh and Singh (1983) reported that proline accumulation increased with increasing stress levels and also accumulation of free proline was more in drought resistant (HD-1981) variety of wheat when compared to susceptible cultivar (UP-319). Proline accumulation requires fully developed chloroplasts and systematic development of plants (Ibarra-Caballero *et al.*, 1988).

Betaine is another compound that accumulates under water stress and has a time course of accumulation similar to proline. Hanson and Nelson (1978) suggested that selection against high betaine genotypes might be useful in breeding programme.

2.4.3 Physiological basis for drought resistance

The information on physiological characters related to drought resistance continues to grow, yet it is difficult to conclude a major relationship between a trait (or) traits and drought resistance with practical application to a plant breeding programme (Fischer and Wood, 1979).

Peacock and Wilson (1984) studied characters related to drought tolerance in sorghum and concluded that tolerance to desiccation and heat, osmotic adjustment and assimilate distribution are some important traits aiding in drought tolerance. Aceredo *et al.*, (1979) reported that in response to moderate water stress, seasonal osmotic adjustment occurs in field grown sorghum, maize and soybean.

Production under water stress increases when transpiration is sustained and when water use efficiency and harvest index are improved (Blum, 1988). Gu *et al.* (1990) reported the maize cultivar Yuvu No. 3 to be drought resistant as it reduced water loss by increased stomatal resistance and osmotic potential. Drought tolerant lines maintained significantly higher transpiration efficiency, water use efficiency and plant water status than sensitive lines (Subbarao and Jana, 1991).

Kirkham *et al.* (1984) studied canopy temperature in maize genotypes and classified them as drought tolerant and susceptible lines with cooler canopy temperature than air tended to yield more grain than lines with warmer temperature. Stark (1989) gave a different conclusion that genotypes of potato which were warmer, were generally less susceptible to drought than cooler genotypes.

Leaf rolling and leaf shedding (leaf area reduction) are common ways of reducing water loss. Changes in leaf angle reduced water loss by providing more shading of lower leaves and by reducing canopy temperature. Reduced tassel size, narrower leaves and leaf enlargement following drought stress were considered to be good and easy to evaluate (Jurgens *et al.*, 1978).

However, too steep angle had little effect on photosynthesis. Changed leaf surface properties like production of hairs, surface wax or salt which increase reflectance of leaves decreased transpiration more than photosynthesis and thus improved water use efficiency (Mooney *et al.*, 1977; Ehleringer, 1977).

Bennett and Hammond (1983) reported that drought reduced leaf area by 19 per cent. Resistant lines had lesser leaf area per plant under drought (Morizet *et al.*, 1984). Sobrado (1990) observed reduction in leaf area under drought and suggested that small leaf area as a consequence of water deficit during vegetative development of crop decreases the carbon source available for grain growth.

The timing and completeness of stomatal closure during water stress and following water relief, is an importation of water by closing of stomatal is an important drought resistant mechanism as continued photosynthesis involves continuous water loss (Teare *et al.*, 1973). The relation between productivity and total water use also depend on the role of stomata in the exchange of carbon dioxide and water vapour between plant and atmosphere (Fischer, 1980). In plants which have been allowed to wilt and were rewatered, the stomata remained closed for several days, even when there was a rapid recovery of the full turgidity (Hiron and Wright, 1973).

When leaves are wilting, a sudden increase in Abscisic acid (ABA) content will be observed. The effect of water deficit on transpiration is well

known. The effect of ABA as an agent that lowered rate of transpiration of leaves was first noted by Little and Eidt (1968). ABA caused the stomata to close and thus reduced the rate of transpiration (Jones and Mansfield, 1970). Sharp reductions in photosynthesis and sharp increases in leaf diffusion resistance at specific water potentials could be the result of ABA induced stomatal closure.

Ackerson (1983) studied a US corn belt hybrid and a latent hybrid and found that levels of ABA were higher in the latent hybrid, particularly under water stress during vegetative and grain filling stages. ABA accumulation coincided with stomatal closure and lower conductance. Larque-Saavedra *et al.* (1989) observed that differences in ABA content were more pronounced in mature leaves than in seedlings.

Johnson and Herrero (1981) listed the plant processes in order of decreasing sensitivity to drought: cell and leaf enlargement, floral development, photosynthesis, transpiration, respiration and translocation.

2.4.3.1 SCMR Reading

The chlorophyll meter (or SPAD meter) is a simple, portable diagnostic tool that can measure the greenness or relative chlorophyll content of leaves (Inada, 1985; Karlia *et al.*, 1982).

SPAD chlorophyll meter reading (SCMR) is an indication of the light-transmittance characteristics of the leaf which is dependent on the leaf chlorophyll content.

Rao *et al.* (2003) recorded SPAD values ranging from 33 to 50 per cent at 50% flowering and these values could be used as a surrogate for leaf and stem nitrogen percentage in post rainy season sorghum.

Reddy *et al.* (2003) observed significant negative correlation between SCMR and SLA, while the correlation between SCMR with total

chlorophyll content and seed yield were positive in groundnut genotypes. Genotypes with high SCMR had greater photosynthetic capacity and thereby assimilated more carbon per unit leaf area, which might have influenced seed yield (Latha, 2004).

Sudhakar *et al.* (2006) reported significant positive correlation between SCMR and yield under terminal moisture stress conditions in greengram and blackgram. Abdellah *et al.* (2011) also observed similar decrease in chlorophyll content under moderate and severe water stress situations.

Kumari and Ganesamurthy (2010) studied 22 Sorghum genotypes and found that the sorghum genotypes exhibited high mean values for SPAD chlorophyll reading, and grain yield when compared to other genotypes under stress based on *per se* performance. These genotypes also recorded low drought susceptibility index, high relative yield, stress tolerance index and yield stability ratio and they can be used as parents for future breeding programmes.

Majid *et al.* (2011) during their studies on effect of drought stress on leaf chlorophyll content and stress resistance in maize cultivars (*Zea mays*) revealed that genotypes BC678 and BC404 have highest chlorophyll index. They also revealed that drought stress had a negative effect on genotypes BC404 and BC678 and they had maintained same yield and chlorophyll content.

Ganji *et al.* (2012) reported that effect of drought stress was significant ($p < 0.01$) on leaf chlorophyll content. They also revealed that drought resistant wheat genotype 'Kavir' had the highest (SPAD: 51.89) chlorophyll content in drought stress. Ghods and Tajan genotypes which are susceptible to drought stress had low chlorophyll content (44.26 and 45.01 SPAD).

2.4.3.2 Specific Leaf Area (SLA)

SLA is one of the physiological traits in plant growth analysis and is the ratio of leaf area to its dry weight. The SLA is often considered as an indirect measure of leaf expansion. The SLA was negatively related to WUE and was positively related to harvest index, suggesting that selection for low SLA might result in the production of more dry matter with minimal influence on pod weight (Wright *et al.*, 1993, 1983).

Higher SLA means higher leaf area per unit biomass and a larger surface area for transpiration. On the other hand, if SLA is higher, the leaf thickness would be less and hence the capacity of photosynthesis would be smaller. Since transpiration and photosynthetic capacity determine the variability in TE, an inverse relationship between SLA and WUE is normally observed (Wright *et al.*, 1994).

Dingkuhn *et al.* (2001) found that there is a strong case for SLA being responsible to a large extent for varietal differences in tillering ability and LAI in rice. High SLA is a major factor enabling early ground cover and light interception; therefore, it determines potential growth in many situations.

Bindu *et al.* (2002) provided an evidence that the relationship between WUE and SLA was predominantly due to a strong association between SLA and specific leaf nitrogen, which has strong positive linkage with SCMR.

Talwar *et al.* (2004) and Latha and Reddy (2007) also reported a significant genotypic difference for SLA in groundnut genotypes.

Babitha *et al.* (2006) reported that the groundnut Spanish genotype JAL-07 had lower SLA (101.6 cm²) and high SCMR (52) indicating that it can tolerate both water deficit and high temperature.

The most drought-affected parts of the plants were the stem and the panicle at both growth stages, compared with root and leaf biomass, which were least affected by drought. Although leaf dry weight (LDW) changed little under drought, LA decreased 50-75% compared with control conditions, at both stages of assessment. This was related to leaf thickening in part indicated by a 30-50% decrease of the specific leaf area (SLA) in all the genotypes under drought conditions at the vegetative stage and reproductive stage (Kholova *et al.*, 2010).

2.4.3.3 Relative membrane Injury % (RI)

The leakage of solutes from tissue can be used as a dynamic measure of the damage to membranes due to stress experienced by the plasma membrane. It is generally protected from desiccation-induced damage by the presence of membrane-compatible solutes, such as sugars and amino acids. Therefore, a link might exist between the capacity for osmotic adjustment and the degree of membrane protection from the effect of dehydration (Leopold *et al.*, 1981).

As the high temperature effects are primarily seen on membrane related processes, the heat tolerance appears to be determined by the thermal sensitivity of primary photochemical reactions occurring in the thylakoid membrane system. Therefore, electrolyte leakage has been used to assess stress-induced damage in many crop plants (Hawarth *et al.*, 1997).

It is reported that membrane thermo-stability is particularly significant only at those extreme temperatures where membrane disruption is likely to occur (Hawarth *et al.*, 1997).

Membrane stability was associated with drought tolerance in rice (Tyagi *et al.*, 1999) and it is suggested that genotypic variations may be exploited to enhance genetic resources for the high temperature tolerance (Nautiyal *et al.*, 2002).

Higher membrane stability under drought contributed significantly to drought tolerance in rice (Kumar and Kujur, 2003).

Gowri (2005) reported a decrease in the values of membrane stability in aerobic rice. Babitha *et al.* (2006) reported that genotypes with low RI are more thermo-stable than those of the genotypes with high RI. They also reported lower membrane injury in Spanish groundnut genotype JAL-07 and Virginia groundnut CSMG84-1 and found better suitability for higher temperatures.

Vijayalakshmi *et al.* (2012) investigated the physiological and biochemical basis of water stress tolerance in pearl millet hybrid ICMH 356 and its parents ICMR 356 and ICMB 88004 in response to and recovery from drought stress and also to comprehend crop adaptation under dryland conditions. They revealed significant positive association of yield with membrane stability index, leaf area index and total biomass under water-deficit stress. This clearly indicated that such relationships can be positively attributed to drought tolerance.

2.4.3.4 Canopy leaf temperature

Leaf Temperature, Temperature differences between both the upper and lower leaf surfaces, measured by thermocouple, highly correlated with transpiration under most conditions (Pallas *et al.*, 1967). It is measured with infrared thermometer and thermocouples in both the East and West canopy positions, as also done for micro meteorological monitoring (Ribeiro *et al.*, 2005). Plants protect one of their most important functions, Photosynthesis, by maintaining average leaf temperatures at around 21°C, regardless of the weather (Heidi, 2008).

In plant breeding and selection for drought resistance, the interest is in finding genotypes that maintain transpiration, gas exchange and therefore a lower canopy temperature as compared with other genotypes under the

same field conditions. Relatively lower canopy temperature in drought stressed crop plants indicates a relatively better capacity for taking up soil moisture and for maintaining a relatively better plant water status by various plant constitutive or adaptive traits (Blum *et al.*, 1990).

Many of the physiological processes of plants are temperature-dependent and for this reason experimenters attempt to characterise plant environments by recording, amongst other things, the temperature of the air. However, the site of many of these processes is the leaf, and ultimately it is leaf temperature which decides the rate of these processes. Leaf temperature does not bear a fixed relationship to air temperature. Net radiation, air movement, and the humidity of the air all affect leaf temperature, and it is therefore necessary to measure leaf temperature in order to fully understand the plants response to a given environment (Acock, 1996).

Changes in leaf angle were found to reduce leaf temperature. A leaf angle of 70° reduced leaf temperature under extreme conditions by 2-3°C and reduced transpiration by 12% in *Atriplex hymenylatra* (Mooney *et al.*, 1977).

Sanjay and Suresh (1994) evaluated role of alternative respiration, a thermogenic pathway, in temperature rise of water stressed plants. They monitored transpiration rate, plant temperature and respiratory dynamics in field grown irrigated and unirrigated sorghum (*Sorghum vulgare* Pers.) hybrid CSH 6 and pearl millet (*Pennisetum typhoides* (Burm. f.) Stapf and Hubbard) var. J 104 for 22 days. Transpiration rate of irrigated plants was always higher than the unirrigated plants. But the plant temperature and the alternative respiration activity of irrigated plants was always lower than unirrigated plants. The reduction in transpiration rate of unirrigated pearl millet was more as compared to unirrigated sorghum. However, alternative respiration activity was higher in unirrigated sorghum as compared to unirrigated pearl millet. Temperature of unirrigated sorghum plants

increased by 10.4°C during 22 days and it was 8.0°C higher than irrigated sorghum at day 22. Stressed pearl millet showed an increase of 3.9°C during 22 days and it was 2.9°C higher than the irrigated pearl millet at day 22. It is suggested that the heat released because of the alternative respiration activity also contributes towards temperature rise of water stressed plants.

2.4.3.5 Relative water content % (RWC)

The concept of relative water content was first developed by Weatherly (1950) and later modified by Barrs and Weatherly (1962). The RWC is one of the measures which gives an idea of tissue water status. Ravindra *et al.* (1990) found that relative water content was significantly reduced under stress at the vegetative phase in groundnut.

Slayter (1955) reported that the rate of dry matter accumulation and transpiration of groundnut was initially reduced when relative water content of the leaves dropped below 90 per cent. Iyama and Murata (1961) revealed that the groundnut had an enhanced capacity for maintaining leaf water content against a soil water deficit.

Patel *et al.* (1983) found that the RWC of groundnut leaf declined with decrease in soil water potential from -0.05 to -2.0 MPa. However, RWC of the leaf did not recover to its original value on re-watering after severe stress. The leaf water potential and relative water content were negatively correlated with a correlation coefficient of -0.95. The linear regression equation was $\psi_L = 64.8 - 0.61 \text{ RWC}$. Perceptibly, stressed plants have lower RWC than non-stressed plants. RWC of non stressed plants ranged from 85 to 90 per cent, while in drought stressed plants, it may be as low as 30 per cent (Babu and Rao, 1983).

Ayub *et al.* (2012) investigated the physiological (relative water content, pod dry weight, pods per plant, pod yield, shelling (%), plant

height) and biochemical (endogenous ABA level) traits of peanut cultivar 'Swat Phalli-96' variety of pea nut under drought stress. The result showed that drought stress significantly ($p < 0.05$) reduced relative water content (RWC), pod dry weight, pods per plant, pod yield, shelling (%) and plant height.

Awol *et al.* (2013) screened drought tolerance of 96 finger millet accessions (*Eleusine coracana* L. Gaertn.) for plant height (PH), green leaf number (GLN), green leaf area (GLA), ear number (EN), ear length (EL) and relative water content (RWC). Significant differences ($P < 0.05$) were obtained between accessions for most selected physiological, morphological and yield related traits such as Chlorophyll Content Index and RWC. Based on high RWC, GLN, EL, and EN, Grain Yield per head and per plant, a total of 23 accessions were categorized as drought stress tolerance and promoted to the next intensive physiological and yield related evaluation.

Seenaiyah *et al.* (2015) studied six cluster bean lines on effects of drought on morphological and physiological effect on root growth, shoot growth, leaf area, relative water content (RWC) and Chlorophyll SPAD reading values variations. They found that the shoot-root ratio, leaf area and RWC were high and chlorophyll SPAD reading values were less in water stressed conditions in the cluster bean genotypes.

2.4.3.6 Polyethylene Glycol (PEG) Induced Drought Stress

Polyethylene glycol (PEG) technique has been used to identify and select the drought tolerant genotypes. It involves exposing seedlings or plants to osmotic stress conditions by using polyethylene glycol (MW6000) compound of different concentrations along with control conditions.

Osman Basha *et al.* (2015) studied five tomato germplasm lines for drought tolerance using 0 %, 2 %, 4 %, 6 %, 8 %, 10%, 12 %, 14 % and 16% PEG-6000. No significant difference was observed in germination rate

between control and PEG concentration and reduction in germination was observed at 22 % of PEG solution. The shoot length increased significantly in Arka Rakshak, Arka Vikas and PKM- OP at 2 % PEG stress condition in comparison to control. The longest shoot length (6.5 cm) was noticed in Arka Rakshak at 2 % PEG in comparison to other germplasm.

Khafagy *et al.* (2014) experimented on two rice cultivars, Sakha 101 and Giza 178 under salinity (NaCl) or drought (PEG) condition. The results showed that hydro-priming for 48 h caused significant improvement of germination indices under water stress condition in comparison with other priming treatments. Also NaCl or PEG, in general, inhibited the germination process as reflected by a decrease in the germination percentage, root and shoot lengths as well as fresh and dry weight. The reduction was significantly higher in Sakha101 compared to Giza 178. It was concluded that Giza 178 proved to be more tolerant against drought and salt stress conditions than Sakha 101.

Toosi *et al.* (2014) studied on effect of PEG 6000 stress on *B. juncea* (L.). Shoots elongation significantly decreased by concentration of 2-8 MPa whereas no hypocotyl elongation at concentration of 10 and 12 MPa and shoot elongation was completely inhibited.

Naveena Sharon *et al.* (2015) evaluated five finger millet varieties against five levels (0, 10, 15, 18 and 21%) of polyethylene glycol (PEG-6000); PEG-induced drought stress decreased Final Grain Percentage, Germination Energy % and led to reduction in shoot and root length and dry weight in all varieties and the magnitude of reduction increased with increasing drought stress concentrations. Germination was highly inhibited in all five varieties at 21% PEG concentration. Finger millet varieties Sattai kelvaragu and GPU 48 showed greater drought tolerance during germination (germinated at 15% PEG).

2.4.3.7 Temperature Induction Response (TIR) Technique

Temperature Induction Response (TIR) has been utilized in recent studies as a potential tool for empirical assessment for cell survival and recovery growth at seedling or whole plant level (Senthil *et al.*, 2004). Temperature Induction Response (TIR) technique has been developed to identify and select the thermo tolerant genotypes. It involves exposing seedlings or plants to induction stress and subsequently challenging with severe temperature and selecting the surviving seedlings at the end of a recovery period. This approach of TIR involves, first the identification of challenging temperature and induction temperature and later standardizing them before being used for screening the material for intrinsic stress tolerance.

Venkatachalayya *et al.* (2001) screened 32 pea (*Pisum sativum*) genotypes using the TIR technique. By employing Z-analysis they have grouped the genotypes into thermo tolerant (Acc.623, Acc.765) and susceptible (Acc.476, Bonneville) genotypes. Among the tolerant lines one of the cultivars Acc.623 showed higher threshold temperature for thermo tolerance when compared to others.

Senthil *et al.* (2004) followed the TIR technique and screened sunflower hybrid KBSH-1 parents, CMS 234 A, CMS 234 B and 6 D-1 and screened for high temperature tolerance. The selected hybrid also showed enhanced expression of the heat shock proteins HSP 90 and HSP 104 and also accumulated higher levels of the heat shock transcription factor HSFA.

Ashraf and Hafeez (2004) assessed thermo tolerance of pearl millet (*Pennisetum glaucum* cv. ICMV-94133) and maize (*Zea mays* cv. Golden) at germination and vegetative stage. Final percentage of germinated seeds and rate of germination (number of days to 50 % germination) decreased due to high temperature (45 °C) similarly in both the species. In contrast, at

the vegetative stage, high temperature (38/27 °C) caused a significant reduction in shoot dry mass of maize, whereas this attribute remained almost unchanged in pearl millet.

Gangappa *et al.* (2006) evaluated 32 selected groundnut genotypes for temperature tolerance employing the thermo induction response (TIR) technique. Genotypes K-134, K-1240, TNAU-325 and JL-24 were identified as thermo tolerant and AK-159, VG-9711, TNAU-284 and JSSP-15 as susceptible genotypes.

Ehab *et al.* (2012) adapted temperature induction response (TIR) technique in Cotton and revealed that Old World Cotton species showed better thermo tolerance than New World cotton species. Among 36 diverse *Gossypium hirsutum* germplasm lines, *G. hirsutum* (H-28) was identified as thermo tolerant genotype by the TIR technique, demonstrated increased cell viability and protein synthesis capacity during alleviation from high temperature stress. They suggested that TIR is a robust and powerful technique and can be used to screen breeding lines or germplasms to identify thermo tolerant lines.

Sudhakar *et al.* (2012) screened 72 rice germplasm lines using the thermo induction response (TIR) technique for identifying the thermo tolerant rice genotypes. They reported that genotype NLR-145 showed the highest thermo tolerance in terms of 100 per cent seedling survival and no reduction in root and shoot growth.

Venkatesh *et al.* (2013) standardized temperature induction response technique (TIR) for 100 ragi germplasms. Among the genotypes, GP-160 and GP-27 showed highest thermo tolerance in terms of 100 per cent seedlings survival and no reduction in root and shoot growth.

Ravi *et al.* (2015) standardized TIR protocol for 76 pearl millet germplasm lines. Among the genotypes, 52 R, 150 R, 163 R and 164 R

showed high thermo tolerance in terms of 100 per cent seedlings survival and no reduction in root and shoot growth. This study revealed that TIR technique can be used for identification of thermo tolerant pearl millet genotypes. The identified pearl millet germplasm lines can be used as donor source for developing high temperature tolerant pearl millet genotypes.

2.5 YIELD AND YIELD COMPONENTS UNDER DROUGHT

Grain yield was reduced under water stress and the reduction was maximum when stress was imposed at the silking stage and was attributed to reduction in the kernel weight and kernel number (Classen and Shaw, 1970). Hall *et al.*, (1981) observed reduction in total grains per cob, 500-grain weight and cob length thus reduction in grain yield. Frederick *et al.*, (1989) also reported yield reduction under drought to an extent of 35 to 65 per cent and reduction was less in tolerant genotypes when compared to susceptible varieties.

Brunda *et al.* (2015a) studied 75 foxtail millet genotypes for yield and its attributing traits during rainy and summer seasons of 2014. All the genotypes displayed considerable amount of differences in their mean performance with respect to all the characters. The analysis of variance revealed the presence of highly significant differences in germplasm collections for all the characters under study for indicating presence of genetic variability for most of the traits. The grain yield per plot in summer season was higher than the rainy season. In rainy season among the 75 genotypes, 20 of them have recorded the higher grain yield per plant than best check SIA 326 of which DHF 1 has recorded highest grain yield followed by DHF 16 and Ise 900. In summer season genotypes DHF 26 followed by DHF 27 and DHF 13 recorded the highest grain yield per plant when compared to the high yielding check HMT 100-1.

2.6 GENETIC VARIABILITY

Genetic improvement of any crop largely depends on the magnitude of genetic variability present in the crop. Variability results due to differences either in the genetic constitution of the individuals of a population or in the environment in which they are grown. The existence of variability is essential for resistance to biotic and abiotic factors as well as for wider adaptability. Selection is also effective when there is genetic variability among the individuals in a population. Hence, a detailed study on the extent of variability in different characters associated with yield and the nature of their heritability in relation to the yield are the prime requisites for an efficient plant breeding programme.

Selvarani and Gomathinayagam (2000) evaluated variability, heritability and genetic advance of yield and yield components in 50 genotypes of foxtail millet. High levels of genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) were estimated for the number of productive tillers and grain yield per plant. Low GCV and PCV levels were obtained for days to 50% flowering, plant height and days to maturity. The differences between GCV and PCV for these traits were low. High heritability estimates were observed in all traits, indicating that these characteristics are stable. The genetic advance, as a percentage of the mean was high for the number of productive tillers, grain yield per plant and plant height. High heritability and low genetic advance were recorded for days to 50% flowering and days to maturity.

Bedis *et al.* (2006) in their study with 37 genotypes in finger millet revealed maximum genetic variability for days to flowering, days to maturity, plant height and grain yield per plant. High heritability was also recorded for days to flowering, plant height, grain yield per plant and fodder yield.

Shanmuganthan *et al.* (2006) studied genetic variability in pearl millet with 104 germplasm accessions of different origin. Analysis of variance indicated significant differences among the accessions for all the characters studied. They recorded maximum variation for panicle length, green fodder yield and grain yield in pearl millet. They also observed high heritability coupled with high genetic advance as percentage of mean for all characters except days to 50% flowering.

Meena *et al.* (2008a) experimented with 20 diverse genotypes of pearl millet and reported high GCV for grain yield per plant, spike thickness and number of productive tillers. They also registered high heritability values ranging from 84.43 % for days to 50% flowering to 99.12 per cent for spike yield per plant. They also observed high estimates of heritability with genetic advance for plant height and grain yield per plant.

Govindaraj *et al.* (2010) conducted a study with 21 diverse elite lines and cultivars of Pearl millet and noticed highly significant differences among the genotypes for all the traits except number of productive tillers and days to maturity. Highest variability was recorded for plant height, number of productive tillers and for grain yield. High estimates of broad sense heritability coupled with higher genetic advance was observed for grain yield per plant and panicle length.

Nirmalakumari and Vetriventhan (2010) evaluated 741 foxtail millet germplasm accessions and recorded the highest heritability, genotypic coefficient of variation and genetic advance as per cent of mean for grain yield per plant while these were lowest for days to 50% flowering.

Veena *et al.* (2010) estimated the variability of 69 pearl millet germplasm entries raised during rabi 2004 under irrigated conditions for seven quantitative characters and three qualitative characters. They observed high variability for fodder yield and its associating characters and

high GCV estimates for fodder yield. They revealed high heritability estimates for all the characters and also high genetic advance as percentage of mean for plant height and fodder yield.

Sumathi *et al.* (2010) reported a wide range of variation for grain yield and its component characters in 47 diverse genotypes of Pearl millet, during *kharif*, 2008. The traits, ear head length and seed yield showed moderate PCV and GCV, while the traits, days to 50% flowering, plant height and ear head breadth showed low PCV and GCV. High heritability was observed for all the traits under study. High heritability combined with high genetic advance as per cent of mean was observed for ear head length and seed yield.

Ganapathy *et al.* (2011) conducted a study with 230 indigenous and exotic accessions of finger millet and recorded high PCV and GCV levels for productive tillers per plant and moderate levels for the traits viz., days to 50 per cent flowering, plant height, finger length and grain yield per plant and low PCV and GCV for days to maturity. They also observed high heritability coupled with high genetic advance for days to 50 per cent flowering, plant height, productive tillers per plant, finger length and seed yield per plant.

Priyadharshini *et al.* (2011) evaluated 21 hybrids along with seven parents of finger millet during *kharif*, 2009 and they reported high PCV and GCV for number of productive tillers per plant and moderate PCV and GCV for harvest index. They also registered high heritability along with high genetic advance as per cent of mean for plant height, number of productive tillers per plant, harvest index and single plant grain yield.

Prasanna *et al.* (2013) studied genetic variation, heritability and genetic advance for 13 characters in 34 exotic genotypes of foxtail millet during Autumn, 2008 and Spring, 2009. High phenotypic coefficients of

variation (PCV) coupled with high genotypic coefficients of variation (GCV) were observed for grain yield per plant, ear weight, calcium content and carotene during both seasons. The trait 1000 grain weight recorded high PCV and GCV during Autumn, whereas number of productive tillers per plant and straw weight during Spring. Straw weight showed high GCV during Autumn. It indicated presence of wider variability for these traits in the genotypes studied. High heritability coupled with high genetic advance as percent of mean recorded for all characters except days to 50% flowering, days to maturity and plant height during both seasons revealed operation of additive gene action in the inheritance of these traits and improvement in these characters is possible through simple selection.

Musa and Atif (2013) evaluated 15 genotypes of pearl millet during the summer season 2009 and 2010 and observed highly significant differences for days to 50% flowering and days to maturity in both the seasons, whereas for plant height, number of grains /plant, 1000 grain weight and grain yield (t/ha) in the summer season of 2009 and for panicle length in the summer season of 2010. They also reported high estimates of heritability and genetic advance for days to 50% flowering and days to maturity.

Brunda *et al.* (2014) carried out genetic variability for productivity related traits in 75 foxtail millet germplasm collections during rainy and post rainy season. In both the seasons high values for phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) was recorded for number of tillers per plant, followed by panicle weight per plant, straw weight and grain yield per plant. Moderate GCV and PCV were recorded for days to flowering and panicle length. The low GCV and PCV was recorded for days to maturity and plant height. The grain yield and its components viz., days to flowering, number of productive tillers, panicle length, test weight, grain yield per plant and straw yield per plant exhibited high genetic

advance as per cent of mean coupled with high estimates of h^2b indicating that, the variations are attributable to high level of heritable variation and selection would be effective for improvement of these traits.

Johar *et al.* (2015) investigated coefficients of genetic variation, heritability and genetic advance for 13 characters in 34 exotic genotypes of foxtail millet during Autumn, 2008 and Spring, 2009. High phenotypic coefficients of variation (PCV) coupled with high genotypic coefficients of variation (GCV) were observed for grain yield per plant, ear weight, calcium content and carotene during both seasons. The trait 1000 grain weight recorded high PCV and GCV during Autumn, whereas number of productive tillers per plant and straw weight during Spring. Straw weight showed high GCV during Autumn. It indicated presence of wider variability for these traits in the genotypes studied. High heritability coupled with high genetic advance as percent of mean recorded for all characters except days to 50% flowering, days to maturity and plant height during both seasons reveals operation of additive gene action in the inheritance of these traits and improvement in these characters is possible through simple selection.

Ravi *et al.* (2015) studied genetic variability in 76 pearl millet germplasm accessions. The coefficient of variation at phenotypic and genotypic levels were high for root dry weight followed by green fodder yield per plant, root volume, dry fodder yield per plant, grain yield per plant, ear bearing tillers per hill, green fodder yield per plot, dry fodder yield per plot, grain yield per plot, relative injury, leaf area duration, number of grains per ear head, ear head length and plant height and moderate for test weight, harvest index, ear head girth and root spread while the traits, specific leaf area followed by chlorophyll stability index, days to 50% flowering SCMR, leaf temperature and days to maturity showed low PCV and GCV. These results revealed, high heritability coupled with high genetic advance observed for relative injury, dry fodder yield per plot, ear bearing

tillers per hill, dry fodder yield per plant, root volume, grain yield per plant, leaf area duration, root dry weight, green fodder yield per plot, green fodder yield per plant, number of grains per ear head, ear head length, plant height, test weight and grain yield per plot which indicates the preponderance of additive gene effects in controlling these traits. Early and simple selection could be exercised due to fixable additive gene effects for improving these traits.

Geethanjali *et al.* (2016) evaluated 51 foxtail germplasm lines for genetic variability. Considerable variability was observed among the genotypes for all the traits. Among these, grain yield per plant exhibited the maximum variation with a CV of 22.5%, while days to fifty per cent flowering and plant height exhibited the least variation with a CV of 7.2% and 9.3% respectively. PCA analysis revealed that the first four components in the PCA results contributed to a maximum of 70 per cent of the variability, the contributions from PC1, PC2, PC3 and PC4 being 30.1%, 14.2%, 13.8%, and 11.4%, respectively. The first two components were a measure of vegetative and inflorescence characters, while the third component was a measure of thousand seed weight.

Bendi and Sarma (2016) studied genetic variability and diversity existing in the 55 genotypes of finger millet. The coefficient of variation at phenotypic (PCV) and genotypic (GCV) levels were high for number of basal tillers, peduncle length, inflorescence length, inflorescence width, length of finger and grain yield per plant. High heritability coupled with high genetic advance observed in days to 50% flowering, plant height, number of basal tillers, peduncle length, inflorescence exertion, inflorescence length, inflorescence width, length of finger, number of fingers, grain yield per plant which indicated the predominance of additive gene effects.

2.7 CORRELATION ANALYSIS

Drought resistance itself is a very complex phenomenon. Grain yield of a plant is the net result of several genetic factors and their individual or combined interplay with environmental factors. Therefore, character association among themselves or with grain yield is of importance.

The breeder in his effort to improve the genotypes, would like to improve several attributes simultaneously with either no change or minimum change in desired characteristics. In furthering these objectives, knowledge on correlations is necessary. Measuring of correlation serves as an aid in determining the association between any two characters and forms the basis for selection index. The correlation may be either due to pleiotropy or due to linkage of genes. If the correlation is due to linkage, if required, it is possible to reverse the correlation, provided the linkage is not very close.

Correlation measures the actual relationship between various plant characters and helps the plant breeder in fixing selection criteria for grain yield in parental lines and segregating populations. Correlation coefficient reveals the type, nature and magnitude of association between any pair of characters. Phenotypic correlation is the association between two characters, which can be directly observed and is subjected to changes in the environment. It measures the environmental deviations together with non-additive gene action. Genotypic correlation is the correlation of the breeding values *i.e.*, additive and (additive x additive) gene effects (Falconer, 1989). Knowledge of the association of yield components with each other and with yield is helpful in improvement of yield for which direct selection is not effective.

A brief review of available literature on the association of characters in foxtail millet as well as other millets is presented hereunder.

Anarase and Ugale (2001) in their study with 40 genotypes of Pearl millet revealed that fodder yield/plant, plant height, ear length and ear girth had strong positive significant correlation with grain yield. In addition, 1000-grain weight had strong correlation with both grain and fodder yield per plant. These characters had also positively and significantly correlated among themselves in both environments.

Maloo and Philip (2001) in their study with 40 diverse varieties of foxtail millet sown in three sets of environments revealed strong correlation of 1000 seed weight and harvest index in all the crop seasons with seed yield per plant. They also registered positive and strong association of panicle length and plant height in all three environments.

Yadav *et al.* (2003) reported that 1000-grain mass and harvest index of pearl millet, measured in the non stress environments had positively correlated to yield under stress but degree of association was less as compared to these traits measured under stress conditions. Other traits like grains per panicle had positive association with yield under stress only. Stover yield was moderately associated with yield under stress but not in non stress condition.

Ezeaku *et al.* (2006) studied 30 grain sorghum varieties originating from ICRISAT, Kano, reported high positive significant correlation between grain yield and 1000-grain mass ($r=0.522$). They also observed that plant height had high positive phenotypic and genotypic correlation coefficients with grain yield.

Aruselvi *et al.* (2008) in their study involving crossing of seven male sterile pearl millet lines with nine testers and the resultant sixty three hybrids were utilized for path analysis. They reported positive and significant correlation of plant height, number of productive tillers, ear head length and ear head girth on grain yield.

Meena *et al.* (2008b) experimented with 20 diverse genotypes of pearl millet and recorded highly significant and positive association of spike length, plant height, spike thickness, number of productive tillers with spike yield and 1000 grain weight in bajra crop.

Nirmalakumari *et al.* (2010) evaluated 109 little millet germplasm accessions during rabi, 2008-2009 for correlation and path analysis of yield and its components. They observed highly significant positive correlations of most of the component characters with grain yield and strong inter correlation among themselves indicated possibility of simultaneous improvement of these characters by selection. It was also recorded high positive direct effect and indirect effects of other characters through days to 50 per cent flowering indicating this character should be given importance in selection.

Ganapathy *et al.* (2011) in a study with 230 indigenous and exotic accessions of finger millet during *kharif*, 2007, revealed significant positive correlation of productive tillers per plant and finger length with grain yield.

Priyadharshini *et al.* (2011) evaluated 21 hybrids along with seven parents of Finger millet during *kharif*, 2009 and revealed positive correlation of number of productive tillers and harvest index with grain yield in finger millet.

Abuali *et al.* (2012) studied 15 genotypes of pearl millet at two locations (Elrawakeeb and Shambat) of Sudan, during the years 2003 and 2004. They observed significant positive genotypic and phenotypic correlations between grain yield/plant and harvest index ($r_p=0.754$, $r_g=1.08$) and grain yield/plant and number of seeds per panicle ($r_p=0.608$, $r_g=0.820$) and with other quantitative characters in pearl millet. They also recorded negative association of grain yield/plant with days to 50% flowering and date to maturity.

Prasanna *et al.* (2013) evaluated 34 exotic genotypes of foxtail millet in *kharif* and *rabi* seasons and revealed positive significant correlation of days to 50% flowering, plant height, days to maturity, number of productive tillers per plant, ear length, ear weight and straw weight with yield per plant during *kharif* whereas during *rabi* besides these characters flag leaf area and 1000 grain weight were also observed to influence yield. The association of protein content and calcium content with grain yield was in negative direction. The association of carotene with grain yield was negative during *kharif* only. The study indicated that direct selection based on number of productive tillers per plant during *kharif* whereas in *rabi* ear weight and straw weight were found effective as the association and direct effects were positive for these traits during both the seasons.

Brunda *et al.* (2015b) carried out correlation and path analysis in 75 foxtail millet genotypes for 10 characters during rainy season and summer season in 2013 and 2014 and indicated that direct selection based on the traits, days to maturity, plant height, number of tillers, panicle length, panicle weight, test weight and straw weight during rainy season where as in post-rainy season days to maturity, panicle length, panicle breadth, panicle weight and straw weight are effective as the association and direct effects were positive for these traits with grain yield.

Reddy *et al.* (2015) evaluated 24 foxtail millet genotypes including three checks for correlation analysis. It was reported that grain yield was positively associated with panicle length, plant height, days to maturity, days to 50% flowering and number of tillers/plant and negatively associated with fodder yield. Genotypes TNSI 267, SiA 3222, DhFTMV 2-5, SiA 3221, SiA 3159, SiA 3223, SiA 3163 and TNSI 309 have one or more extreme traits which may be useful as parents for development of varieties.

2.8 PATH COEFFICIENT ANALYSIS

Simple correlation does not give the direct and indirect effect or character association towards yield. Path coefficient analysis is, therefore, an useful method of estimating the direct and indirect contribution of an attribute.

Path coefficient analysis is a statistical device developed by Wright (1921) which helps in partitioning of the correlation coefficients into direct and indirect effects of independent variable on dependent variable. The correlation coefficients do not give a complex picture of the causal basis of association. Path coefficient analysis of different components of yield brings out relative importance of their direct and indirect effects and gives a clear understanding of their association with yield. Thus, path coefficient analysis helps in formulating the selection criteria based on these direct and indirect effects. Hence, path analysis is of much importance in any plant breeding programme.

A brief review of path analysis of yield and yield components reported in foxtail millet and other related millet crops is presented hereunder.

Hawlader and Hamid (1988) carried out path coefficient analysis on 30 local and exotic genotypes of foxtail millet to delineate the nature and extent of direct and indirect effects of yield components on grain yield. Of the six yield components studied, 1000-grain weight had the highest direct contribution (0.639) to grain yield, followed by days to flower (0.605), productive tillers (0.313) and ear length (0.290). The Plant height had a negligible direct effect (-0.004). The indirect effects of days to maturity through days to flower and 1000-grain weight were highly positive. The results clearly indicated that 1000-grain weight and days to flower were the

two major component characters that directly contributed to grain yield and were most important in breeding for yield improvement.

Anarase and Ugale (2001) in their study with 40 genotypes of pearl millet revealed large and positive direct effects of 1000-grain weight and ear girth on grain yield in both environments. The plant height also had a large and positive direct effect in E_1 environment but fodder yield/plant, ear length and effective tillers/plant had large positive direct effects in E_2 environment.

Maloo and Philip (2001) in their study with 40 diverse varieties of foxtail millet sown in three sets of environments under rainfed and irrigated conditions reported maximum direct effects of biological yield and harvest index on seed yield. The traits, seed yield per panicle, 1000 seed weight and days to flower showed positive direct contribution in atleast one crop season.

Chikurte *et al.* (2003) investigated 15 inbreds of Pearl millet for 12 characters in four environments and revealed that the characters, panicle length and test weight had positive direct effects in two or more environments on grain yield.

Ezeaku *et al.* (2006) studied 30 sorghum varieties originating from ICRISAT Kano, revealed that 1000 grain mass had high positive indirect effect on grain yield.

Kebera *et al.* (2006) observed that 1000-grain weight, finger number and productive tillers as major contributors to grain yield per plant in finger millet.

Jayarame *et al.* (2007) reported high positive direct effect of plant height, culm thickness, days to 50 per cent flowering and days to maturity on grain yield and suggested these could be used as indirect measure to select for high yield in finger millet.

Vetriventhan and Nirmalakumari (2007) evaluated 150 pearl millet hybrids along with their parents and reported that the total productive tillers had moderate positive direct effect followed by ear head girth and plant height (moderate) on grain yield. Selection should be in positive side for total productive tillers, ear head length, ear head girth, 100-grain weight and plant height for increase in the grain yield. Selection based on early flowering plants would also improve the grain yield because days to 50% flowering exhibited negative association with grain yield.

Salini *et al.* (2010) showed positive direct effect of plant height, number of productive tillers and hundred grain weight indicating direct selection for these characters would improve the grain yield in proso millet.

Priyadharshini *et al.* (2011) evaluated 21 hybrids along with seven parents of Finger millet during kharif, 2009 and revealed high positive direct effect of harvest index and moderate direct effect of number of productive tillers on grain yield in finger millet.

Abuali *et al.* (2012) studied 15 genotypes of pearl millet during the years 2002 and 2004 through path analysis indicated that number of fertile tillers/plant had the highest direct effect (0.512) on grain yield/plant. However, thousand-seed weight was greatly reduced by the negative indirect effects through number of fertile tillers/plant and number of seeds/head in pearl millet.

Govindaraj and Selvi (2012) assessed 61 indigenous pearl millet germplasm lines and reported moderate to low positive direct effect of plant height, days to 50% flowering, days to maturity and panicle girth on grain yield in pearl millet. They also observed positive and significant effect of productive tillers per plant, 100 grain weight and panicle length on grain yield.

Prasanna *et al.* (2013) evaluated 34 exotic genotypes of foxtail millet for path coefficient analysis during *kharif* and *rabi*. The study indicated that direct selection based on number of productive tillers per plant during *kharif* whereas in *rabi* ear weight and straw weight were found effective as the association and direct effects were positive for these traits during both the seasons.

Brunda *et al.* (2015) studied path analysis in 75 foxtail millet genotypes for 10 characters during rainy season and summer season in 2013 and 2014. They concluded that direct selection based on the characters, panicle weight, test weight and straw weight showed high and positive effect on grain yield per plant in both rainy and summer season indicating the true relationship between these characters with grain yield per plant, which helps in indirect selection for improving the grain yield per plant.

Ravi *et al.* (2016) evaluated 76 pearl millet genotypes during *kharif*, 2012. Among ten physiological traits, the highest positive direct effect on grain yield per plant was shown by root dry weight followed by harvest index, relative injury, root volume, specific leaf area, chlorophyll stability index, SPAD chlorophyll meter reading, leaf area duration and root spread. Hence, selection based on these physiological traits would be effective in increasing the grain yield per plant under moisture stress.

2.9 D² ANALYSIS

Genetic diversity is considered as an important factor in discriminating the genotypes to select genetically diverse parents for obtaining high yielding lines for efficient and successful hybridization. Selection of diverse parents belonging to distant groups lead to wide spectrum of gene combinations of quantitatively inherited traits.

A brief review of available literature on diversity among foxtail millet genotypes as well as other crops is detailed hereunder.

Sheriff *et al.* (1992) evaluated 225 genotypes of foxtail millet and subjected to multivariate analyses through Mahalanobis' D^2 statistics and canonical analysis and both analyses suggested the existence of considerable divergence among the material. D^2 analysis resulted in 33 clusters. Genetic divergence has not been found to be related with geographical diversity.

Upadhyaya *et al.* (2009) conducted a hierarchical cluster analysis using the scores of the first five principal coordinates and the accessions were grouped in to 29 clusters. From each cluster, 10 per cent of the accessions were selected to constitute a core collection of 155 accessions in foxtail millet.

Kumar *et al.* (2010) experimented on 140 diverse genotypes of finger millet. On the basis of non-hierarchical Euclidean cluster analysis, all the 140 genotypes were grouped into ten non-overlapping clusters. Maximum no. of genotypes (31) were included in cluster I followed by 28 genotypes in cluster V, 19 genotypes in cluster III, 14 genotypes each in clusters II and VIII, 11 genotypes in cluster VII, 10 genotypes in cluster IV, seven genotypes in cluster VI, five genotypes in cluster IX, while there was only one genotype in cluster X respectively. The inter-cluster distance varied from 16.85 between clusters X and I to 1.94 between clusters III and VIII. Genetic diversity was observed to be independent of the geographical origin of the genotype.

Nirmalakumari and Vetriventhan (2010) carried out cluster analysis of 741 accessions of foxtail millet using DARWIN5 for yield and yield contributing traits. The population was grouped into nine clusters which showed wide range of diversity in the population.

Govindaraj *et al.* (2011) selected 61 elite germplasm lines of pearl millet by using Mahalanobis D^2 statistic grouped them into eight different

clusters. The maximum divergence with high mean performance was observed between clusters II, V and VII. Hence, hybridization between the genotypes of these clusters may exhibit high heterosis as well as high level of production and quality.

Analysis with the Unweighted Pair Group Method with Arithmetic Mean (UPGMA) method and Principal Component Analysis (PCA) revealed in foxtail millet that the 324 landraces could be divided into three groups. Agronomical analyses with a plant height of 80.6 to 155.2 cm, spike length of 7.5 to 28.9 cm and growth periods of between 141 and 178 days had shown that there was enough variation to create promising lines for breeding programs. (Heng Sheng Lin *et al.*, 2012)

Mahajan and Wadika (2012) assessed genetic divergence among 24 sorghum genotypes by using Mahalanobis D^2 analysis. The genotypes were grouped in to eight clusters, which revealed wide diversity in the experimental material. Harvest index contributed maximum towards genetic divergence. The maximum inter cluster distance was observed between clusters VII and VIII followed by clusters II and VIII and clusters II and VI. The high diverse clusters could serve as potential sources of the accessions for their use in hybridization programme.

Andualem and Ketema (2013) conducted an experiment on 84 finger millet germplasm lines. Based on multivariate analysis using Mahalanobis's D^2 statistics, the germplasm was grouped in to eight clusters. The analysis showed that germplasm collected from the same geographic area were placed into different cluster groups and those collected from different geographic regions were placed in the same cluster.

Brunda *et al.* (2015) carried out an investigation on genetic diversity among 75 genotypes of foxtail millet during rainy season 2013. Observations were recorded for ten quantitative traits. On the basis of

Mahalanobis D^2 statistics these genotypes were grouped into seven clusters. The highest intra-cluster distance was recorded for cluster-III. The genotypes from cluster V may be crossed with those in cluster VII as they are more diverse. The clusters were highly divergent suggesting the presence of wide diversity between these clusters. Therefore, genotypes from these clusters can be selected for hybridization programme to get desirable recombinants. The days to flowering have maximum contribution towards the genetic divergence followed by test weight and grain weight.

Reddy *et al.* (2015) evaluated 24 foxtail millet genotypes including three checks for genetic diversity for yield and yield attributing traits. Out of seven principal components, PC1 and PC2 contributed 61.90% and 16.15% variation respectively. UPGMA method based cluster analysis arranged genotypes in four clusters with wide variation for yield traits. Cluster II(d) associated maximum genotypes with high grain yield, cluster II(c) represented three extra early maturing genotypes and cluster I(a) and I(b) contained genotypes each four respectively with high plant height, number of tillers/plant and fodder yield.

Geethanjali *et al.* (2016) experimented on 51 accessions of foxtail millet for morphological diversity based on nine quantitative traits *viz.*, plant height, number of basal tillers, days to flowering, flag leaf length, flag leaf width, petiole length, inflorescence length, thousand seed weight and single plant yield. Cluster analysis based on the nine morphological traits assorted the 51 genotypes into four main clusters. Plant height, number of tillers, days to fifty per cent flowering, grain yield per plant, and 1000 seed weight were found to be the most important traits in distinguishing the major clusters of foxtail millet genotypes at the morphological level.

Gangurde *et al.* (2016) studied the nature and magnitude of genetic divergence in 66 foxtail millet genotypes using multivariate analysis through Mahalanobis D^2 statistics. Based on relative magnitude of D^2 , the genotypes

were grouped into five different non-overlapping clusters. Cluster I, having 36 genotypes, emerged with highest number of entries; cluster II were constituted by 15 genotypes. Cluster III comprising 13 genotypes. Cluster IV and V having one genotype each. The maximum intra-cluster distance was observed for cluster II, followed by cluster III and cluster I. The highest inter-cluster distance was recorded between cluster IV and III followed by cluster IV and V, then cluster IV and I followed by cluster III and I. Among the 13 characters studied, the highest contribution in manifestation of genetic divergence was exhibited by grain iron content (ppm) followed by flag leaf length, grain zinc content (ppm), straw weight, flag leaf area, plant height, flag leaf width, panicle weight and grain yield.

Ravi *et al.* (2016) studied genetic divergence and clustering pattern of 76 pearl millet genotypes. Based on the genetic distance (D^2 value), the 76 accessions were grouped into 12 clusters. Of them, cluster I with 38 genotypes forms the largest followed by cluster II and III with 13 in each. The character relative injury contributed the maximum to the divergence. Based on the average inter-cluster distance (D), the clusters VI and XI followed by clusters XI and XII were found to be highly divergent from the other clusters. Maximum diversity was observed between 65 R (VI) vs. (XI) followed by 80 R (XI) vs. 1 B (XII).

Ravikanth and Sarma (2017) studied genetic variability and diversity existing in 55 genotypes of finger millet. Mahalanobis D^2 analysis grouped 55 genotypes into eight clusters. Clustering pattern failed to indicate any relationship between genetic diversity and geographic diversity. Cluster 1 (29) has the maximum number of genotypes followed by II (11), III (9), IV (2) and remaining four were solitary clusters. Among the characters studied calcium content followed by days to 50% flowering contributed maximum towards the total divergence.

Chapter III

MATERIAL AND METHODS

The present investigation on “Studies on genetic divergence and character association for yield and drought related traits in foxtail millet (*Setaria italica* L.)” was carried out in pursuance of the objectives.

3.1 LOCATION OF THE EXPERIMENTAL SITE

The experiment was laid out during *Kharif*, 2016 at Agricultural Research Station, Perumallapalle farm, Tirupati situated at an altitude of 182.9 m above mean sea level, 13°N latitude and 79°E longitude. The material used and methods followed pertaining to the present investigation are presented here under.

3.1.1 Environmental Conditions

The weather conditions were moderate during the crop period. The rainfed crop experience 23 days of drought period during seedling (15 DAS), 11 days during vegetative (22 and 43 DAS) and 18 days during flowering stages (70 DAS). The rainfall received between the drought spells was sufficient for crop growth. Weekly mean data on meteorological parameters during the crop growth period is presented in the Appendix-I.

3.2 MATERIALS

The base material for the present study comprised of sixty lines including seven checks, which were collected from Agricultural research station, Nandyal. The details of the sixty lines studied are presented in Table 3.1.

Table 3.1 Details of 60 foxtail millet genotypes

S.No	Genotype	Parentage	Salient Features
1	Suryanandi (Check)	Pure line selection from SiA 1244	Early maturing, Tall height, Medium ear length.
2	SiA-3539	Selection from GS-848	Late maturing, Tall height, Medium ear length.
3	SiA-3542	Selection from GS-734	Late maturing, Tall height, Long ear length.
4	SiA-3543	Selection from GS-813	Late maturing, Tall height, Long ear length.
5	SiA-3545	Selection from GS-1549	Late maturing, Tall height, Long ear length.
6	SiA-3546	Selection from GS-1242	Early maturing, Tall height, Short ear length.
7	SiA-3550	Selection from GS-1464	Early maturing, Tall height, Short ear length.
8	SiA-3551	Selection from GS-1384	Early maturing, Tall height, Medium ear length.
9	SiA-3554	Selection from GS-890	Early maturing, Tall height, Medium ear length.
10	SiA-3555	Selection from GS-805	Early maturing, Tall height, Medium ear length.
11	Narasimharaya (Check)	SiA 805 X SiA 242	Early maturing, Tall height, Long ear length.
12	SiA-3558	Selection from GS-869	Early maturing, Medium height, Medium ear length.
13	SiA-3559	Selection from GS-1043	Late maturing, Medium height, Short ear length.
14	SiA-3560	Selection from GS-1297	Late maturing, Medium height, Short ear length.
15	SiA-3562	Selection from GS-1263	Late maturing, Medium height, Medium ear length.
16	SiA-3563	Selection from GS-1369	Late maturing, Tall height, Long ear length.
17	SiA-3569	Selection from GS-999	Early maturing, Tall height, Short ear length.
18	SiA-3570	Selection from GS-1509	Early maturing, Medium height, Short ear length.
19	SiA-3572	Selection from GS-699	Early maturing, Medium height, Short ear length.
20	SiA-3574	Selection from GS-874	Late maturing, Medium height, Short ear length.
21	Prasad (Check)	Pure line selection from Nallamalla Korra	Early maturing, Short height, Short ear length.
22	SiA-3575	Selection from GS-1186	Early maturing, Medium height, Medium ear length.
23	SiA-3578	Selection from GS-1462	Late maturing, Tall height, Long ear length.
24	SiA-3580	Selection from GS-1016	Early maturing, Medium height, Short ear length.
25	SiA-3581	Selection from GS-1519	Early maturing, Medium height, Short ear length.
26	SiA-3582	Selection from GS-770	Late maturing, Short height, Short ear length.
27	SiA-3583	Selection from GS-1036	Late maturing, Short height, Medium ear length.
28	SiA-3584	Selection from GS-926	Early maturing, Short height, Short ear length.
29	SiA-3585	Selection from GS-1476	Early maturing, Short height, Short ear length.
30	SiA-3586	Selection from GS-873	Early maturing, Short height, Short ear length.

Contd...

Table 3.2 contd..

S.No	Genotype	Parentage	Silent Features
31	Sri Lakshmi (Check)	Pure line selection	Early maturing, Medium height, Medium ear length.
32	SiA-3589	Selection from GS-1159	Late maturing, Medium height, Medium ear length.
33	SiA-3591	Selection from GS-889	Early maturing, Medium height, Medium ear length.
34	SiA-3595	Selection from GS-1315	Early maturing, Tall height, Long ear length.
35	SiA-3596	Selection from GS-888	Early maturing, Tall height, Short ear length.
36	SiA-3598	Selection from GS-686	Late maturing, Medium height, Short ear length.
37	SiA-3600	Selection from GS-732	Early maturing, Medium height, Medium ear length.
38	SiA-3604	Selection from GS-122	Early maturing, Medium height, Medium ear length.
39	SiA-3605	Selection from GS-702	Early maturing, Medium height, Medium ear length.
40	SiA-3607	Selection from GS-1163	Early maturing, Short height, Short ear length.
41	Krishnadevaraya (Check)	SiA 326 X SiA 242	Late maturing, Medium height, Medium ear length.
42	SiA-3608	Selection from GS-875	Late maturing, Tall height, Long ear length.
43	SiA-3610	Selection from GS-1329	Early maturing, Tall height, Short ear length.
44	SiA-3611	Selection from GS-1012	Late maturing, Short height, Long ear length.
45	SiA-3613	Selection from GS-42	Early maturing, Medium height, Medium ear length.
46	SiA-3615	Selection from GS-55	Early maturing, Short height, Short ear length.
47	SiA-3618	Selection from GS-144	Early maturing, Medium height, Medium ear length.
48	SiA-3619	Selection from GS-219	Early maturing, Medium height, Short ear length.
49	SiA-3622	Selection from GS-630	Late maturing, Medium height, Medium ear length.
50	SiA-3623	Selection from GS-430	Early maturing, Tall height, Short ear length.
51	SiA-3085 (Check)	Pure line selection from SiA 2644	Late maturing, Medium height, Medium ear length.
52	SiA-3625	Selection from GS-146	Late maturing, Medium height, Long ear length.
53	SiA-3626	Selection from GS-77	Early maturing, Medium height, Short ear length.
54	SiA-3628	Selection from GS-467	Early maturing, Tall height, Long ear length.
55	SiA-3631	Selection from GS-683	Late maturing, Medium height, Medium ear length.
56	SiA-3632	Selection from GS-583	Late maturing, Medium height, Medium ear length.
57	SiA-3634	Selection from GS-111	Early maturing, Medium height, Medium ear length.
58	SiA-3636	Selection from GS-211	Late maturing, Tall height,
59	SiA-3637	Selection from GS-265	Early maturing, Medium height, Medium ear length.
60	SiA-3156 (Check)	Selection from SiA 2871	Early maturing, Medium height, Medium ear length.

3.3 METHODS

3.3.1 Field layout

The experiment was laid out in a randomized block design with two replications (plate 1). All the sixty foxtail millet genotypes were sown on 01/08/2016 in the main field with uniform spacing. A spacing of 22.5 cm between the rows and 10 cm between plants within a row was provided. Each genotype was planted in two rows of 3 m length with each row consisting of 40 plants.

3.3.2 Crop husbandry

The crop was provided with fertilizers to supply 40:30 N: P kg ha⁻¹. The half of N and entire P were applied as basal and second half of N was applied as top dressing after 35 days of sowing. The crop was raised under completely rainfed conditions. Recommended cultural and agronomic measures were followed during the crop period.

3.4 METHODS OF RECORDING DATA

Observations were recorded on five randomly chosen plants in each genotype in each replication for all the characters except days to 50% flowering and days to maturity which were recorded on per plot basis. The values of five competitive plants were averaged and expressed as mean of the respective character. The details of data recorded are as follows.

3.4.1 Days to 50 per cent flowering (days)

Number of days taken after sowing for panicle emergence in 50 per cent of the tillers in each genotype was recorded.

3.4.2 Days to maturity (days)

Number of days taken from sowing for attainment of physiological maturity in 50 per cent of the tillers in each genotype was recorded.



Plate 1. Overall view of experimental field

3.4.3 Plant height (cm)

Length of the main culm from ground level to the tip of the panicle at maturity was recorded in centimeters.

3.4.4 Ear bearing tillers per hill

Number of tillers bearing ears that arise from the basal portion of the plant were counted and recorded for each individual plant.

3.4.5 Ear length (cm)

Measured in centimeters from the base to the tip of the main ear at harvest and recorded for each individual plant.

3.4.6 Number of grains per ear head

Number of grains per ear head were counted from five randomly selected main tiller ear heads and averaged.

3.4.7 Grain yield per plant (g)

The weight of all the sun dried ear heads of a plant were recorded and expressed in grams.

3.4.8 Test weight (g)

Thousand grains from the seeds collected from five randomly selected plants were weighed and expressed in grams.

3.4.9 Dry fodder yield (g)

After complete drying of stalks (fodder), the weight was recorded for each genotype in grams.

3.5 PHYSIOLOGICAL CHARACTERS

3.5.1 Specific leaf area (SLA: cm² g⁻¹)

Specific Leaf Area (SLA) was recorded by taking five leaves from the third leaf from top of main tiller of each plant. These leaves were cleaned and their leaf area was estimated using a leaf area meter (LICOR model-3100). They were dried in a hot air oven at 80°C and dry weight was recorded. The formula used for calculating SLA was as follows.

$$SLA = \frac{\text{Leaf area (cm}^2\text{)}}{\text{Leaf dry weight (g)}}$$

3.5.2 SPAD Chlorophyll Meter Reading (SCMR)

The SPAD meter (Soil Plant Analytical Development) is a simple hand held and portable instrument which provides information on the relative amount of leaf chlorophyll. The SCMR was measured on third leaf from the top of the main tiller at 30 and 45 DAS using SPAD meter of Minolta Company, NJ, USA.

3.5.3 Canopy Leaf temperature (°C)

It was recorded by using infrared thermometer on third leaf of main tiller of the plant, excluding the mid ribs and measured in the degrees celsius (°C).

3.5.4 Relative water content % (RWC)

The concept of relative water content was first developed by Weatherly (1950) and later modified by Barrs and Weatherly (1962). The RWC is one of the measures which gives an idea of tissue water status. Leaves were collected from the flag and the second leaf from top to down, in order to minimize age effects. A sharp razor blade was used to cut the leaf base.

The leaf was trimmed to 1 cm² leaf discs and immediately fresh weight (FW) was determined. These pieces of leaves were floated in distilled water inside a closed Petri dish for 24 hr. Then, the water was wiped out gently from the leaf surface with tissue paper and turgid weight (TW) was determined.

Subsequently the leaf disks were dried in the oven at 80⁰ C for 48 hrs to obtain the dry weight (DW). The DW was then determined using the same balance and finally RWC was calculated using the following formula:

$$\text{RWC (\%)} = \frac{\text{Fresh weight} - \text{dry weight}}{\text{Turgid weight} - \text{dry weight}} \times 100$$

3.5.5 Relative membrane injury (%)

Cell membrane integrity was tested by exposing leaves to high temperature and computing relative injury to the membranes in terms of electrolytes leakage. Relative injury was measured at 30 and 45 DAS using third leaf from top of respective genotypes. One gram of fresh leaf sample was collected from the selected foxtail millet genotypes and incubated in 10 ml of distilled water (known volume) filled in a beaker and kept for mild shaking for three hrs. Then light absorbance values were recorded at 273 nm (initial absorbance, I_a), using UV 1800 visible spectrophotometer (Shimadzu). The beakers were transferred to hot water bath (100⁰C) for 30 minutes. Final absorbance values were recorded at 273 nm (final absorbance, F_a) using spectrophotometer and the cell content leak was calculated by following formula (Leopold *et al.*, 1981). Higher the leakage and higher the injury and lower the thermo tolerance.

$$\text{Per cent leakage (\%)} = \frac{I_a}{F_a} \times 100$$

where, I_a = Initial absorbance F_a = Final absorbance

3.5.6 Peg-Induced Drought Stress

Polyethylene glycol (PEG) germination technique has been used to identify and select the drought tolerant foxtail genotypes. It involves exposing seedlings or plants to osmotic stress conditions by using polyethylene glycol compound of different concentrations along with control conditions (0%, 15%, 20%, 25% and 30%). The upsurge in concentration of PEG caused a decrease in germination percentage and seedling vigour in crop plants.

Healthy and uniform seeds of 60 foxtail millet germplasm lines were surface sterilized with 1% sodium hypochlorite for 3 min, 70% ethanol and washed with distilled water and surface dried. Twenty seeds for each cultivar in each treatment were allowed to germinate on a filter paper in 9 cm diameter Petri dishes. Each filter paper was moistened with solutions of 0 (distilled water) as a control, or 15%, 20%, 25% and 30% of PEG (MW 6000) concentration. PEG 6000 was used as it is small enough to influence the osmotic potential but cannot be fully absorbed by the plant and is not phytotoxic. A quantity of 10 ml of appropriate solution was applied to each Petri dish. The Petri plates were arranged in completely randomized design (CRD) with three replicates for each treatment. Germination room temperature was maintained at $25 \pm 1^\circ\text{C}$ and a relative humidity of 70%. Petri plates were periodically checked and respective solutions were applied to compensate evaporation. Seeds were considered germinated when the radicle had extended for at least 2mm. Seedling shoot and root length of randomly selected seedlings from each replication were measured after 4 and 9 days after treatment application by using a scale. After final count, final germination percent (FGP) was calculated by the following formula

$$\text{GP (\%)} = \frac{\text{Number of final germinated seeds}}{\text{Total number of seeds tested}} \times 100$$

3.5.7 Thermo Induction Response (TIR) Technique

Temperature Induction Response (TIR) technique has been developed to identify and select the thermo tolerant genotypes. It involves exposing seedlings or plants to induced stress and subsequently challenging with severe temperature and selection is based on seedling survival at the end of recovery period. This approach of TIR involves, first the identification of challenging temperature and induction temperature and later standardizing them before using for screening the material for intrinsic stress tolerance.

3.5.7.1. Identification of lethal temperature treatment

To assess the challenging temperatures for 100 per cent mortality, 24 hour old foxtail millet seedlings were exposed to different lethal temperatures (55°C, 56°C, 57°C, 58°C and 59°C) for the same duration (2 hours) without prior induction. Thus, exposed seedlings were allowed to recover at 30⁰C and 60 per cent relative humidity for 48 hours (Fig 3.1). At the end of recovery period the temperature at which 90% mortality of the seedlings occurred was taken as the challenging temperature in order to assess the genetic variability for seedling survival. Per cent mortality of foxtail millet genotypes after recovery was recorded. The lethal temperature of 59°C for 2 hours was considered in this context, as maximum mortality (100%) of seedlings (Table 3.2).

3.5.7.2 Identifications of sub lethal (induction) temperature

During the induction treatment, the seedlings were exposed to a gradual increase in temperature for a specific period. The temperature regimes and duration varies from crop to crop and need to be standardized. The germinated foxtail millet seedlings (24 hour old seedlings) were subjected to gradually increasing temperatures for a period of five hours. After this induction treatment, seedlings were exposed to lethal temperature *i.e.*, 59⁰C for two hours and then transferred to the normal temperature for

recovery. The temperature regimes and durations varied to arrive at optimum induction protocol. The optimum sub lethal temperatures were arrived based on the per cent survival of seedlings. The sub lethal treatment which recovered least per cent seedlings survival reduction was considered as optimum range of temperatures *i.e.*, 38°C-58°C (Table 3.3).

A lethal temperature of 59°C for 2 hours and induction treatment from 38-58°C for five hours was standardized using TIR (Thermo Induction Response) and considered as best lethal and induction temperatures for Phenotyping of foxtail millet seedlings for intrinsic heat tolerance at cellular level.

Fig 3.1 Protocol of the technique: Temperature Induction Response (TIR)

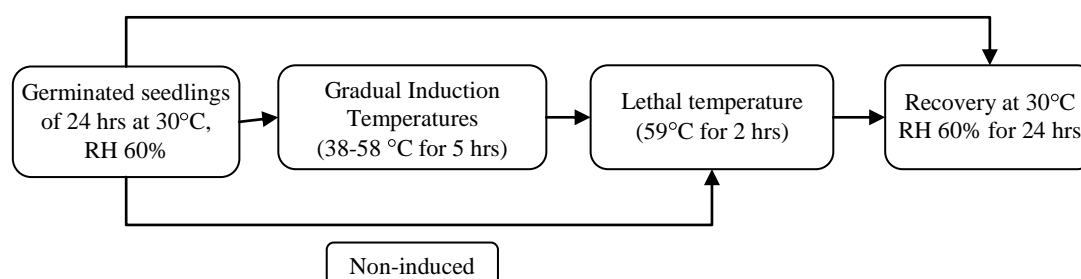


Table 3.2. Per cent mortality of foxtail seedlings at different lethal temperatures

Sl. No.	Temperature °C	Per cent mortality of foxtail seedlings after recovery		
		Duration of temperature		
		1 hour	2 hour	3 hour
1	55	0	0	7
2	56	0	21	33
3	57	0	50	59
4	58	51	81	86
5	59	62	100	100

Table 3.3. Per cent survival of foxtail seedlings at different induction (sub lethal) temperature range

S. No.	Temperature Range (Induction treatment for 5 hrs) °C	Per cent survival of seedlings
1	34-53	80
2	34-55	86
3	36-56	86
4	36-57	88
5	38-58	95
6	38-59	84

3.5.7.3 Assessment of Thermo Induction Response (TIR) and genotypes

Foxtail millet seeds were surface sterilized by treating with 5 per cent carbendazim solution for 30 minutes and washed with the distilled water for 4-5 times and kept for germination at 30°C and 60 per cent relative humidity in the incubator. After 24 hours, uniform seedlings were selected in each genotype and sown in aluminium trays (50 mm) filled with soil. These trays with seedlings were subjected to sub lethal temperatures (gradual temperatures increasing from 38°C-58°C) for five hours in the environmental chamber (WGC-450 Programmable Plant Growth Chamber). Later these seedlings were exposed to lethal temperatures (59°C) for 2 hours (induced).

Induced and non induced foxtail seedlings were allowed to recover at 30°C and 60 per cent relative humidity for 24 hours. The following parameters were recorded from the seedlings 4 days after treatment.

a) Per cent survival of seedlings =

$$\frac{\text{No. of seedlings survived at the end of recovery}}{\text{Total number of seedlings sown in the tray}} \times 100$$

b) Per cent reduction in root growth =

$$\frac{\text{Actual root growth of control seedlings} - \text{Actual root growth of treated seedlings}}{\text{Actual root growth of control seedlings}} \times 100$$

c) Per cent reduction in shoot growth

$$\frac{\text{Actual shoot growth of control seedlings} - \text{Actual shoot growth of treated seedlings}}{\text{Actual shoot growth of control seedlings}} \times 100$$

3.6 STATISTICAL ANALYSIS

The mean values for each character over two replications were subjected to the following statistical analysis.

1. Analysis of variance and genetic parameters.
2. Character associations.
3. Path coefficient analysis and
4. Genetic divergence using Mahalanobis's generalized distance (D^2) and canonical analysis.

3.6.1 Analysis of variance

The differences among 60 genotypes for different characters were tested for significance by using analysis of variance technique (Panse and Sukhatme, 1961).

$$Y_{ij} = \mu + g_i + \gamma_j + e_{ij}$$

where,

Y_{ij} = Phenotypic observation on 'i'th genotype in 'j'th replication.

μ = General mean

g_i = Effect of i^{th} genotype

γ_j = Effect of j^{th} replication

e_{ij} = Random error associated with i^{th} genotype and j^{th} replication.

The analysis of variance for each character was carried out as follows:

Source of variation	Degree of freedom	Sum of squares	Mean sum of squares	'F' ratio
Replications	(r-1)	RSS	Mr	Mr/Me
Genotypes	(t-1)	VSS	Mv	Mv/Me
Error	(r-1)(t-1)	ESS	Me	-
Total	(rt-1)	TSS		

Where,

r = Number of replications

t = Number of genotypes

Mr = Mean sum of squares due to replications

Mv = Mean sum of squares due to genotypes

Me = Mean sum of squares due to error.

The significance test was carried out by referring to standard 'F' table values given by Fisher and Yates (1963).

3.6.2 Estimation of genetic parameters

The estimates of mean sum of squares from ANOVA were utilized for calculation of following parameters.

3.6.2.1 Variance

The genotypic and phenotypic variances were calculated as per the formulae proposed by Burton (1952)

$$(i) \text{ Genotypic variance } \hat{\sigma}_g^2 = \frac{\text{MSS due to genotypes} - \text{MSS due to error}}{\text{Number of replications}}$$

$$(ii) \text{ Phenotypic variance } \hat{\sigma}_p^2 = \sigma_g^2 + \sigma_e^2$$

$$\sigma_g^2 = \text{Genotypic variance}$$

$$\sigma_e^2 = \text{Error variance}$$

3.6.2.2 Genotypic and phenotypic coefficient of variation

The genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) were calculated by the formulae given by Burton (1952).

$$(i) \text{ GCV (\%)} = \frac{\sigma_g}{\bar{X}} \times 100$$

$$(ii) \text{ PCV (\%)} = \frac{\sigma_p}{\bar{X}} \times 100$$

Where, σ_g , σ_p and \bar{X} were genotypic standard deviation, phenotypic standard deviation and general mean of the character, respectively.

Categorization of the range of variation was done as proposed by Sivasubramanian and Madhava menon (1973)

Less than 10% - Low

10 – 20 % - Moderate

More than 20% - High

3.6.2.3 Broad sense Heritability

Heritability in broad sense refers to the proportion of genotypic variance to the total variance of the population. Heritability in broad sense [$h^2_{(b)}$] was calculated by the formula given by Lush (1940).

$$\text{Broad sense Heritability} = \frac{\sigma_g^2}{\sigma_p^2} \times 100$$

where,

σ_g^2 = Genotypic variance

σ_p^2 = Phenotypic variance

As suggested by Johnson *et al.* (1955), heritability estimates were categorized as

Less than 30% - Low

30 – 60 % - Moderate

More than 60% - High

3.6.2.4 Genetic advance

Genetic advance refers to the expected genetic gain in the next generation by selecting the superior individuals under certain amount of selection pressure. From the heritability estimates, the genetic advance was estimated by the following formula given by Johnson *et al.* (1955).

$$GA = k \sigma_p H$$

where,

GA = Genetic advance

σ_p = Phenotypic standard deviation

H = Heritability (broad sense)

k = Selection differential at 5% selection intensity

3.6.2.5 Genetic advance as percent of mean (GA as percent mean)

Genetic advance as percent of mean was calculated as per the formula.

$$GA \text{ as percent of mean} = \frac{GA}{\bar{X}} \times 100$$

where,

GA = Genetic advance

\bar{X} = Grand mean of the character

The range of genetic advance as percent of mean was classified as suggested by Johnson *et al.* (1955).

Less than 10%	-	Low
10 – 20 %	-	Moderate
More than 20%	-	High

3.6.3 Character association analysis

Genotypic and phenotypic correlation coefficients were calculated using the method given by Johnson *et al.* (1955b).

3.6.3.1 Genotypic correlation coefficient (r_g)

$$r_g(x_i x_j) = \frac{\text{CoV}_g(x_i x_j)}{\sqrt{V_g(x_i) V_g(x_j)}}$$

where,

$r_g(x_i x_j)$ = Genotypic correlation between ' i^{th} ' and ' j^{th} ' characters

$V_g(x_i)$ = Genotypic variance of ' i^{th} ' character

$V_g(x_j)$ = Genotypic variance of ' j^{th} ' character

$\text{Cov}_{(g)}(x_i x_j)$ = Genotypic covariance between ' i^{th} ' and ' j^{th} ' characters.

3.6.3.2 Phenotypic correlation coefficient (r_p)

$$r_p(x_i x_j) = \frac{\text{CoV}_p(x_i x_j)}{\sqrt{V_p(x_i) \cdot V_p(x_j)}}$$

where,

$V_p(x_i)$ = Phenotypic variance of ' i^{th} ' character

$V_p(x_j)$ = Phenotypic variance of ' j^{th} ' character

$\text{Cov}(x_i x_j)$ = Phenotypic covariance between ' i^{th} ' and ' j^{th} ' characters.

The significance of correlation coefficients was tested by comparing the genotypic and phenotypic correlation coefficients with table value

[Fisher and Yates (1963)] at (n-2) degrees of freedom at 5% and 1% level where, 'n' denotes the number of treatments used in the calculations.

3.6.4 Path Coefficient Analysis

Path coefficient analysis was carried out by the procedure originally proposed by Wright (1921) which was subsequently elaborated by Dewey and Lu (1959) to estimate the direct and indirect effects of the individual characters on yield.

The following set of simultaneous equations were formulated and solved for estimating various direct and indirect effects.

$$\begin{aligned}
 r_{1y} &= p_{1y} + r_{12}p_{2y} + r_{13}p_{3y} + \dots + r_{1i}p_{iy} \\
 r_{2y} &= r_{21}p_{1y} + p_{2y} + r_{23}p_{3y} + \dots + r_{2i}p_{iy} \\
 &\cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \\
 &\cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \\
 &\cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \\
 r_{iy} &= r_{i1}p_{1y} + r_{i2}p_{2y} + r_{i3}p_{3y} + \dots + p_{iy}
 \end{aligned}$$

where,

- r_{12} to r_{i-1} = Coefficient of correlation among causal factors.
- p_{1y} to p_{iy} = Direct effects of characters '1' to i on character 'y'.

The above equations were written in matrix forms as under:

$$\begin{matrix} \text{A} \\ \left(\begin{array}{c} r_{1y} \\ r_{2y} \\ r_{3y} \\ \cdot \\ \cdot \\ \cdot \\ r_{iy} \end{array} \right) \end{matrix} = \begin{matrix} \text{C} \\ \left(\begin{array}{cccc} 1 & r_{12} & r_{13} & \dots & r_{1i} \\ r_{21} & 1 & r_{23} & \dots & r_{2i} \\ r_{31} & r_{32} & 1 & \dots & r_{3i} \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ r_{i1} & r_{i2} & r_{i3} & \dots & 1 \end{array} \right) \end{matrix} \cdot \begin{matrix} \text{B} \\ \left(\begin{array}{c} p_{1y} \\ p_{2y} \\ p_{3y} \\ \cdot \\ \cdot \\ \cdot \\ p_{iy} \end{array} \right) \end{matrix} \cdot$$

Then $B = [C]^{-1}A$

where,

$$[C]^{-1} = \begin{pmatrix} C_{11} & C_{12} & C_{13} \dots \dots \dots C_{1i} \\ C_{21} & C_{22} & C_{23} \dots \dots \dots C_{2i} \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ C_{i1} & C_{i2} & C_{i3} \dots \dots \dots C_{ii} \end{pmatrix}$$

Then, direct effects were calculated as follows:

$$P_{1y} = \sum_{i=1}^I C_{1i} r_{1y}$$

$$P_{2y} = \sum_{i=1}^I C_{2i} r_{2y}$$

$$P_{iy} = \sum_{i=1}^I C_{ii} r_{iy}$$

Besides the direct and indirect effects, the residual effect which measures the contribution of the characters not considered in the causal scheme was obtained as:

$$\text{Residual effect } (P_{RY}) = \sqrt{1 - [P_{1y}r_{1y} + p_{2y}r_{2y} + \dots \dots \dots + p_{iy}r_{iy}]^2}$$

where,

P_{RY} = Residual effect

p_{iy} = Direct effect of 'x_i' on 'y'

r_{iy} = Correlation coefficient of 'x_i' with 'y'.

The scales for path coefficients as proposed by Lenka and Mishra (1973) are as follows:

Value for Direct or Indirect effect	Rate or Scale
0.00-0.09	Negligible
0.10-0.19	Low
0.20-0.29	Moderate
0.30-0.99	High
More than 1.00	Very high

3.6.5 Genetic Divergence

The data collected on different characters was analyzed by Mahalanobis's Generalized distance (D^2) and canonical root analysis.

3.6.5.1 Mahalanobis's Generalized distance (D^2)

Genetic diversity between genotypes was estimated by using D^2 statistics given by Mahalanobis (1936).

3.6.5.2 Test of significance

Variances were calculated for all the nineteen characters and test of significance was done. Analysis of covariance for the character pairs was estimated on the basis of mean values (Panse and Sukhatme, 1961). After testing the difference between genotypes for each of the character, a simultaneous test of significance of differences between the mean values of a number of correlated variables with regard to the pooled effect of 19 characters was carried out using 'V' statistic, which in turn utilized Wilk's 'Λ' criterion (Wilks, 1932). The sum of squares and sum of products of error and error plus Variety Variance, Covariance matrix were used for this purpose. The estimation of 'Λ' (Wilk's criterion) was done using the following relationship:

$$' \Lambda ' = \frac{(E)}{(E + V)}$$

where,

(E) = Determinant of error matrix

(E + V) = Determinant of error + varieties matrix

The significance of 'Λ' was tested by

$$\chi^2_{pq} = V = -m \log_e \Lambda$$

where,

$m = n - (p + q + 1)/2$ with 'pq' degree of freedom

n = Degrees of freedom of error + varieties

p = Number of characters

q = Number of genotypes – 1

$\log_e \Lambda = 2.3407 \log_{10} \Lambda$

3.6.5.3 Transformation of correlated variables

Transformation was done using pivotal condensation method. Transformation of correlated variables into standardized uncorrelated ones was done before working out the D^2 values because computation of D^2 values were reduced to simple enumeration of differences in mean values of various characters of the two genotypes *i.e.*, $\sum d_i^2$

3.6.5.4 Computation of D^2 values

The D^2 value between 'ith' and 'jth' genotypes for 'p' characters was calculated as

$$D_{ij} = p \sum_{t=1} (\bar{Y}_{it} - \bar{Y}_{jt})^2$$

where,

\bar{Y}_{it} = Uncorrelated mean value of 'ith' genotype for 't' character

\bar{Y}_{jt} = Uncorrelated mean value of 'jth' genotype for 't' character

D_{ij} = D^2 value between 'ith' and 'jth' genotypes

3.6.5.5 Testing the significance of D² values

The D² values obtained for a pair of genotypes was taken as the calculated value of χ^2 and tested against the tabulated χ^2 at 'p' degree of freedom where 'p' is the number of characters considered.

3.6.5.6 Determination of group constellations (or) clusters

Grouping of genotypes into different clusters was done by using Tocher's method as described by Rao (1952). The criterion used in clustering by this method is that any two variables belonging to the same cluster should atleast, on an average show smaller D² values of the combinations of each genotype arranged in increasing (ascending) order of their magnitude in a tabular form as described by Singh and Choudhary (1977).

To start with, two populations having the smallest distance from each other were considered, to which a third population having smaller D² value from the first two populations was added. Similarly, the nearest next fourth population was considered and this procedure was continued. At certain stage when it was felt that after adding a particular population, there was an abrupt increase in the average D², that population was not considered for including in that cluster. The groups of the first cluster were then omitted and the rest were treated in similar way. This process was continued till all the populations were included into one or the other cluster. After the formation of the cluster, the average inter and intra cluster divergence (distances) were calculated.

3.6.5.7 Average intra-cluster distance

For the measurement of intra cluster distance, the formula used was

$$\Sigma D_i^2 / n$$

where,

ΣD_i^2 = the sum of distance between all possible combinations (n) of the populations included in a cluster.

3.6.5.8 Average inter- cluster distance

Clusters are taken one by one and their distance from other clusters was calculated. The distance between two clusters was the sum of the product of number of genotypes in both the clusters under consideration.

3.6.5.9 Cluster diagram

The clusters and their mutual relationships were presented diagrammatically. The square root of average D^2 , which was an approximate measure of divergence between groups, had been used to denote the distance.

3.6.5.10 Contribution of individual characters towards divergence

In all the combinations, each cluster was ranked on the basis of their contribution towards divergence between two entries ($d_i = Y_{it} - Y_{jt}$). Rank one is given to the highest mean difference and rank 'p' to the lowest difference, where 'p' is the total number of characters. Percentage contribution of each character (X) towards genetic divergence is calculated by using the formula:

$$X = \frac{(N \times 100)}{M}$$

where,

N = Number of genotype combinations where the character was ranked first

M = All possible combinations of number of genotypic pairs.

Chapter – IV

RESULTS AND DISCUSSION

A study on genetic analysis of parameters related to drought tolerance in foxtail millet was conducted under complete rainfed conditions utilising 60 lines including seven checks. The results obtained on different genetic parameters are presented in the following major heads in this chapter.

4.1 Analysis of variance

4.2 Mean performance

4.3 Genetic parameters

4.4 D²-analysis and canonical analysis

4.5 Correlation coefficient analysis

4.6 Path coefficient analysis

4.1 ANALYSIS OF VARIANCE

The analysis of variance for 19 characters is presented in the Table 4.1. The analysis of variance revealed highly significant differences among the genotypes for all 19 characters under rainfed conditions.

4.2 MEAN PERFORMANCE

4.2.1 Mean Performance of Genotypes for Yield and Yield Attributes

The mean performance of 60 genotypes of foxtail millet for yield and yield attributes are presented in Table 4.2.

Table 4.1 Analysis of variance for 19 quantitative characters in foxtail millet

S. No	Characters	Mean sum of squares		
		Replications (df: 1)	Genotypes (df: 59)	Error (df: 59)
1	Days to 50% flowering	0.533	17.850**	1.245
2	Days to maturity	10.208	16.495**	2.221
3	Plant height	8.253	167.262**	12.627
4	Ear bearing tillers per hill	0.867	0.713**	0.218
5	Ear head length	3.996	6.296**	1.505
6	Number of grains per ear head	11880.300	141019.279**	1333.266
7	Grain yield/plant	0.054	1.982**	0.110
8	1000 seed weight	0.024	1.300**	0.110
9	Fodder yield	0.687	1.832**	0.107
10	Specific leaf area at 30 DAS	120.159	909.144**	26.222
11	Specific leaf area at 45 DAS	14.393	707.776**	14.864
12	SCMR at 30 DAS	3.685	22.486**	2.620
13	SCMR at 45 DAS	0.003	19.103**	1.224
14	Canopy leaf temperature at 30 DAS	0.372	3.989**	1.555
15	Canopy leaf temperature at 45 DAS	9.031	38.531**	1.112
16	Relative membrane injury at 30 DAS	0.846	276.279**	0.944
17	Relative membrane injury at 45 DAS	2.578	219.025**	1.153
18	Relative water content at 30 DAS	11.618	24.263**	0.523
19	Relative water content at 45 DAS	18.135	34.540**	1.763

* Significant at 5% level; ** Significant at 1 % level

Table 4.2 Mean performance of sixty genotypes of foxtail millet for grain yield and yield attributing characters

S. No	Genotypes	Days to 50% flowering	Days to maturity	Plant height (cm)	Ear bearing tillers/ hill	Ear head length (cm)	No of grains/ ear head	Grain yield/ plant (g)	1000 seed weight (g)	Fodder yield/plant (g)
1	Suryanandi (Check)	44.00	86.50	100.00	3.10	18.90	1206.50	4.52	3.66	3.50
2	SiA-3539	53.00	95.75	109.00	3.70	19.90	1573.50	7.55	4.01	7.65
3	SiA-3542	51.00	90.00	116.25	2.40	21.00	1327.50	6.87	3.06	6.73
4	SiA-3543	50.00	91.00	110.70	3.00	20.30	1299.50	7.15	2.71	3.85
5	SiA-3545	47.00	91.25	104.40	3.20	17.40	1371.50	4.93	3.51	3.99
6	SiA-3546	45.00	86.00	109.60	2.40	17.00	1961.50	6.01	3.10	5.37
7	SiA-3550	45.00	87.50	106.90	3.00	20.40	2126.50	6.69	4.19	5.27
8	SiA-3551	44.00	89.00	107.80	3.30	18.00	1822.00	6.47	3.25	4.21
9	SiA-3554	44.00	89.00	107.10	2.10	19.50	1767.00	6.19	2.60	4.73
10	SiA-3555	46.00	86.00	107.70	3.80	19.40	1631.50	5.40	4.12	4.72
11	Narasimharaya (Check)	53.00	89.00	122.50	4.25	23.30	1997.00	8.19	3.08	5.50
12	SiA-3558	46.00	86.00	99.40	4.10	19.30	1762.50	5.71	3.51	5.37
13	SiA-3559	50.00	90.75	97.70	4.00	17.40	965.00	6.87	3.09	6.05
14	SiA-3560	54.00	90.75	90.00	3.10	15.10	1368.50	5.07	2.61	4.26
15	SiA-3562	51.00	92.25	95.65	4.00	18.00	1573.00	3.58	2.72	3.30
16	SiA-3563	49.00	91.25	102.40	4.80	19.10	1656.00	6.32	4.02	4.62
17	SiA-3569	43.00	84.00	103.40	3.70	17.30	2371.50	4.22	2.91	4.03
18	SiA-3570	47.00	87.00	95.60	3.00	16.20	1632.50	6.42	2.42	4.04
19	SiA-3572	47.00	89.50	91.90	3.60	16.60	1254.50	5.80	3.22	3.54
20	SiA-3574	49.00	91.00	96.90	2.90	16.60	1430.00	6.48	2.74	4.02
21	Prasad (Check)	46.00	88.00	88.10	2.10	17.80	1771.50	7.20	4.65	6.41
22	SiA-3575	43.00	85.00	99.30	3.10	19.00	1562.50	7.12	3.71	5.08
23	SiA-3578	50.00	91.50	105.10	3.60	20.80	1935.50	6.59	2.59	5.76
24	SiA-3580	45.00	87.50	96.00	3.40	17.30	1666.50	5.81	3.12	4.56
25	SiA-3581	46.00	86.50	94.30	2.75	16.95	1565.50	5.84	3.06	4.59
26	SiA-3582	46.00	90.25	85.65	2.50	15.80	1354.00	6.24	3.50	4.57
27	SiA-3583	49.00	91.00	86.40	2.50	18.00	1561.50	4.51	3.03	2.93
28	SiA-3584	45.00	89.00	77.65	3.60	15.43	1156.50	7.33	3.58	4.40
29	SiA-3585	51.00	86.75	83.10	2.60	16.50	1600.00	6.85	3.26	3.39
30	SiA-3586	46.00	88.00	78.80	2.20	15.70	1849.50	6.57	3.16	3.92
31	Sri Lakshmi (Check)	48.00	85.50	96.95	3.20	19.10	1999.00	8.24	7.40	4.60

Contd...

Table 4.2.Contd...

S. No	Genotypes	Days to 50% flowering	Days to maturity	Plant height (cm)	Ear bearing tillers/ hill	Ear head length (cm)	No of grains/ ear head	Grain yield/ plant (g)	1000 seed weight (g)	Fodder yield/plant (g)
32	SiA-3589	50.00	93.75	92.20	2.50	19.10	1865.50	6.89	4.46	6.22
33	SiA-3591	48.00	85.50	97.80	3.10	20.70	1860.50	4.76	4.41	4.12
34	SiA-3595	50.00	86.00	104.70	3.00	19.20	1738.00	5.71	2.98	4.48
35	SiA-3596	48.00	86.25	108.00	2.50	20.30	2005.00	6.02	2.96	5.39
36	SiA-3598	53.00	95.75	107.40	2.90	18.80	1954.00	7.70	3.50	4.80
37	SiA-3600	49.00	86.25	98.70	3.30	16.50	1720.50	5.66	3.30	4.45
38	SiA-3604	47.00	86.25	92.30	3.00	17.30	1487.50	7.57	4.18	4.81
39	SiA-3605	48.00	86.50	91.30	3.30	16.70	1677.00	5.58	3.25	4.81
40	SiA-3607	53.00	88.50	88.68	2.25	15.38	1233.50	6.40	3.37	5.34
41	Krishnadevaraya (Check)	45.00	90.50	99.00	3.60	18.80	1753.00	7.17	3.96	4.39
42	SiA-3608	48.00	90.00	105.10	4.10	21.10	1841.50	6.33	3.43	4.37
43	SiA-3610	51.00	89.25	104.80	3.00	18.60	1360.00	6.18	4.42	4.14
44	SiA-3611	53.00	93.25	89.90	2.80	16.90	1755.50	7.24	3.78	4.50
45	SiA-3613	50.00	87.00	96.20	3.40	19.20	1774.00	6.86	4.66	5.11
46	SiA-3615	43.00	85.50	86.40	2.80	15.00	1261.00	5.79	2.52	4.78
47	SiA-3618	44.00	86.50	93.40	2.80	18.20	1435.00	5.52	3.00	3.58
48	SiA-3619	49.00	86.50	92.05	2.90	16.20	1512.50	6.33	4.01	5.01
49	SiA-3622	54.00	91.50	92.60	3.70	16.10	1694.50	7.10	3.49	3.66
50	SiA-3623	50.00	86.75	102.40	3.10	17.80	1761.50	6.19	3.17	4.63
51	SiA-3085 (Check)	51.00	95.00	94.90	3.10	18.80	1922.00	5.92	5.28	3.39
52	SiA-3625	48.00	91.00	94.70	2.60	17.20	1679.00	5.02	3.38	3.42
53	SiA-3626	46.00	87.50	96.10	2.90	16.80	1834.50	6.53	3.66	3.88
54	SiA-3628	48.00	87.00	101.30	3.30	19.60	1758.50	7.29	4.25	5.83
55	SiA-3631	47.00	91.50	86.90	2.35	17.60	1524.00	7.00	4.88	4.42
56	SiA-3632	52.00	90.00	95.50	3.20	16.60	1754.50	6.07	3.45	4.86
57	SiA-3634	47.00	85.00	82.90	2.70	15.70	1659.00	6.30	2.88	3.08
58	SiA-3636	53.00	91.50	115.20	4.60	20.90	2006.00	8.71	3.93	6.64
59	SiA-3637	50.00	88.75	96.60	3.00	18.60	1850.00	7.14	3.44	3.62
60	SiA-3156 (Check)	41.00	83.25	91.88	2.60	17.70	1848.00	7.08	3.51	5.44
	General Mean	48.13	88.74	97.75	3.12	18.07	1660.75	6.34	3.55	4.63
	SEd	1.116	1.49	3.554	0.467	1.227	36.514	0.333	0.833	0.328
	CD at 5%	2.239	2.99	7.129	0.938	2.461	73.25	0.668	1.667	0.658

4.2.1.1 Days to 50% flowering

Among 60 germplasm lines, mean range for days to 50% flowering ranged from 41.00 days (SiA 3156) to 54.00 days (SiA 3622) among lines with a general mean of 48.13 days. Among the lines, SiA 3156, 3615, 3569 and 3575 were the earliest to flower. Therefore, these genotypes can be utilized in the hybridization programme as donor parents to evolve short duration varieties. Twenty seven lines exceeded the general mean value of 48.13.

4.2.1.2 Days to maturity

The mean values of genotypes for this character ranged from 83.25 days (SiA 3156) to 95.75 days (SiA 3598) with a general mean of 88.74 days. Among all the genotypes, SiA 3156 followed by 3569, 3634 and 3575 were found to be early maturing genotypes. Therefore, these genotypes can be utilized in the hybridization programme as donor parents to evolve short duration varieties. Thirty genotypes were late in maturity while thirty lines were early as compared to general mean (88.74).

4.2.1.3 Plant height (cm)

Among 60 lines, Narasimharaya was found to be the tallest (122.50 cm) (Plate 2) while SiA 3584 was the shortest (77.65 cm). The general mean height of the genotypes was 97.75 cm. Considering plant height, the genotypes SiA 3584, 3586 and 3634 recorded higher *per se* performance. Hence, these genotypes could be utilized for developing dwarf genotypes with lodging resistance. Twenty seven genotypes exceeded the general mean value.



Plate 2. Plant height of selected foxtail millet lines

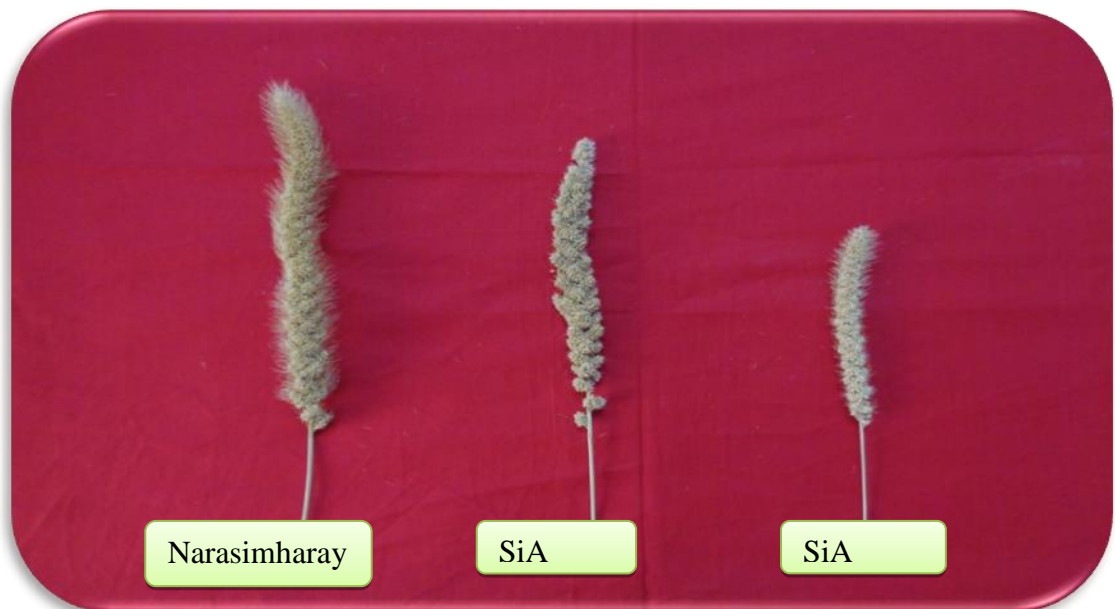


Plate 3. Ear head length of selected foxtail millet lines

4.2.1.4 Ear bearing tillers per hill (No.)

The maximum ear bearing tillers per hill were recorded in the genotype SiA 3563 (4.80) while 3554 and Prasad had minimum ear bearing tillers per hill (2.10). The genotypes SiA 3563, 3636, Narasimharaya and 3558 exhibited superiority in *per se* performance for ear bearing tillers per hill. Twenty four genotypes recorded higher ear bearing tillers per hill than the general mean (3.12)

4.2.1.5 Ear head length (cm)

Ear head length (cm) was found maximum in Narasimharaya (23.30 cm) (Plate 3) and the lowest was registered in the genotype SiA 3615 (15.00 cm). The genotype, Narasimharaya followed by SiA 3608 and 3542 registered maximum ear head length. Twenty seven genotypes were found to exceed the general mean 18.07cm for ear head length.

4.2.1.6 Test weight (g)

The test weight among the germplasm lines was ranged from 2.42 g (SiA 3570) to 7.40 g (Sri Lakshmi). The genotypes *viz.*, Sri Lakshmi, SiA 3085, and SiA 3631 lines displayed higher *per se* performance for test weight. Twenty two genotypes exceeded the general mean test weight of 3.55 g.

4.2.1.7 Number of grains per ear head

Among the 60 genotypes, SiA 3569 displayed the maximum number of grains per ear head (2371.50) and SiA 3559 displayed the minimum number of grains per ear head (965.00). The genotype SiA 3569 followed by 3550 and 3636 lines showed better mean performance for number of grains per ear head. The general mean was 1660.75 for grains per ear and thirty three genotypes had lesser than mean value.

4.2.1.8 Grain yield per plant (g)

The genotype SiA 3636 displayed the highest grain yield (8.71 g) while SiA 3562 displayed the lowest (3.58 g) grain yield per plant. The genotypes, SiA 3636, Sri Lakshmi and Narasimharaya lines recorded high *per se* performance for grain yield per plant. Thirty genotypes showed superior performance compared to general mean of 6.34 g.

4.2.1.9 Fodder yield per plant (g)

Among germplasm lines, the lowest fodder yield per plant was recorded in SiA 3583 (2.93 g) and the highest in SiA 3539 (7.65 g). The genotypes *viz.*, SiA 3539, 3542 and 3636 recorded relatively high fodder yield per plant. Twenty five genotypes exhibited high fodder yield per plant than the general mean fodder yield of 4.64 g.

4.2.2 Mean Performance of Genotypes for Physiological Traits

The mean performance of 60 genotypes of foxtail millet recorded for physiological traits at 30 and 45 DAS are presented below.

4.2.2.1 Canopy Leaf temperature (°C)

Plants protect one of their most important functions, photosynthesis, by maintaining average leaf temperatures at around 21°C, regardless of the weather (Heidi Ledford, 2008).

Breeding for drought resistance involves the identification of genotypes that maintain transpiration, gas exchange and a lower canopy temperature as compared with other genotypes under the same field conditions. Relatively lower canopy temperature in drought stressed crop plants indicates a relatively better capacity for taking up soil moisture and

Table 4.3 Mean performance of 60 genotypes of foxtail millet for five physiological characters at 30 and 45 DAS

S. No	Genotypes	SLA at 30 DAS (cm ² g ⁻¹)	SLA at 45DAS (cm ² g ⁻¹)	SCMR at 30 DAS	SCMR at 45 DAS	Leaf temperature at 30DAS (C ⁰)	Leaf temperature at 45DAS (C ⁰)	Membrane injury at 30DAS (%)	Membrane injury at 45DAS (%)	Relative water content at 30DAS (%)	Relative water content at 45DAS (%)
1	Suryanandi (Check)	122.02	160.30	32.87	33.72	36.50	31.30	48.69	60.44	89.13	85.65
2	SiA-3539	184.03	192.10	35.52	37.54	35.50	35.66	66.99	80.57	93.59	95.08
3	SiA-3542	143.69	180.39	36.08	37.95	35.00	39.80	44.20	60.72	88.27	92.56
4	SiA-3543	187.81	208.16	36.68	36.86	32.25	33.82	50.70	62.81	88.98	95.74
5	SiA-3545	148.28	174.70	40.57	41.20	34.25	40.58	67.86	55.65	93.68	92.79
6	SiA-3546	113.83	144.78	37.59	39.00	34.25	36.69	46.79	56.73	73.93	96.02
7	SiA-3550	172.08	178.43	37.03	39.40	34.75	37.85	52.86	80.55	90.96	90.73
8	SiA-3551	135.23	158.21	40.52	41.32	33.75	32.42	40.40	65.52	89.88	94.59
9	SiA-3554	164.48	167.90	37.85	36.84	33.00	34.74	75.54	73.01	91.00	90.99
10	SiA-3555	188.79	193.50	36.77	36.98	34.50	28.80	58.58	73.82	91.47	91.51
11	Narasimharaya (Check)	199.67	258.33	42.45	41.81	37.25	38.05	71.77	63.70	91.07	86.14
12	SiA-3558	185.11	179.02	42.61	42.94	32.75	30.95	57.34	76.45	84.81	85.58
13	SiA-3559	193.91	190.91	35.26	36.89	37.00	34.80	57.19	55.68	91.08	92.79
14	SiA-3560	139.65	175.90	41.51	42.91	36.00	43.90	73.93	83.91	89.04	92.92
15	SiA-3562	106.21	182.02	41.42	43.28	35.00	38.63	53.06	74.21	89.62	92.86
16	SiA-3563	182.47	167.93	43.80	45.90	35.50	42.88	58.97	63.66	80.62	93.64
17	SiA-3569	184.28	190.26	38.13	40.92	33.25	41.60	78.99	57.54	87.86	88.49
18	SiA-3570	145.27	186.48	38.22	42.65	34.25	30.97	42.88	78.71	86.86	93.21
19	SiA-3572	150.82	162.72	35.95	37.43	34.50	27.56	43.99	71.81	91.39	86.51
20	SiA-3574	172.50	171.51	33.51	40.80	36.00	37.86	60.81	59.98	89.11	94.25
21	Prasad (Check)	175.92	175.01	40.45	42.24	33.00	32.25	60.84	59.98	90.52	88.89
22	SiA-3575	172.82	172.00	33.12	33.45	34.00	34.68	77.43	90.88	93.00	88.71
23	SiA-3578	192.68	193.89	31.45	34.80	33.25	32.91	65.93	63.57	89.75	91.90
24	SiA-3580	184.52	172.04	35.16	34.65	32.75	33.80	62.87	76.81	89.08	77.55
25	SiA-3581	173.60	156.78	31.13	33.70	33.25	28.85	53.69	64.06	89.71	93.54
26	SiA-3582	126.34	195.20	35.09	33.95	32.50	33.75	60.52	64.80	90.59	93.57
27	SiA-3583	167.04	163.56	37.29	41.90	35.75	38.52	54.91	67.87	92.58	93.68
28	SiA-3584	168.85	160.64	39.31	40.01	37.00	31.48	59.93	73.40	90.65	97.76
29	SiA-3585	152.15	163.41	38.61	40.12	37.25	35.58	58.35	70.70	91.91	94.51
30	SiA-3586	180.72	178.17	34.02	40.50	37.50	39.45	77.05	81.40	85.64	95.75
31	Sri Lakshmi (Check)	142.47	172.01	36.13	38.17	35.85	33.07	52.21	61.00	90.95	92.59

Contd...

Table 4.3.Contd...

S. No	Genotypes	SLA at 30 DAS (cm ² g ⁻¹)	SLA at 45DAS (cm ² g ⁻¹)	SCMR at 30 DAS	SCMR at 45 DAS	Leaf temperature at 30DAS (C ^o)	Leaf temperature at 45DAS (C ^o)	Membrane injury at 30DAS (%)	Membrane injury at 45DAS (%)	Relative water content at 30DAS (%)	Relative water content at 45DAS (%)
32	SiA-3589	178.42	170.10	36.86	37.72	35.05	35.98	52.73	65.05	88.42	95.73
33	SiA-3591	156.00	167.07	32.90	33.60	36.50	33.00	76.86	57.24	88.21	91.57
34	SiA-3595	151.70	171.21	35.10	36.70	35.25	38.05	63.87	72.03	95.30	95.44
35	SiA-3596	145.68	216.72	34.38	38.89	35.00	25.78	91.97	75.08	91.10	84.06
36	SiA-3598	139.11	164.50	41.97	41.02	34.25	36.40	65.68	72.62	92.11	91.92
37	SiA-3600	163.84	165.05	36.75	40.33	33.30	43.87	59.85	76.77	90.65	92.87
38	SiA-3604	143.55	147.75	33.83	44.14	37.00	42.97	50.78	67.67	92.98	79.72
39	SiA-3605	176.77	169.97	37.55	40.60	36.25	33.75	75.62	79.20	81.15	93.76
40	SiA-3607	163.08	173.17	29.28	32.57	37.35	30.45	52.12	96.10	90.82	93.78
41	Krishnadevaraya (Check)	162.82	200.69	44.45	43.30	34.75	36.90	60.17	87.53	91.84	94.41
42	SiA-3608	162.49	190.73	32.93	34.20	33.25	32.25	37.51	73.94	87.81	92.28
43	SiA-3610	149.82	180.74	37.57	39.50	35.25	35.69	55.66	92.69	89.64	93.78
44	SiA-3611	172.55	172.16	34.46	38.25	36.75	27.07	53.74	75.62	87.70	95.61
45	SiA-3613	186.00	190.39	37.30	38.08	37.25	28.17	66.87	46.79	93.92	95.94
46	SiA-3615	166.40	171.33	39.45	38.12	35.75	35.76	68.03	78.44	91.11	84.74
47	SiA-3618	148.91	152.99	36.12	39.97	35.73	30.55	46.76	49.78	92.19	95.68
48	SiA-3619	154.86	161.43	30.00	35.75	35.75	31.40	55.62	70.75	90.10	95.85
49	SiA-3622	165.29	182.20	38.46	41.73	35.25	35.40	33.65	74.13	90.55	96.62
50	SiA-3623	154.26	169.92	34.55	44.10	37.89	43.80	45.38	74.94	88.55	87.68
51	SiA-3085 (Check)	183.54	190.82	37.25	41.06	36.00	31.10	61.88	81.97	85.65	89.76
52	SiA-3625	210.83	216.00	35.35	35.66	35.25	33.00	44.91	82.72	88.86	94.79
53	SiA-3626	171.90	167.62	33.98	42.85	35.25	37.85	69.43	68.14	88.86	92.74
54	SiA-3628	151.59	156.38	36.07	39.21	35.50	39.15	53.17	70.30	92.71	97.51
55	SiA-3631	161.43	167.40	39.68	39.21	34.50	32.66	42.67	75.22	95.52	90.28
56	SiA-3632	168.05	182.90	34.62	39.22	34.75	37.77	47.54	75.75	88.86	93.05
57	SiA-3634	171.39	174.99	40.10	39.23	34.75	35.20	53.55	58.93	84.91	92.17
58	SiA-3636	168.82	158.17	32.00	39.23	34.00	35.55	51.94	60.05	90.78	91.40
59	SiA-3637	172.10	171.38	36.77	39.24	34.75	34.45	56.00	80.65	90.71	91.09
60	SiA-3156 (Check)	124.24	146.52	40.44	39.25	34.25	27.93	76.55	83.00	88.65	84.54
	General Mean	163.04	176.27	36.77	39.04	35.07	34.92	58.43	70.88	89.60	91.82
	SEd	5.12	3.858	1.619	1.108	1.247	1.055	0.968	1.073	0.725	1.324
	CD at 5%	10.28	7.739	3.248	2.223	2.502	2.116	1.943	2.152	1.455	2.656

for maintaining a relatively better plant water status by various plant constitutive or adaptive traits (Blum *et al.*, 1990).

In the present study, maximum leaf temperature was recorded in SiA 3623 (37.88°C) at 30 DAS and SiA 3560 (43.90°C) at 45 DAS while it was minimum in SiA 3543 (32.25°C) at 30 DAS and SiA 3596 (25.78°C) at 45 DAS. Twenty nine genotypes at 30 DAS and twenty nine genotypes at 45 DAS have registered leaf temperature above the general mean leaf temperatures of 35.07°C and 34.92°C, at two stages respectively. The genotypes *viz.*, SiA 3543, 3582 and 3558 at 30 DAS and SiA 3596, 3611 and 3572 at 45 DAS recorded relatively low leaf temperature in turn they maintained cool temperature though high temperature prevailed in the environment. It might be due to high transpiration rate of the plants.

4.2.2.2 Specific leaf area (cm²g⁻¹)

A wide variation in specific leaf area of the foxtail millet genotypes were observed where in, SiA 3625 recorded the maximum specific leaf area (210.83 cm²g⁻¹) while SiA 3562 displayed the lowest specific leaf area (106.21 cm²g⁻¹) at 30 DAS. Similarly, Narasimharaya registered the maximum specific leaf area (258.33 cm²g⁻¹) while SiA 3546 displayed the lowest specific leaf area (144.78 cm²g⁻¹) at 45 DAS. Among the lines, SiA 3562, 3546 and Suryanandi at 30 DAS whereas SiA 3546, 3156 and 3604 at 45 DAS registered low *per se* performance. Thirty three and twenty three genotypes had recorded higher values of specific leaf area compared to mean SLA of 163.11 and 176.27 cm²g⁻¹ at 30 and 45 DAS respectively.

Wright *et al.* (1994) reported that if SLA is lowered the leaf thickness would be more, hence, the capacity of photosynthesis would be higher and thus these genotypes also recorded high NAR values. They also reported an inverse relationship between SLA and WUE, thus indicating the genotypes

with thick leaves (low SLA) under moisture stress conditions may be water use efficient ones.

4.2.2.3 SCMR

The mean values of SPAD chlorophyll meter reading ranged from 29.28 (SiA 3607) to 44.45 (Krishnadevaraya) at 30 DAS while at 45 DAS, the mean SPAD chlorophyll meter readings ranged from 32.57 (SiA 3607) to 45.90 (SiA 3563). The SCMR reading was maximum in Krishnadevaraya, SiA 3563 and 3558 at 30 DAS and in SiA 3563, 3604 and 3623 at 45 DAS. For this trait, twenty eight and thirty four genotypes surpassed their corresponding mean SCMR values of 36.77 and 39.04 at 30 DAS and 45 DAS, respectively.

A significant positive correlation between SCMR and WUE and a negative correlation between SCMR and SLA were considered as good criterion of drought tolerance which was already established in groundnut (Latha, 2004). Hence, low SLA and high SCMR are the indicators of selection for high WUE.

Therefore, these two traits are used indirectly to select for high water use efficiency genotypes which concomitantly select for drought tolerant genotypes. Hence these genotypes will be utilized for exploiting the higher yields under drought condition.

4.2.2.4 Relative water content (%)

Relative water content was highest in the genotype SiA 3631 (95.52) while it was lowest (73.92%) in SiA 3546 at 30 DAS while among lines at 45 DAS, it was highest in the genotype SiA 3584 (97.76%) while it was lowest (77.54%) in SiA 3580. Relatively low water content was observed in those lines at 30 DAS *viz.*, SiA 3546, 3563 and 3605 and in three lines at 45 DAS *viz.*, SiA 3580, 3604 and 3596 indicating low turgidity of available

water which decides the magnitude of physiological process occurring in leaf tissue of these genotypes. Thirty six and thirty nine genotypes recorded high water content when compared to grand mean of 89.60% and 91.82% at 30 and 45 DAS respectively.

4.2.3 Thermotolerance Traits

4.2.3.1 Relative injury (%)

Among the sixty foxtail lines, relative injury was highest in the genotype SiA 3596 (91.97%) while it was lowest (33.64%) in SiA 3622 at 30 DAS while at 45 DAS, it was highest in the genotype SiA 3607 (96.10%) and lowest (46.79%) in SiA 3613. Relatively low injury was observed in three lines at 30 DAS viz., SiA 3622, 3608 and 3551 and at 45 DAS viz., SiA 3613, 3618 and 3545 indicating high membrane integrity of these genotypes. Twenty eight and thirty two genotypes recorded high relative injury when compared to grand mean of 58.43% and 70.88% at 30 and 45 DAS respectively.

The genotype SiA 3607 showed higher membrane damage under water stress i.e. 96.09 per cent which denotes its sensitivity to high temperature stress. Hence, this genotypes with lower relative injury possess high drought tolerance as it maintained high thermo tolerance apart from moisture stress tolerance.

Higher percentage of injury under water stress was also reported in susceptible wheat genotypes (Sairam *et al.*, 1997). The leakage of solutes from tissue can be used as a dynamic measure of the damage of the membranes increased by stress experience (Leopold *et al.*, 1981). Similarly, Babitha *et al.* (2006) reported that cellular membranes of groundnut genotypes with low relative injury values that are more thermostable than the genotypes with high relative injury.

4.2.4 Mean Performance of Top Ten High Yielding Genotypes

The mean performance of top ten genotypes for yield, yield components and physiological traits were furnished in Table 4.4 and 4.5 respectively and Fig 4.1.

A perusal of top ranking of ten lines indicated that SiA 3636, SiA 3539, Prasad, SiA 3628 and Narasimharaya among registered high grain yield and fodder yield (Table 4.4). Hence, these can be utilized for breeding of dual purpose genotypes. The genotypes, SiA 3584, Prasad, SiA 3604, SiA 3628 and Sri Lakshmi were found to be earliest to flower. Similarly, these genotypes registered early maturity. Hence, these could be suitable for breeding of short duration genotypes.

The genotypes SiA 3584, Prasad and SiA 3611 can be exploited for developing dwarf genotypes with high yield.

For the remaining traits, the genotypes SiA 3636 and Narasimharaya for ear bearing tillers per hill, Sri Lakshmi and Prasad for test weight, SiA 3636 and Sri Lakshmi for number of grains per ear head, Narasimharaya and SiA 3636 for ear head length were found to exhibit highest mean performance and hence, these genotypes could be further exploited for development of agronomically superior hybrids of foxtail millet.

As far as physiological traits are concerned, the genotypes, Prasad and SiA 3636 had the lowest leaf temperature at 30 DAS while the genotypes, SiA 3611 and SiA 3584 recorded the lowest leaf temperature at 45 DAS which led to higher yield by minimizing the transpiration losses (Table). These results are in accordance with the findings of Fischer *et al.* (1989) that under severe moisture stress, yield was significantly correlated with canopy temperature. Thus, for obtaining higher yields, selection can be based on lower leaf temperature to identify high yielding genotypes.

Table 4.4 Mean performance of top ten high yielding genotypes of foxtail millet for grain yield and its attributing characters

S.No	Genotype	Grain yield/ plant(g)	Days to 50% flowering	Days to maturity	Plant height(cm)	Ear bearing tillers / hill	Ear head length(cm)	No of grains/ ear head	1000 seed weight (g)	Fodder yield/ plant (g)
1	SiA 3636	8.71	53.00	91.50	115.20	4.60	20.90	2006.00	3.93	6.64
2	Sri Lakshmi	8.24	48.00	85.50	96.95	3.20	19.10	1999.00	7.40	4.60
3	Narasimharaya	8.19	53.00	89.00	122.50	4.25	23.30	1997.00	3.08	5.50
4	SiA 3598	7.70	53.00	95.75	107.40	2.90	18.80	1954.00	3.50	4.80
5	SiA 3604	7.57	47.00	86.25	92.30	3.00	17.30	1487.50	4.18	4.81
6	SiA 3539	7.55	53.00	95.75	109.00	3.70	19.90	1573.50	4.01	7.65
7	SiA 3584	7.33	45.00	89.00	77.65	3.60	15.43	1156.50	3.58	4.40
8	SiA 3628	7.29	48.00	87.00	101.30	3.30	19.60	1758.50	4.25	5.83
9	SiA 3611	7.24	53.00	93.25	89.90	2.80	16.90	1755.50	3.78	4.50
10	Prasad	7.20	46.00	88.00	88.10	2.10	17.80	1771.50	4.65	6.41

Table 4.5 Mean performance of top ten high yielding genotypes of foxtail millet for physiological characters

S. No	Genotypes	SLA at 30DAS (cm² g⁻¹)	SLA at 45DAS (cm² g⁻¹)	SCMR at 30 DAS	SCMR at 45 DAS	Leaf temperature at 30DAS (°C)	Leaf temperature at 45DAS (°C)	Membrane injury at 30DAS (%)	Membrane injury at 45DAS (%)	Relative water content at 30DAS (%)	Relative water content at 45DAS (%)
1	SiA 3636	168.82	158.17	32.00	39.23	34.00	35.55	51.94	60.05	90.78	91.40
2	Sri Lakshmi	142.47	172.01	36.13	38.17	35.85	33.07	52.21	61.00	90.95	92.59
3	Narasimharaya	199.67	258.33	42.45	41.81	37.25	38.05	71.77	63.70	91.07	86.14
4	SiA 3598	139.11	164.50	41.97	41.02	34.25	36.40	65.68	72.62	92.11	91.92
5	SiA 3604	143.55	147.75	33.83	44.14	37.00	42.97	50.78	67.67	92.98	79.72
6	SiA 3539	184.03	192.10	35.52	37.54	35.50	35.66	66.99	80.57	93.59	95.08
7	SiA 3584	168.85	160.64	39.31	40.01	37.00	31.48	59.93	73.40	90.65	97.76
8	SiA 3628	151.59	156.38	36.07	39.21	35.50	39.15	53.17	70.30	92.71	97.51
9	SiA 3611	172.55	172.16	34.46	38.25	36.75	27.07	53.74	75.62	87.70	95.61
10	Prasad	175.92	175.01	40.45	42.24	33.00	32.25	60.84	59.98	90.52	88.89

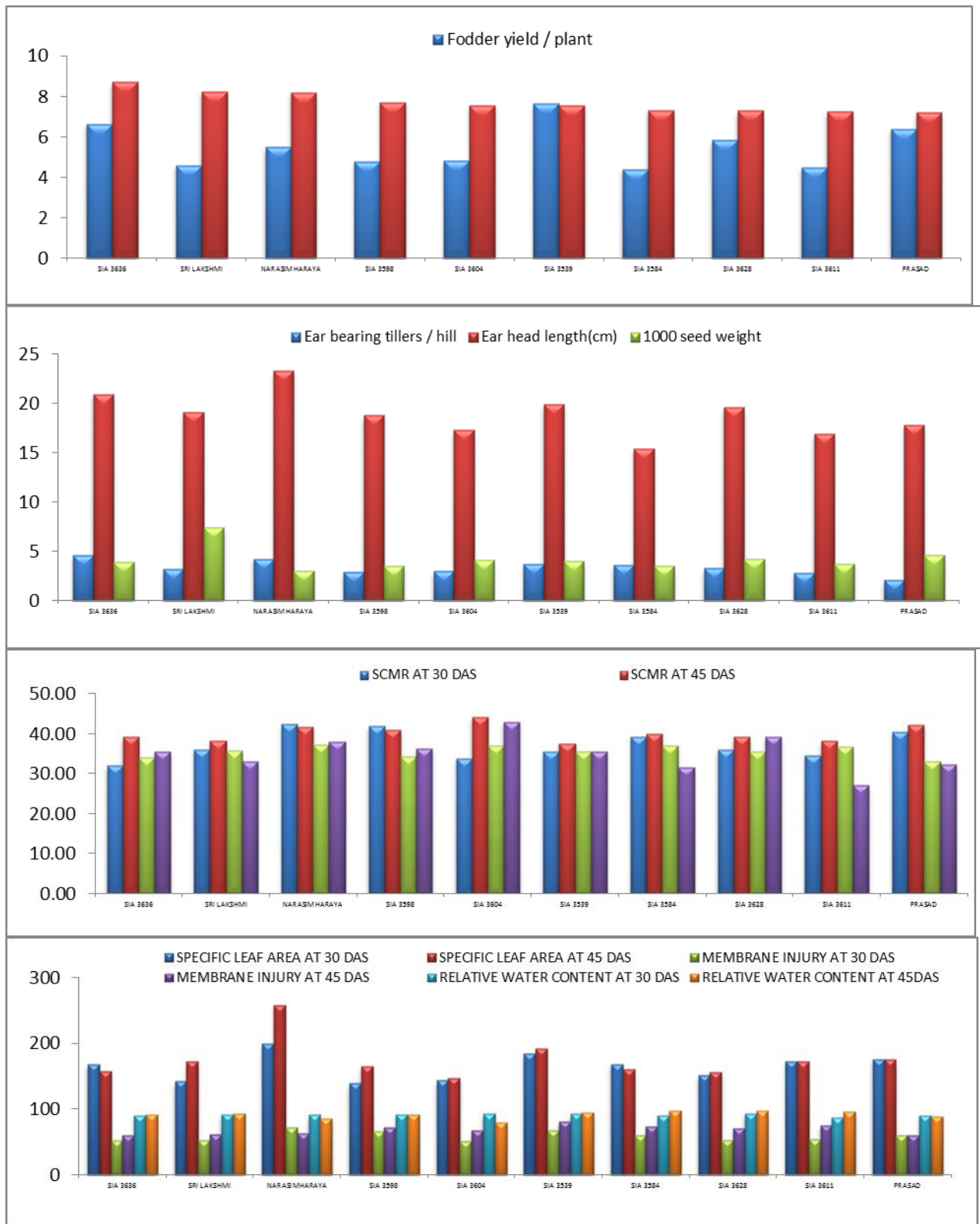


Fig 4.1 Mean performance of top ten foxtail millet genotypes for yield, yield components and physiological trait

Considering the water use efficiency traits, the genotypes, Narasimharaya, SiA 3598, Prasad, SiA 3539 and SiA 3584 registered the maximum mean values for SCMR and specific leaf area at 30 DAS and Narasimharaya, Prasad, SiA 3604, SiA 3539 and SiA 3598 registered the maximum mean values for SCMR and specific leaf area at 45 DAS respectively. Hence, these genotypes could be utilized for exploiting the higher yields in drought environment. Similarly, the genotypes, SiA 3636, Sri Lakshmi, Prasad, SiA 3628 and SiA 3598 for relative injury at 30 and 45 DAS and SiA 3539, SiA 3598 and SiA 3584 for relative water content at 30 and 45 DAS registered the maximum *per se* performance for thermo tolerant traits. Hence, these can be utilized as donor parents for developing thermo tolerant lines in view of climate change.

From the above results, it is to emphasize that SiA 3636, Sri Lakshmi and Narasimharaya have recorded desirable mean performance for most of the yield and yield attributing traits while SiA 3636, Prasad, SiA 3598 and SiA 3539 have displayed the maximum *per se* performance for the most of the physiological traits. Hence, these genotypes can be utilised for breeding of drought tolerant genotypes with high grain and fodder yields. Moreover, these genotypes were also earliest to flower, early to mature and dwarf in stature.

4.2.5 Thermo Induction Response (TIR) of Foxtail Millet Genotypes

A set of diverse foxtail millet germplasm comprising of 60 genotypes was screened for intrinsic tolerance using the standardized Thermo Induction Response (TIR) protocol. The experimental data were recorded and presented in Table 4.7.

The genotypes showed high genetic variability for per cent survival of seedlings, per cent reduction in root and shoot growth respectively. The per cent survival of seedlings varied from 55 to 100 per cent with a mean survival of 76.17 per cent (Table 4.8). The per cent reduction in root growth

Table 4.7 Mean performance of foxtail millet germplasm for Thermo Induction Response (TIR) characters

S. No	Genotype	% of survival of seedlings		% reduction in root growth			% reduction in shoot growth				
				Actual root growth in control	Actual root growth in treatment	% reduction in root growth*	Actual shoot growth in control	Actual shoot growth in treatment	% reduction in shoot growth*		
1	Suryanandi (Check)	95	(77)	4.75	3.98	16.21	(23.75)	6.30	3.95	37.30	(37.66)
2	SiA-3539	90	(72)	3.75	1.45	61.33	(51.58)	5.53	3.88	29.77	(33.09)
3	SiA-3542	85	(67)	3.78	1.25	66.89	(54.90)	4.80	1.98	58.85	(50.13)
4	SiA-3543	90	(72)	5.00	1.83	63.50	(52.86)	5.13	2.30	55.12	(47.96)
5	SiA-3545	75	(60)	5.08	1.88	63.05	(52.59)	4.33	1.98	54.34	(47.51)
6	SiA-3546	70	(57)	3.73	1.60	57.05	(49.08)	6.35	2.25	64.57	(53.50)
7	SiA-3550	80	(63)	5.89	2.38	59.68	(50.61)	5.80	2.60	55.17	(47.99)
8	SiA-3551	85	(67)	3.70	1.75	52.70	(46.57)	5.45	1.95	64.22	(53.29)
9	SiA-3554	65	(54)	4.35	2.20	49.43	(44.69)	5.30	2.08	60.85	(51.29)
10	SiA-3555	60	(51)	4.65	1.28	72.58	(58.45)	4.98	1.53	69.25	(56.35)
11	Narasimharaya (Check)	100	(90)	4.80	2.78	42.19	(40.53)	6.03	4.73	21.49	(27.63)
12	SiA-3558	75	(60)	4.80	3.23	32.81	(34.96)	4.43	3.00	32.20	(34.59)
13	SiA-3559	60	(51)	4.05	1.73	57.41	(49.28)	5.13	1.83	64.29	(53.33)
14	SiA-3560	70	(57)	3.18	2.40	24.41	(29.62)	5.95	2.93	50.84	(45.50)
15	SiA-3562	60	(51)	6.58	2.43	63.12	(52.63)	5.38	2.25	58.14	(49.71)
16	SiA-3563	60	(51)	3.98	1.25	68.55	(55.92)	5.65	1.83	67.61	(55.34)
17	SiA-3569	55	(48)	3.48	1.25	64.03	(53.17)	5.80	1.73	70.26	(56.98)
18	SiA-3570	60	(51)	3.48	1.80	48.20	(43.99)	6.00	2.45	59.17	(50.31)
19	SiA-3572	55	(48)	4.00	1.50	62.50	(52.27)	5.13	2.13	58.54	(49.94)
20	SiA-3574	65	(54)	3.85	2.33	39.61	(39.02)	4.63	2.53	45.41	(42.39)
21	Prasad (Check)	100	(90)	3.93	3.78	3.69	(11.09)	5.98	4.85	18.83	(25.73)
22	SiA-3575	95	(77)	2.33	2.25	3.23	(10.35)	4.63	2.78	40.00	(39.25)
23	SiA-3578	90	(83)	3.95	1.90	51.90	(46.11)	5.45	2.50	54.13	(47.39)
24	SiA-3580	95	(77)	2.73	2.50	8.26	(16.71)	5.38	4.99	7.16	(15.53)
25	SiA-3581	70	(57)	2.60	2.20	15.38	(23.11)	5.35	2.75	48.60	(44.22)
26	SiA-3582	75	(60)	3.58	1.45	59.44	(50.47)	5.33	2.15	59.62	(50.57)
27	SiA-3583	75	(60)	3.20	2.05	35.94	(36.85)	4.93	3.00	39.09	(38.72)
28	SiA-3584	70	(57)	2.10	1.63	22.62	(28.41)	5.75	1.98	65.65	(54.15)
29	SiA-3585	75	(60)	3.35	1.95	41.79	(40.30)	5.18	2.75	46.86	(43.22)
30	SiA-3586	85	(67)	4.00	1.90	52.50	(46.46)	5.40	2.78	48.61	(44.23)
31	Sri Lakshmi (Check)	70	(57)	4.53	1.88	58.56	(49.96)	5.90	2.48	58.05	(49.66)
32	SiA-3589	55	(48)	3.40	1.98	41.91	(40.37)	4.58	4.00	12.57	(20.77)

Contd...

Table 4.7 Contd...

S. No	Genotype	% of survival of seedlings	% reduction in root growth				% reduction in shoot growth			
			Actual root growth in control	Actual root growth in treatment	% reduction in root growth*		Actual shoot growth in control	Actual shoot growth in treatment	% reduction in shoot growth*	
33	SiA-3591	70 (57)	2.80	1.88	33.04	(35.10)	5.23	3.00	42.58	(40.76)
34	SiA-3595	65 (54)	4.80	2.15	55.21	(48.01)	6.33	2.40	62.06	(52.00)
35	SiA-3596	70 (57)	4.98	2.35	52.76	(46.61)	4.83	3.99	17.31	(24.59)
36	SiA-3598	80 (63)	3.05	2.40	21.31	(27.51)	6.18	2.53	59.11	(50.27)
37	SiA-3600	65 (54)	3.30	1.68	49.24	(44.59)	5.63	2.65	52.89	(46.68)
38	SiA-3604	95 (77)	3.00	2.55	15.00	(22.80)	5.65	4.98	11.86	(20.15)
39	SiA-3605	55 (48)	3.13	2.35	24.80	(29.88)	5.90	2.68	54.66	(47.70)
40	SiA-3607	70 (57)	3.65	1.65	54.79	(47.78)	5.45	2.85	47.71	(43.71)
41	Krishnadevaraya (Check)	70 (57)	3.30	2.40	27.27	(31.50)	5.18	1.85	64.25	(53.31)
42	SiA-3608	75 (60)	3.25	2.35	27.69	(31.77)	6.55	3.05	53.44	(46.99)
43	SiA-3610	60 (51)	3.08	1.40	54.47	(47.59)	5.33	2.50	53.05	(46.77)
44	SiA-3611	75 (60)	2.88	1.98	31.30	(34.04)	6.20	2.65	57.26	(49.20)
45	SiA-3613	60 (51)	3.18	2.68	15.75	(23.39)	5.23	4.21	19.43	(26.16)
46	SiA-3615	70 (57)	2.40	1.98	17.71	(24.90)	5.88	3.35	42.98	(40.98)
47	SiA-3618	95 (77)	3.18	3.09	2.68	(9.42)	6.05	5.25	13.22	(21.33)
48	SiA-3619	85 (67)	3.75	3.43	8.67	(17.13)	5.55	3.65	34.23	(35.83)
49	SiA-3622	70 (57)	4.13	2.53	38.79	(38.54)	6.15	2.83	54.07	(47.36)
50	SiA-3623	70 (57)	3.55	3.48	2.11	(8.36)	4.85	4.00	17.53	(24.76)
51	SiA-3085 (Check)	75 (60)	2.65	2.48	6.60	(14.90)	4.60	3.00	34.78	(36.16)
52	SiA-3625	100 (90)	3.50	3.18	9.14	(17.61)	4.18	3.49	16.41	(23.91)
53	SiA-3626	85 (67)	2.68	2.05	23.36	(28.92)	5.58	2.25	59.64	(50.58)
54	SiA-3628	100 (90)	2.98	2.65	10.92	(19.31)	5.83	4.83	17.08	(24.42)
55	SiA-3631	85 (67)	2.98	1.95	34.45	(35.96)	5.55	4.00	27.93	(31.92)
56	SiA-3632	70 (57)	4.35	3.40	21.84	(27.87)	4.65	2.50	46.24	(42.86)
57	SiA-3634	90 (72)	3.05	2.43	20.49	(26.93)	5.25	3.88	26.10	(30.74)
58	SiA-3636	85 (67)	3.00	2.18	27.50	(31.64)	5.85	3.79	35.21	(36.42)
59	SiA-3637	80 (63)	2.78	2.25	18.92	(25.80)	5.88	3.13	46.81	(43.19)
60	SiA-3156 (Check)	85 (67)	3.00	2.25	25.00	(30.02)	5.73	3.68	35.81	(36.77)
	Mean	76.17			36.52				44.67	
	SE (m)	1.82			2.79				2.61	
	CD at 5%	5.17			5.91				4.62	

*Values in parenthesis denote Arc-sine transformed values.

varied from 2.11 (SiA 3618, SiA 3623) to 72.58 (SiA 3555) per cent with a mean of 36.52 per cent and the per cent reduction in shoot growth varied from 7.16 (SiA 3580) to 70.26 (SiA 3569) per cent with a mean of 44.67 per cent.

The TIR response of top ten genotypes revealed that Prasad showed the lowest percent reduction in root (3.6%) and shoot growth (18.8%) with 100% of survival of seedlings followed by SiA 3628 and 3604 (Table 4.6). Hence, these can be used as a potential donor parents for obtaining thermo tolerant varieties.

Table 4.6 Thermo tolerance of top ten high yielding foxtail genotypes

S. No.	Genotype	Grain yield/ plant (g)	% survival of seedlings	% reduction in root growth	% reduction in shoot growth
1	SiA 3636	8.71	85	27.5	35.2
2	Sri Lakshmi	8.24	70	58.5	58.0
3	Narasimharaya	8.19	100	42.1	21.4
4	SiA 3598	7.70	80	21.3	59.1
5	SiA 3604	7.57	95	15.0	11.8
6	SiA 3539	7.55	90	61.3	29.7
7	SiA 3584	7.33	70	22.6	65.6
8	SiA 3628	7.29	100	10.9	17.0
9	SiA 3611	7.24	75	31.3	57.2
10	Prasad	7.20	100	3.6	18.8

Among all the genotypes, Prasad, SiA 3580, SiA 3604, SiA 3618, SiA 3623 and SiA 3625 showed the highest thermo tolerance in terms of 70 to 100 per cent seedlings survival and lower reduction in root and shoot growth (Plate 4). These varieties are able to survive even when they were exposed to lethal temperatures. These results are in conformity with several studies, which showed that acclimatized plants survive upon exposure to a severe stress, which otherwise could be lethal and is considered to be as thermo tolerant (Senthil *et al.*, 2003).

The seedling survival, shoot and root growth were completely affected in the genotypes SiA 3555, SiA 3563, SiA 3569 and SiA 3572 despite of the recovery conditions maintained after exposing to sub lethal to lethal temperature. In spite of exposing to 59°C, germination and seedling growth were not affected in the

genotypes Prasad, SiA 3580, SiA 3604, SiA 3618, SiA 3623 and SiA 3625 probably due to acquired thermo tolerance.

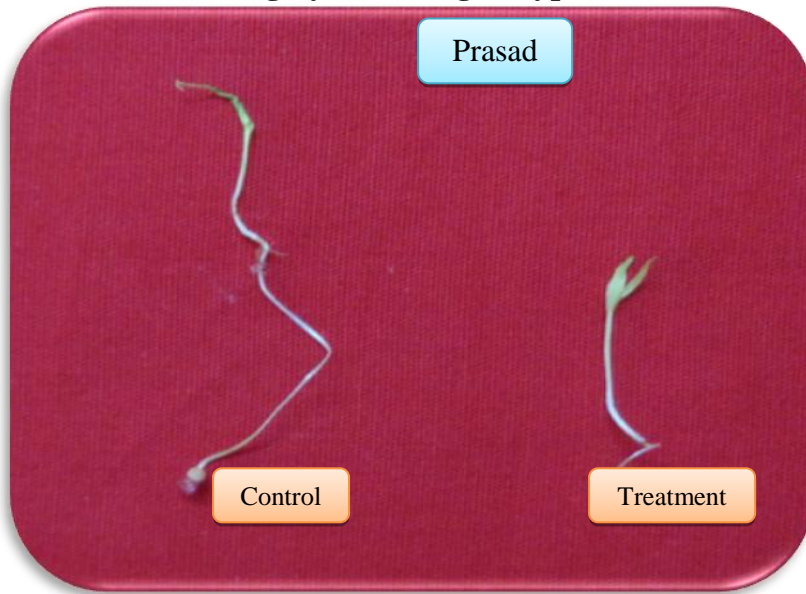
The technique of exposing young seedlings to sub lethal and lethal temperatures has been validated in many crop species (Venkatesh *et al.*, 2013 in ragi; Vijaya *et al.*, 2015 in rice; Sudhakar *et al.*, 2012 in rice; Senthil *et al.*, 2003 in sunflower; Ehab *et al.*, 2012 in cotton; Gangappa *et al.*, 2006 in groundnut; Venkatachalayya *et al.*, 2001 in pea). This novel temperature induction response technique has been demonstrated to reveal genetic variability in intrinsic stress tolerance at cellular level (Narayana, 2010). The present study also revealed that the TIR technique can very well be used in foxtail millet crop for identification of thermo tolerant genotypes. The identified genotypes *viz.*, Prasad, SiA 3580, SiA 3604, SiA 3618, SiA 3623 and SiA 3625 were found to possess high level of thermo tolerance. These genotypes can be used as potent donors for developing a wide spectrum of foxtail genotypes against high temperatures.

Six foxtail millet lines *viz.*, Prasad, SiA 3580, SiA 3604, SiA 3618, SiA 3623 and SiA 3625 which showed 70-100 per cent survival of seedlings, 2 to 15 per cent reduction in root growth and 7 to 18 per cent reduction in shoot growth were selected and needs to be evaluated further under imposed moisture stress conditions. Based on the observations from this technique, six lines were contributed highly tolerant lines and four lines were classified as sensitive lines (Table 4.8).

Table 4.8 Identification of promising thermo tolerant foxtail genotypes through TIR technique

Tolerance range	Genotype	Per cent reduction in root growth	Per cent reduction in shoot growth	Per cent survival of seedlings
Highly Tolerant Germplasm Lines	Prasad	3	18	100
	SiA 3580	8	7	95
	SiA 3604	15	11	95
	SiA 3618	2	13	95
	SiA 3623	2	17	70
	SiA 3625	9	16	100
Highly Sensitive Germplasm lines	SiA 3555	72	69	60
	SiA 3563	68	67	60
	SiA 3569	64	70	55
	SiA 3572	62	58	55

Highly tolerant genotype



Highly sensitive genotype

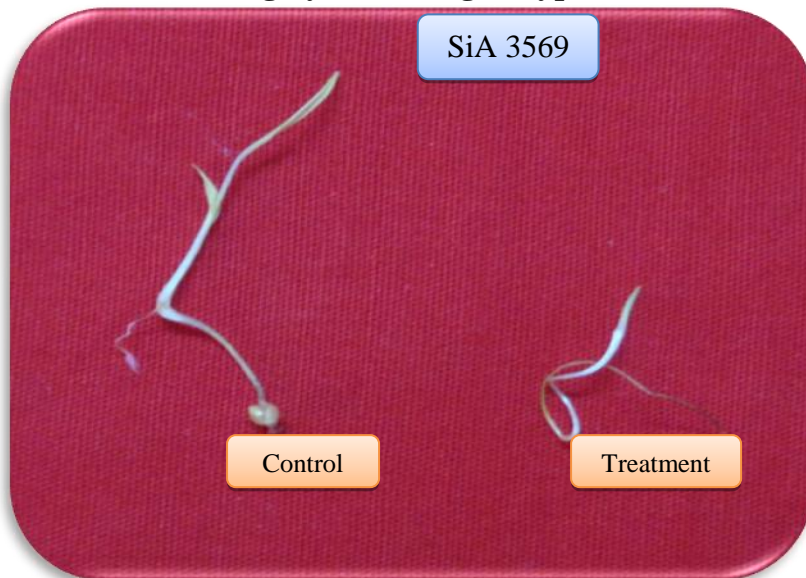


Plate 4. Thermo induction response of foxtail millet seedlings in tolerant and sensitive genotypes

4.2.6 Polyethylene glycol (PEG) induced drought screening of foxtail millet genotypes

This study was to evaluate the influence of drought stress on seeds of 60 different foxtail millet genotypes and to understand the effect of drought on seed germination by using different concentrations of standardized polyethylene glycol (PEG) protocol. Data recorded on germination percentage and other parameters is presented in Table 4.9.

The PEG induced stress response of top ten genotypes revealed that SiA 3628 showed the lowest percent reduction in root and shoot growth at different concentrations of PEG with 94% of survival of seedlings followed by SiA 3604 and 3539 (Table 4.10). Hence, these can be used as a potential donor parents for obtaining varieties for water stress tolerance.

The genotypes showed high genetic variability for per cent survival of seedlings, per cent reduction in root and shoot growth respectively. The per cent survival of seedlings, shoot and root growth of high stress tolerant and stress sensitive genotypes varied for different concentrations of PEG *viz.*, control, 15%, 20%, 25% and 30% (Fig 4.2 and Fig 4.3).

Among all the genotypes, Suryanandi, Prasad, SiA 3551 and SiA 3615 showed the highest stress tolerance in terms of higher per cent seedlings survival and lower reduction in root and shoot growth (Table 4.11). These varieties are able to survive even when they were exposed to higher concentrations of Polyethylene glycol (PEG) compounds used to induce osmotic stress. PEG induced osmotic stress is inductee to decrease cell water potential (Govindaraj *et al*, 2010). These results are in conformity with several studies, which showed that in vitro screening technique using PEG is one of the dependable approaches for the selection of desirable genotypes to study in detail on water scarcity on plant germination indices (Kocheva *et al*, 2003).

Table 4.9 Effect of PEG induced drought stress on germination %, Plumule length and Radicle length of 60 foxtail millet genotypes under different concentrations

S.No	Genotype	Germination per cent at					Plumule length (cm) at					Radicle length (cm) at				
		Control	15%PE	20%PE	25%PE	30%PE	Control	15%PE	20%PE	25%PE	30%PE	Control	15%PE	20%PE	25%PE	30%PE
1	Suryanandi (Check)	100.00	99.33	88.67	79.33	44.00	7.0	7.0	5.3	3.4	2.0	9.5	3.9	5.1	3.2	1.4
2	SiA-3539	100.00	92.00	84.67	78.00	38.00	5.5	4.7	3.2	4.0	1.8	4.7	6.6	4.3	3.2	2.8
3	SiA-3542	100.00	86.67	72.67	72.67	38.67	5.0	4.9	4.7	4.0	1.9	4.9	5.4	5.0	3.9	1.3
4	SiA-3543	100.00	80.00	75.33	82.00	38.67	4.5	5.2	4.1	3.0	1.4	5.6	3.4	2.1	2.1	1.4
5	SiA-3545	96.00	88.00	75.33	62.00	23.33	4.8	4.7	4.4	3.6	2.2	5.7	3.7	5.9	1.7	2.8
6	SiA-3546	100.00	68.00	52.00	65.33	40.67	5.3	5.5	4.7	3.4	1.7	3.3	4.1	2.6	3.6	2.0
7	SiA-3550	100.00	86.67	90.00	70.67	18.00	4.7	5.2	4.9	3.0	1.8	7.3	2.9	4.7	2.5	2.6
8	SiA-3551	97.00	84.00	82.00	66.00	40.00	5.5	5.1	4.1	3.3	2.0	6.1	4.5	5.0	3.0	1.5
9	SiA-3554	98.00	88.00	84.00	70.00	30.00	6.1	5.4	3.8	2.4	2.0	5.2	4.2	4.2	2.8	2.0
10	SiA-3555	96.00	88.00	84.00	74.00	18.00	5.8	5.2	3.8	2.6	1.5	6.3	5.1	3.5	3.4	1.8
11	Narasimharaya (Check)	96.00	82.67	78.00	40.67	32.67	6.5	5.5	4.2	3.1	1.5	6.1	4.0	2.7	3.1	1.6
12	SiA-3558	86.00	62.67	47.33	16.67	2.00	5.8	4.6	4.9	1.5	0.3	3.8	3.7	3.9	2.6	1.4
13	SiA-3559	84.00	91.33	82.67	48.00	6.67	5.4	4.8	3.4	1.9	0.6	4.3	4.9	3.2	1.2	0.4
14	SiA-3560	98.00	74.67	62.00	47.33	9.33	7.4	5.1	4.7	2.4	0.4	8.1	5.2	3.2	3.6	1.0
15	SiA-3562	80.00	61.33	52.67	17.33	0.00	5.0	5.3	3.7	1.2	1.2	5.6	5.3	3.4	2.5	1.2
16	SiA-3563	90.00	79.33	76.00	49.33	3.33	4.4	3.7	3.5	1.8	0.8	3.4	3.1	2.5	2.3	0.9
17	SiA-3569	70.00	84.67	84.67	72.00	8.67	5.4	3.9	2.6	2.7	0.2	5.8	4.4	3.2	2.8	0.6
18	SiA-3570	78.00	66.00	60.00	48.00	24.00	5.9	4.2	2.9	2.4	1.3	7.1	5.1	3.6	4.0	1.2
19	SiA-3572	90.00	80.00	70.00	58.00	12.00	6.1	4.9	3.5	1.9	1.7	5.9	5.4	3.8	3.5	0.9
20	SiA-3574	94.00	84.00	68.00	50.00	30.00	5.4	4.8	4.0	2.3	1.4	6.4	4.9	4.0	3.8	0.5
21	Prasad (Check)	100.00	94.00	98.00	82.67	40.00	6.3	6.4	4.6	3.1	1.2	4.7	5.1	2.5	2.8	1.0
22	SiA-3575	88.00	80.00	66.00	56.00	14.00	6.2	5.2	3.3	3.2	1.7	6.3	5.2	2.9	2.9	2.0
23	SiA-3578	90.00	80.00	72.00	54.00	8.00	6.1	5.0	3.6	2.7	1.9	5.8	4.8	3.8	2.2	1.5
24	SiA-3580	98.00	78.00	64.00	50.00	22.00	5.7	4.8	3.5	2.8	1.4	5.9	6.1	4.0	3.2	1.6
25	SiA-3581	100.00	92.00	78.00	58.00	24.00	5.4	4.2	4.0	3.5	1.3	6.1	5.4	4.1	2.5	0.9
26	SiA-3582	88.00	80.00	76.00	60.00	28.00	5.3	4.4	4.1	3.3	1.0	5.5	5.7	3.5	3.1	0.7
27	SiA-3583	92.00	82.00	62.00	48.00	16.00	2.4	3.5	4.0	3.4	1.2	5.3	5.8	3.6	2.8	2.0
28	SiA-3584	100.00	96.67	82.00	62.00	20.00	6.0	4.4	3.7	2.8	2.0	6.1	4.9	3.9	3.5	0.9
29	SiA-3585	100.00	97.33	88.67	76.67	28.00	6.1	4.0	3.8	2.6	0.5	7.2	5.4	2.8	2.9	1.4
30	SiA-3586	100.00	95.33	93.33	71.33	18.67	5.8	3.6	3.4	3.5	0.9	5.8	5.6	2.5	1.5	1.2

Contd...

Table 4.9 Contd.....

S.No	Genotype	Germination per cent at					Plumule length (cm) at					Radicle length (cm) at				
		Control	15%PEG	20%PEG	25%PEG	30%PEG	Control	15%PEG	20%PEG	25%PEG	30%PEG	Control	15%PEG	20%PEG	25%PEG	30%PEG
31	Sri Lakshmi (Check)	94.00	96.00	94.00	63.33	21.33	5.5	5.6	3.9	2.5	1.4	5.1	3.7	2.2	1.5	0.9
32	SiA-3589	100.00	95.33	92.67	86.00	4.67	4.6	4.2	4.1	1.5	0.7	5.5	4.5	4.6	1.7	1.2
33	SiA-3591	98.00	98.00	94.00	48.00	2.00	4.6	4.8	4.4	1.7	0.4	4.5	3.6	3.8	1.7	0.8
34	SiA-3595	98.00	97.33	92.00	48.00	0.00	5.8	5.7	3.8	1.2	0.3	5.4	5.9	3.6	1.9	0.6
35	SiA-3596	98.00	98.00	94.00	50.67	10.67	4.7	5.5	3.6	0.9	0.5	4.9	5.5	3.6	0.9	0.5
36	SiA-3598	98.00	93.33	84.00	46.67	17.33	5.9	5.5	4.1	1.3	1.1	5.3	5.1	3.0	2.4	1.2
37	SiA-3600	96.00	56.67	30.67	12.67	0.67	5.1	5.0	3.4	2.1	1.5	4.8	4.6	3.6	2.9	1.5
38	SiA-3604	96.00	84.00	90.67	32.67	13.33	5.2	5.1	3.1	1.1	1.6	4.5	4.9	2.5	1.9	1.4
39	SiA-3605	100.00	98.00	94.67	41.33	6.67	5.0	3.5	3.5	2.6	0.4	5.4	4.0	3.6	2.3	2.0
40	SiA-3607	94.00	88.00	78.00	60.00	18.00	4.9	3.2	3.5	2.7	0.5	5.5	5.1	3.8	1.5	1.5
41	Krishnadevaraya (Check)	100.00	86.00	80.00	21.33	2.67	4.3	4.2	4.3	1.6	1.4	4.6	3.5	2.7	2.6	1.6
42	SiA-3608	92.00	88.67	77.33	60.00	25.33	5.3	6.1	4.5	2.7	2.0	5.7	5.6	4.2	3.1	0.7
43	SiA-3610	90.00	86.00	76.00	58.00	24.00	7.3	5.9	6.4	3.7	1.5	5.7	3.8	4.6	2.8	0.5
44	SiA-3611	96.00	82.00	84.67	80.00	33.33	6.6	5.5	4.3	4.4	1.7	4.8	4.7	3.7	2.4	0.9
45	SiA-3613	100.00	88.67	76.00	75.33	24.00	6.4	4.9	2.7	2.8	0.4	4.6	5.0	2.6	3.0	0.8
46	SiA-3615	98.00	88.00	90.00	76.00	33.33	6.1	4.5	3.9	3.1	1.0	6.1	5.2	3.5	1.7	0.7
47	SiA-3618	94.00	93.33	91.33	80.00	18.67	6.2	3.9	3.0	2.5	0.8	5.4	4.8	3.6	1.9	0.8
48	SiA-3619	90.00	90.00	50.67	76.67	18.00	4.8	4.1	3.7	2.2	0.6	5.8	5.1	2.8	2.0	0.9
49	SiA-3622	98.00	84.67	74.67	62.00	12.67	5.6	4.4	3.5	3.2	0.9	5.3	6.0	2.9	1.5	0.7
50	SiA-3623	90.00	80.00	42.67	23.33	6.00	5.8	4.7	2.8	1.9	0.4	4.8	4.0	3.1	2.5	0.4
51	SiA-3085 (Check)	84.00	66.67	66.67	46.67	20.67	5.7	3.5	3.7	2.8	1.1	5.7	4.7	4.0	3.1	0.8
52	SiA-3625	96.00	88.00	76.00	62.00	30.00	5.9	2.8	3.9	2.4	0.8	5.4	4.2	3.5	2.8	0.9
53	SiA-3626	100.00	96.00	82.00	64.00	24.00	6.1	4.1	3.8	2.6	1.8	5.2	5.8	3.9	2.4	0.7
54	SiA-3628	94.00	88.00	78.00	60.00	18.00	5.8	4.0	3.8	2.5	1.4	6.1	4.3	2.7	2.9	0.9
55	SiA-3631	98.00	90.00	78.00	58.00	14.00	5.3	3.3	3.9	3.5	1.2	7.2	5.1	3.0	3.0	0.8
56	SiA-3632	100.00	94.00	82.00	52.00	12.00	4.9	3.9	3.4	3.4	1.5	6.9	5.0	2.8	1.8	0.8
57	SiA-3634	94.00	90.00	76.00	58.00	22.00	5.8	4.0	4.0	3.2	1.0	6.8	3.8	2.9	1.4	0.9
58	SiA-3636	96.00	94.00	82.00	60.00	24.00	6.1	5.0	4.0	3.4	1.2	5.8	5.0	2.8	2.5	0.8
59	SiA-3637	88.00	80.00	72.00	56.00	22.00	4.9	4.0	3.9	2.5	1.1	6.4	3.9	3.0	2.6	0.7
60	SiA-3156 (Check)	98.00	92.00	80.00	58.00	28.00	5.8	4.1	4.1	1.5	1.1	6.2	4.8	2.8	3.1	0.9
	Mean	94.82	87.22	78.51	58.81	19.90	5.6	4.7	3.8	2.6	1.2	5.7	4.8	3.5	2.6	1.2
	SE(m)	1.52	0.90	1.64	1.45	1.12	0.12	0.15	0.15	0.36	0.55	0.13	0.14	0.23	0.34	0.44
	C.D. at 5%	4.31	2.56	4.60	4.87	4.35	0.43	0.42	0.52	0.36	0.61	0.38	0.42	0.67	0.85	0.44

Table 4.10 Stress tolerant performance of top ten high yielding foxtailmillet genotypes

S.No	Genotype	Germination % at different PEG concentrations					Shoot length (cm) at different PEG concentrations					Root length (cm) at different PEG concentrations				
		Control	15%	20%	25%	30%	Control	15%	20%	25%	30%	Control	15%	20%	25%	30%
1	SiA 3636	96	94	82	60	24	6.1	5.0	4.0	3.4	1.2	5.8	5.0	2.8	2.5	0.8
2	Sri Lakshmi	94	96	94	63	21	5.5	5.6	3.9	2.5	1.4	5.1	3.7	2.2	1.5	0.9
3	Narasimharaya	96	82	78	40	32	6.5	5.5	4.2	3.1	1.5	6.1	4.0	2.7	3.1	1.6
4	SiA 3598	98	93	84	46	17	5.9	5.5	4.1	1.3	1.1	5.3	5.1	3.0	2.4	1.2
5	SiA 3604	96	84	90	32	13	5.2	5.1	3.1	1.1	1.6	4.5	4.9	2.5	1.9	1.4
6	SiA 3539	100	92	84	78	38	5.5	4.7	3.2	4.0	1.8	4.7	6.6	4.3	3.2	2.8
7	SiA 3584	100	96	82	62	20	6.0	4.4	3.7	2.8	2.0	6.1	4.9	3.9	3.5	0.9
8	SiA 3628	94	88	78	60	18	5.8	4.0	3.8	2.5	1.4	6.1	4.3	2.7	2.9	0.9
9	SiA 3611	92	82	84	80	33	6.6	5.5	4.3	4.4	1.7	4.8	4.7	3.7	2.4	0.9
10	Prasad	100	94	98	82	40	6.3	6.4	4.6	3.1	2.2	4.7	5.1	2.5	2.8	1.0

Table 4.11 Identification of promising stress tolerant foxtail millet genotypes through PEG technique

Tolerance range	Genotype	Germination % at different PEG concentrations					Shoot length (cm) at different PEG concentrations					Root length (cm) at different PEG concentrations				
		Control	15%	20%	25%	30%	Control	15%	20%	25%	30%	Control	15%	20%	25%	30%
Highly Stress Tolerant Lines	Suryanandi	100	99	88	79	44	7.0	7.0	5.3	3.4	2.0	9.5	3.9	5.1	3.2	1.4
	Prasad	100	94	98	82	40	6.3	6.4	4.6	3.1	2.2	4.7	5.1	2.5	2.8	1.0
	SiA 3551	97	84	82	66	40	5.5	5.1	4.1	3.3	2.0	6.1	4.5	5.0	3.0	1.5
	SiA 3615	98	88	90	76	33	6.1	4.5	3.9	3.1	1.0	6.1	5.2	3.5	1.7	0.7
Highly Stress Sensitive Lines	SiA 3563	90	79	76	49	3	4.4	3.7	3.5	1.8	0.8	3.4	3.1	2.5	2.3	0.9
	SiA 3558	86	62	47	16	2	5.8	4.6	4.9	1.5	0.3	3.8	3.7	3.9	2.6	1.4
	SiA 3600	96	56	30	12	0.6	5.1	5.0	3.4	2.1	1.5	4.8	4.6	3.6	2.9	1.5
	SiA 3623	90	80	42	23	6	5.8	4.7	2.8	1.9	0.4	4.8	4.3	3.1	2.5	0.4

Fig 4.2 Effect of PEG induced drought stress on plumule length (cm) of stress tolerant and sensitive foxtail millet lines

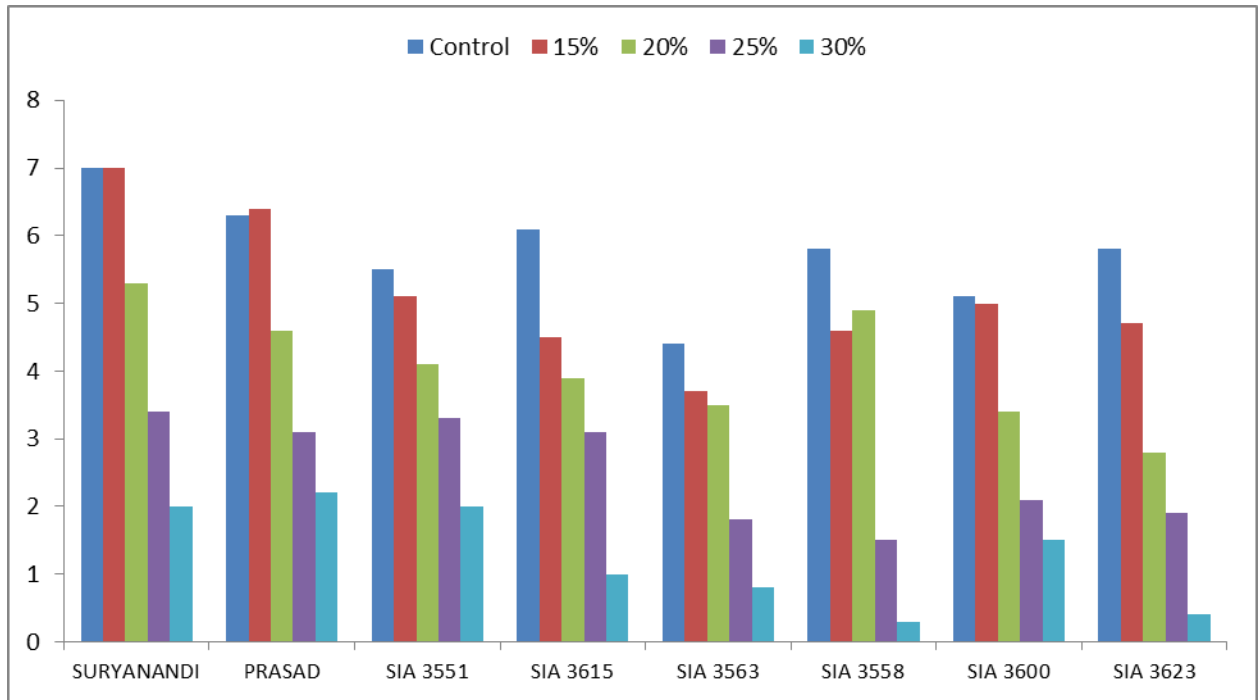


Fig 4.3 Effect of PEG induced drought stress on radicle length (cm) of stress tolerant and sensitive foxtail millet lines

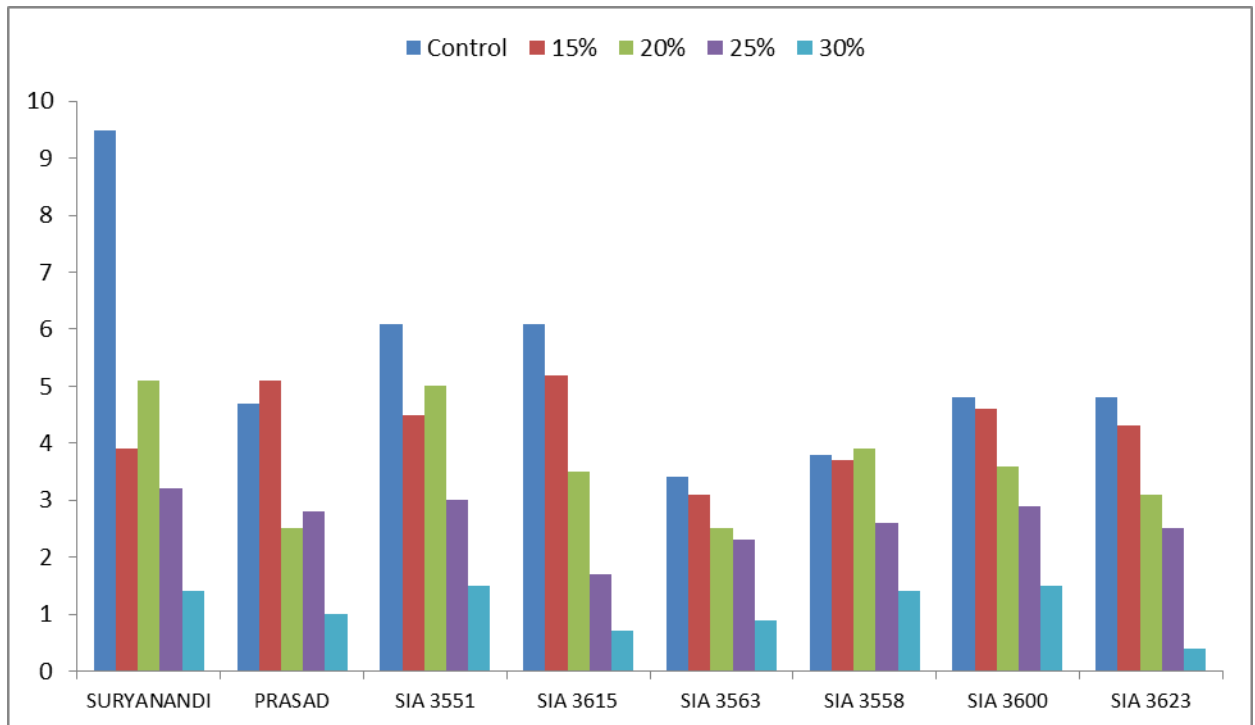
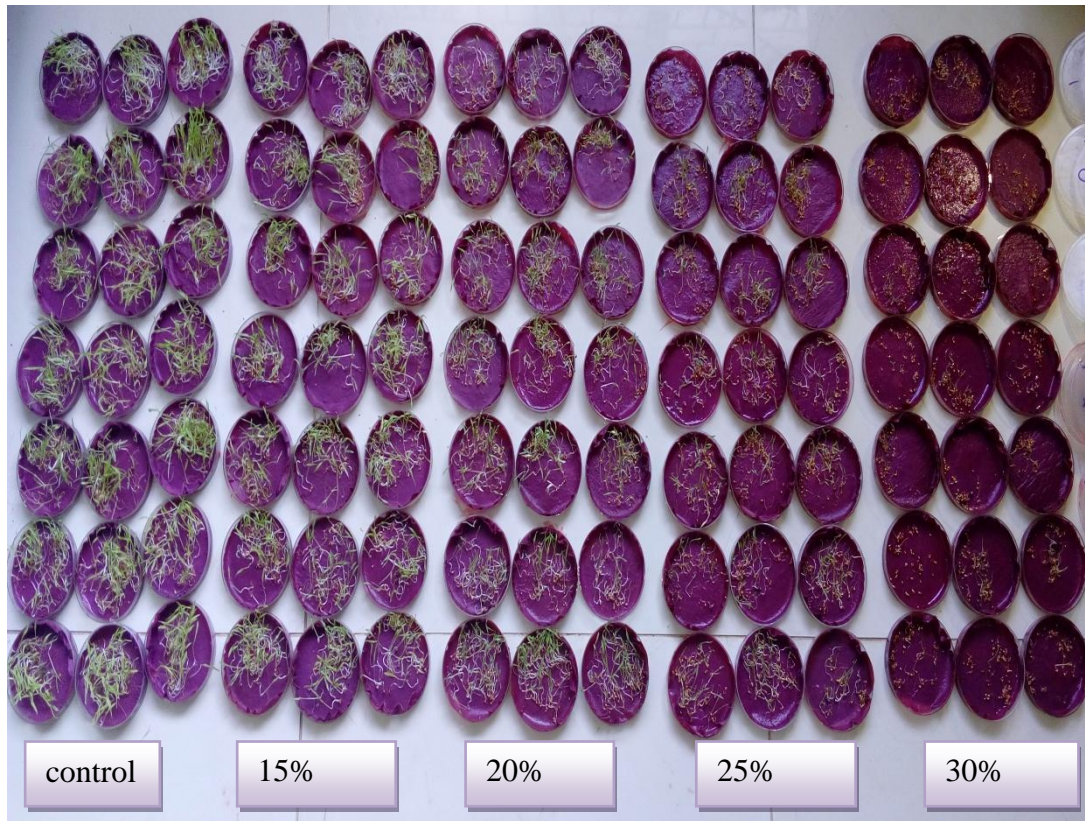


Plate. 5. An experimental view of Polyethylene glycol (PEG) technique in laboratory



The seedling survival, shoot and root growth were completely affected in the genotypes SiA 3563, SiA 3558, SiA 3600 and SiA 3623 due to their lesser tolerance ability to osmotic stress conditions induced by higher concentrations of PEG. In spite of treated with higher concentrations of PEG *viz.*, 15%, 20%, 25% and 30% germination and seedling growth were not affected in the genotypes Suryanandi, Prasad, SiA 3551 and SiA 3615 probably due to acquired higher stress tolerance.

The technique of treating germplasm lines to different concentration of PEG has been validated in many crop species (Osman *et al.*, 2015 in tomato; Khafagy *et al.*, 2014 in rice; Toosi *et al.*, 2014 in *B. juncea*; Naveena *et al.*, 2015 in finger millet). The present study also revealed that the PEG technique can very well be used in foxtail crop for identification of stress tolerant genotypes. The identified genotypes *viz.*, Suryanandi, Prasad, SiA 3551 and SiA 3615 were found to possess high level of water stress tolerance. These genotypes can be used as potent donors for developing a wide spectrum of foxtail millet varieties against severe water stress conditions.

4.3 GENETIC PARAMETERS

The estimates of phenotypic and genotypic coefficients of variation (GCV, PCV), heritability in broad sense, genetic advance and genetic advance as per cent of mean for nineteen characters of 60 genotypes of foxtail millet are furnished in Table 4.12.

4.3.1 Variability

In the present study, the estimates of PCV for all the characters were little higher than the estimates of GCV, which may be due to the interaction of genotypes with the environment.

Table 4.12 Mean, coefficients of variation, heritability (broad sense) and genetic advance as per cent of mean for nineteen characters in 60 foxtail millet genotypes

S. No	Character	Mean	Range		Variance		Coefficient of Variation		Heritability (Broad sense) (%)	Genetic advance (GA)	Genetic Advance as per cent of mean (%)
			Max.	Min.	Genotypic	Phenotypic	Genotypic	Phenotypic			
1	Days to 50% flowering	48.13	54.00	41.00	8.303	9.548	5.978	6.411	87.00	5.535	11.484
2	Days to maturity	88.74	95.75	83.25	7.137	9.358	3.011	3.447	76.30	4.806	5.416
3	Plant height (cm)	97.75	122.50	77.65	77.318	89.945	8.995	9.702	86.00	16.794	17.180
4	Ear bearing tillers per hill	3.12	4.80	21.00	0.247	0.466	15.922	21.852	53.10	0.746	23.898
5	Ear head length (cm)	18.07	23.30	15.00	2.395	3.901	8.563	10.928	61.40	2.498	13.823
6	Number of grains / ear head	1660.75	2371.5	965.00	69843.01	71176.27	15.913	16.064	98.10	539.29	32.473
7	Grain yield/plant (g)	6.34	8.71	3.57	0.936	1.047	15.246	16.123	89.40	1.884	29.698
8	1000 seed wt (g)	3.55	7.41	2.42	0.595	0.705	21.727	23.662	84.30	1.459	41.096
9	Fodder yield (g)	4.63	7.64	2.93	0.863	0.97	20.042	21.255	88.90	1.804	38.913
10	Specific leaf area at 30 DAS	163.04	210.83	106.21	441.461	467.684	12.887	13.264	94.40	42.052	25.792
11	Specific leaf area at 45 DAS	176.27	176.27	144.77	346.456	361.321	10.555	10.779	95.90	37.546	21.292
12	SCMR at 30 DAS	36.77	44.45	29.28	9.933	12.553	8.571	9.636	79.10	5.775	15.706
13	SCMR at 45 DAS	39.04	45.90	32.57	8.939	10.164	7.658	8.166	88.00	5.776	14.795
14	Canopy leaf temperature at 30 DAS	35.07	37.88	32.25	1.217	2.772	3.146	4.748	43.90	1.505	4.293
15	Canopy leaf temperature at 45 DAS	34.92	43.90	25.78	18.709	19.822	12.388	12.751	94.40	8.657	24.792
16	Relative membrane injury at 30 DAS	58.43	91.97	33.64	137.667	138.612	20.081	20.15	99.30	24.088	41.226
17	Relative membrane injury at 45 DAS	70.88	96.09	46.79	108.936	110.089	14.725	14.802	99.00	21.388	30.174
18	Relative water content at 30 DAS	89.6	95.51	73.92	11.87	12.393	3.845	3.929	95.80	6.946	7.752
19	Relative water content at 45 DAS	91.82	97.76	77.54	16.388	18.152	4.409	4.64	90.30	7.924	8.630

The highest estimate of coefficient of variation was registered for 1000 seed weight (GCV = 21.727%; PCV = 23.622%) followed by membrane injury at 30 DAS (GCV = 20.081%; PCV = 20.150%), fodder yield (GCV = 20.042%; PCV = 21.255 %), ear bearing tillers per hill (GCV = 15.922%; PCV = 21.852%), number of grains per ear head (GCV = 15.913%; PCV = 16.064%), grain yield per plant (GCV = 15.246%; PCV = 16.123%), membrane injury at 45 DAS (GCV = 14.725 %; PCV = 14.802%), specific leaf area at 30 DAS (GCV = 12.887%; PCV = 13.264 %), leaf temperature at 45 DAS (GCV = 12.388 %; PCV = 12.751 %), specific leaf area at 45 DAS (GCV = 10.555%; PCV = 10.779 %), indicating scope of selection for improvement of these characters.

Moderate estimates of coefficients of variation were observed for plant height (GCV = 8.995%; PCV = 9.702%) followed by SCMR at 30 DAS (GCV = 8.571%; PCV = 9.636%), ear head length (GCV = 8.563%; PCV = 10.928%) and SCMR at 45 DAS (GCV = 7.658%; PCV = 8.166%), while low estimates of coefficients of variation were recorded for Days to 50% flowering (GCV = 5.978%; PCV = 6.411 %) followed by relative water content at 45 DAS (GCV = 4.409%; PCV = 4.640%), relative water content at 30 DAS (GCV = 3.845%; PCV = 3.929%), leaf temperature at 30 DAS (GCV = 3.146%; PCV = 4.748 %) and days to maturity (GCV = 3.011%; PCV = 3.447 %) indicating less scope of selection for improvement of these traits.

High estimates of variability were reported by earlier workers for plant height (Bedis *et al.*, 2006; Vetriventhan and Nirmalakumari, 2007; Lakshmana *et al.*, 2009; Govindaraj *et al.*, 2010; Musa and Atif, 2013; Bendi and Sarma *et al.*, 2016), for ear bearing tillers per hill (Meena *et al.*, 2008; Ganapathy *et al.*, 2011; Lakshmana *et al.*, 2009; Priyadharshini *et al.*, 2011), for ear head length (Shanmuganathan *et al.*, 2006; Vetriventhan and Nirmalakumari, 2007; Lakshmana

et al., 2009; Musa and Atif, 2013), for number of grains per ear head (Musa and Atif, 2013), for grain yield per plant (Bedis *et al.*, 2006; Shanmuganathan *et al.*, 2006; Vidyadhar *et al.*, 2007; Meena *et al.*, 2008; Lakshmana *et al.*, 2009; Govindaraj *et al.*, 2010; Nirmalakumari and Vetriventhan, 2010), and for fodder yield (Vidyadhar *et al.*, 2007; Veena *et al.*, 2010) and corroborates the findings of the present study.

Moderate PCV and GCV values were observed for the traits, plant height, SCMR, ear head length and days to 50% flowering in the present study. These findings are in concurrence with the earlier reports of Ganapathy *et al.* (2011) for days to maturity. On contrary, low PCV and GCV values were recorded for the traits, relative water content, leaf temperature, days to maturity. Similar kind of low estimates of variability was reported earlier by Sumathi *et al.* (2010) and Nirmalakumari and Vetriventhan (2010) for days to 50% flowering and Ganapathy *et al.* (2011) for days to maturity.

4.3.2 Heritability

In general high heritability estimates in broad sense were registered for almost all the characters under the study except for leaf temperature at 30 DAS (0.439%) and ear bearing tillers per hill (0.531%).

High estimate of heritability was recorded for relative injury at 30 DAS (99.3%), membrane injury at 45 DAS (99.0%), number of grains per ear head (98.1%), specific leaf area at 45 DAS (95.90%), relative water content at 30 DAS (95.80%), specific leaf area at 30 DAS (94.40%), leaf temperature at 45 DAS (94.40%), relative water content at 45 DAS (90.3%), grain yield per plant (89.4%), fodder yield (88.9%), SCMR at 45 DAS (88.0%), days to 50% flowering (87.0%) and plant height (86.0%) in the decreasing order of their magnitude indicating the more contribution of genotypic variance to total variance observed

in these traits. Hence selection may be effective for further improvement of these traits.

Moderate heritability was registered for test weight (84.3%), SCMR at 30 DAS (79.1%), days to maturity (76.3%) and ear head length (61.4%). On contrary, low heritability was recorded for ear bearing tillers per hill (53.1%) and leaf temperature at 30 DAS (43.9%) indicating the contribution of both genotypic variance and environmental variance to the total variation of these traits and the selection may be less rewarding for improvement of these traits due to dissipating effects of environment on these traits.

4.3.3 Genetic Advance

The estimate of genetic advance was recorded to be highest for number of grains per ear head (539.29) followed by specific leaf area at 30 DAS (42.05), specific leaf area at 45 DAS (37.54), relative membrane injury at 30 DAS (24.08), membrane injury at 45 DAS (21.38) and plant height (16.79) whereas it was moderate for leaf temperature at 45 DAS (8.65), relative water content at 45 DAS (7.92), relative water content at 30 DAS (6.94) and SCMR at 45 DAS (5.77) indicating of additive genes in their genetic control. The remaining traits *viz.*, SCMR at 30 DAS (5.77), days to 50 % flowering (5.53), days to maturity (4.80), ear head length (2.49), grain yield per plant (1.88), fodder yield (1.80), leaf temperature at 30 DAS (1.50), test weight (1.45) and ear bearing tillers per hill (0.74) registered low genetic advance in their decreasing order and indicated that most of the traits were controlled by polygenes of non-additive nature.

4.3.4 Genetic advance as per cent of mean

The maximum genetic advance as per cent of mean was registered for membrane injury at 30 DAS (41.22) followed by test weight (41.09), fodder yield

(38.93), grains per ear head (32.47), membrane injury at 45 DAS (30.14), grain yield per plant (29.69), specific leaf area at 30 DAS (25.79), leaf temperature at 45 DAS (24.79), ear bearing tillers per hill (23.89) and specific leaf area at 45 DAS (21.29) in the decreasing order.

On contrary, moderate values of genetic advance as per cent of mean were observed for plant height (17.18), SCMR at 30 DAS (15.70), SCMR at 45 DAS (14.79) ear head length (13.82), and days to 50 % flowering (11.48) while, low estimates of genetic advance as per cent of mean were recorded for relative water content at 45 DAS (8.63), relative water content at 30 DAS (7.75), days to maturity (5.41) and leaf temperature (4.29).

In the present investigation, high heritability coupled with high genetic advance as per cent of mean were recorded for no of grains/ear head, days to 50 % flowering, grain yield per plant, ear head length, plant height, and ear bearing tillers per plant indicating the involvement of additive genes in controlling these traits. Hence, simple selection can be practiced to improve these traits. This was in conformity with the findings of Musa *et al.* (2013) for days to 50% flowering, Veena *et al.* (2010), Ganapathy *et al.* (2011), Priyadharshini *et al.* (2011) for plant height. Similarly Ganapathy *et al.* (2011), Govindaraj *et al.* (2011) and Priyadharshini *et al.* (2011) revealed high heritability and high genetic advance for ear bearing tillers per hill, Sumathi *et al.* (2010) for ear head length. Further, Meena *et al.* (2008), Govindaraj *et al.* (2010), Sumathi *et al.* (2010), Ganapathy *et al.* (2011) and Priyadharshini *et al.* (2011) reported high heritability for grain yield per plant.

The high heritability indicated that the influence of environment on expression of the traits is relatively low. Therefore, for improving these traits the selection will be more effective in early generation on the basis of *per se* performance of these traits. These traits may be improved by mass or progeny

selection. High heritability for grain yield per plant suggested that straight selection based on grain yield would be effective for its improvement.

High heritability with moderate genetic advance as per cent of mean was recorded for specific leaf area, relative membrane injury, SPAD chlorophyll meter reading and specific leaf area and fodder yield. These are more likely to be controlled by both additive and non-additive gene effects. Recurrent selection would be more effective to improve these traits.

To sum up, higher GCV, heritability and genetic advance as per cent of mean were observed for ear bearing tillers per hill, grain yield per plant, relative membrane injury, number of grains per ear head, specific leaf area and ear head length which revealed that simple directional selection would be effective for improving these traits with connotation that genetic variation was mainly due to the presence of additive gene effects. Conversely, low GCV, heritability and genetic advance as per cent of mean were registered for test weight, SCMR, relative water content and leaf temperature indicating that these traits are more likely to be governed by the non-additive gene action.

4.4 GENETIC DIVERGENCE

The data collected on the 19 characters were used for quantitative assessment of genetic divergence by adopting Mahalanobis's D^2 statistics.

4.4.1 Test of significance

Wilks 'Λ' (statistic) criterion was used to test the significant differences between the genotypes based on the pooled effects of all the characters. The significance of 'Λ' (statistic) value was tested by χ^2 at 1121 degrees of freedom and value of 'Λ' (statistic) is 3719.03. The significance of sixty genotypes in the analysis of variance of dispersion clearly indicated the significant pooled effect of all the characters studied among different genotypes (Table 4.13). Hence, further analysis was made to estimate the D^2 values.

Table 4.13. Analysis of variance for dispersion of 60 genotypes of foxtail millet

Source of variation	Degrees of freedom	Mean sum of Square
Genotypes	59	3.21E+29**
Error	58	4.65E+08
Total	117	3.21E+29

** Significant at 1% level

4.4.2 Estimation of D^2 values

The mean values of 60 genotypes were transformed into standardized uncorrelated mean values using pivotal condensation method (Y_1-Y_2). The D^2 values were computed for all the possible $[60(60-1)/2]$ 1770 pairs of genotypes.

4.4.3 Grouping of genotypes into clusters

All the genotypes were grouped into 13 clusters using Tocher's method (Rao, 1952) and the distribution of genotypes into each of 13 clusters is presented in Table 4.14.

Cluster I had a large number of thirty six genotypes. Cluster II and IV had five and eight genotypes respectively. Three genotypes were included in cluster IX while Clusters, III, V, VI, VII, VIII, X, XI, XII and XIII had only one genotype in each cluster.

4.4.4 Intra and inter-cluster average distance

The intra and inter-cluster D^2 and D values among 13 clusters are given in Table 4.15 and Fig 4.4.

Intra-cluster average D^2 values ranged from 0.00 to 611.52. Among the clusters, cluster IX had the maximum intra cluster distance (611.52) followed by cluster IV (548.74), cluster II (407.81), cluster I (358.62), while the clusters- III, V, VI, VII, VIII, X, XI, XII and XIII recorded zero values as they included only single genotype in each of them.

The maximum inter-cluster D^2 value was recorded between cluster XII and XIII (2392.47) followed by between cluster VIII and XIII (2286.11) and cluster II and XIII (2216.66), while the minimum D^2 value was found between cluster VI and VII (204.20) followed by between cluster III and IV (290.26) and cluster VI and VIII (297.55).

4.4.5 Cluster means for yield and yield attributes

The cluster means for each of 9 characters are presented in Table 4.16. Considerable differences between clusters means were observed for most of the characters studied. Early flowering was observed in the genotypes of cluster X

(43.50 days), while delayed flowering in the genotypes of cluster VII (52.50 days). Days to maturity ranged from 91.50 days in cluster VII to 84.00 days in cluster X.

The genotypes of cluster XI were taller in height (122.50 cm), while that of cluster IV were shorter in height (94.82 cm). Similarly, ear bearing tillers per hill were ranged from 2.10 in cluster III to 4.60 in cluster VII, whereas ear head length was highest in cluster XI (23.30 cm) and shortest in cluster VII (17.00). The test weight ranged from 2.60 g in cluster III to 7.40 g in cluster VI. The number of grains per ear head were highest in cluster X (2371.50) and was lowest in cluster V (965.00).

The genotypes of cluster VII recorded high grain yield per plant (8.71 g) while genotypes of cluster IX recorded low grain yield per plant (5.63 g). The genotype in cluster VII recorded high fodder yield per plant (6.64 g) while genotype in cluster X recorded low fodder yield per plant (4.03 g).

4.4.6 Cluster means for physiological traits

The cluster means for each of ten characters are presented in Table 4.17. The cluster mean for leaf temperature at 30 DAS was maximum in cluster XI (37.25) and was minimum in cluster III (33.00) and at 45 DAS was maximum in cluster X (41.60) and was minimum in cluster XIII (25.78). Specific leaf area at 30 DAS ranged from 199.67 cm²g⁻¹ in cluster XI to 113.83 cm²g⁻¹ in cluster XII and at 45 DAS was maximum in cluster XI (258.33cm²g⁻¹) and minimum in cluster XII (144.78cm²g⁻¹). The SCMR at 30 DAS was maximum in cluster XI (42.45) and was minimum in cluster VII (32.00) and at 45 DAS ranged from cluster XI (41.81) to cluster II (36.73).

The genotype in cluster XIII recorded high relative injury at 30 DAS (91.97%) while genotypes in cluster VIII recorded low relative injury (40.40%) and at 45 DAS maximum in cluster II (83.91%) and minimum in cluster IX (52.34%). The genotypes of cluster IX recorded high relative water content at 30 DAS (91.74) while

genotype of cluster XII recorded low relative water content (73.93) and at 45 DAS high at cluster XII (96.02) and low at cluster XIII (84.06).

4.4.7 Relative contribution of each character towards diversity

The number of times that each of the nineteen characters appeared in first rank and its respective per cent contribution towards diversity is presented in Table 4.18 and Fig 4.5.

Among all the characters studied, relative injury at 30 DAS contributed the maximum (38.59%) to the diversity by taking first rank in 683 times out of 1770 combinations, followed by membrane injury at 45 DAS (28.42% with 503 times ranked first), grains\ear head (11.13% with 197 times ranked first), relative water content at 30 DAS (6.33% with 112 times ranked first), specific leaf area at 45 DAS (3.95% with 70 times ranked first), leaf temperature at 45 DAS (3.56% with 63 times ranked first), relative water content at 45 DAS (2.88% with 51 times ranked first) and SLA at 30 DAS (2.77% with 49 times ranked first).

The characters viz., days to 50% flowering, grain yield, test weight, fodder yield, SCMR at 30 and 45 DAS, contributed 0.11, 0.23, 0.23, 1.19, 0.06 and 0.56 per cent, respectively, to the genetic divergence.

The characters, viz., days to maturity, plant height, ear bearing tillers/hill, ear head length and leaf temperature at 30 DAS had little contribution towards genetic divergence.

Mahalanobis's D^2 statistics is a powerful tool for quantifying the degree of genetic divergence and grouping the genotypes into different clusters. Genetic divergence studies are the tools for the evaluation of germplasm lines and selection of parents for breeding programme. The results obtained from D^2 analysis were discussed hereunder.

Table 4.16 Cluster means with respect to yield and yield component characters in Foxtail millet

Character / Cluster	Days to 50% flowering	Days to maturity	Plant height (cm)	Ear bearing tillers/ hill	Ear head length (cm)	No of grains/ ear head	Grain yield/ plant (g)	1000 seed weight (g)	Fodder yield/plant (g)
1 Cluster	48.40	89.19	96.08	3.09	17.83	1630.11	6.41	3.56	4.60
2 Cluster	50.30	90.05	97.18	3.13	17.68	1561.70	6.20	3.62	4.18
3 Cluster	44.50	89.00	107.10	2.10	19.50	1767.00	6.19	2.60	4.73
4 Cluster	47.38	87.72	94.82	3.03	17.89	1684.13	5.96	3.34	4.67
5 Cluster	49.00	90.75	97.70	4.00	17.40	965.00	6.87	3.09	6.05
6 Cluster	49.00	85.50	96.95	3.20	19.10	1999.00	8.24	7.40	4.60
7 Cluster	52.50	91.50	115.20	4.60	20.90	2006.00	8.71	3.93	6.64
8 Cluster	45.00	89.00	107.80	3.30	18.00	1822.00	6.47	3.25	4.21
9 Cluster	46.50	86.67	96.53	3.10	18.77	1471.83	5.63	3.77	4.06
10 Cluster	43.50	84.00	103.40	3.70	17.30	2371.50	4.22	2.91	4.03
11 Cluster	52.00	89.00	122.50	4.25	23.30	1997.00	8.19	3.08	5.50
12 Cluster	44.50	86.00	109.60	2.40	17.00	1961.50	6.01	3.10	5.38
13 Cluster	48.00	86.25	108.00	2.50	20.30	2005.00	6.02	2.96	5.39

Table 4.17 Cluster means with respect to physiological characters in Foxtail millet

Character / Cluster	Specific leaf area at 30 DAS	Specific leaf area at 45 DAS	SCMR at 30 DAS	SCMR at 45 DAS	Leaf temperature at 30 DAS	Leaf temperature at 45 DAS	Relative membrane injury at 30 DAS	Relative membrane injury at 45 DAS	Relative water content at 30DAS	Relative water content at 45DAS
1 Cluster	163.83	174.24	37.16	39.65	34.94	35.41	56.04	71.81	89.90	91.76
2 Cluster	170.30	188.57	34.72	36.73	35.27	33.36	44.77	83.91	89.53	94.25
3 Cluster	164.48	167.90	37.85	36.84	33.00	34.74	75.54	73.01	91.00	90.99
4 Cluster	161.39	172.28	36.44	38.29	35.25	35.77	73.90	74.36	88.64	91.49
5 Cluster	193.91	190.91	35.26	36.89	37.00	34.80	57.20	55.68	91.08	92.79
6 Cluster	142.47	172.01	36.13	38.17	35.85	33.07	52.21	61.00	90.95	92.59
7 Cluster	168.82	158.17	32.00	39.24	34.00	35.55	51.94	60.05	90.78	91.40
8 Cluster	135.23	158.21	40.52	41.32	33.75	32.42	40.40	65.52	89.88	94.59
9 Cluster	152.31	167.89	35.43	37.25	36.49	30.01	54.11	52.34	91.74	92.42
10 Cluster	184.28	190.26	38.13	40.92	33.25	41.60	78.99	57.54	87.86	88.49
11 Cluster	199.67	258.33	42.45	41.81	37.25	38.05	71.77	63.70	91.07	86.14
12 Cluster	113.83	144.78	37.59	39.00	34.25	36.69	46.79	56.73	73.93	96.02
13 Cluster	145.68	216.72	34.38	38.89	35.00	25.78	91.97	75.08	91.10	84.06

Table 4.15 Intra cluster (diagonal) and inter-cluster distances of thirteen clusters in foxtail millet

	1	2	3	4	5	6	7	8	9	10	11	12	13
	Cluster	Cluster	Cluster	Cluster	Cluster	Cluster	Cluster	Cluster	Cluster	Cluster	Cluster	Cluster	Cluster
1 Cluster	358.62 (18.937)	572.11 (23.919)	486.62 (22.059)	630.89 (25.118)	596.84 (24.430)	498.66 (22.331)	566.48 (23.801)	503.01 (22.428)	787.31 (28.059)	1117.41 (33.428)	1110.52 (33.324)	797.15 (28.234)	1421.91 (37.708)
2 Cluster		407.81 (20.194)	1061.77 (32.585)	1102.25 (33.200)	1048.07 (32.374)	941.39 (30.682)	996.40 (31.566)	631.76 (25.135)	1400.52 (37.424)	2028.79 (45.042)	1646.71 (40.580)	1048.71 (32.384)	2216.66 (47.081)
3 Cluster			0.00 (0.00)	290.26 (17.037)	690.07 (26.269)	747.43 (27.339)	748.73 (27.363)	1032.38 (32.131)	888.24 (29.803)	379.89 (19.491)	645.38 (25.404)	1228.17 (35.045)	476.93 (21.839)
4 Cluster				548.74 (23.425)	834.58 (28.889)	921.77 (30.361)	1009.31 (31.770)	1192.92 (34.539)	1115.08 (33.393)	775.59 (27.849)	956.11 (30.921)	1286.90 (35.873)	821.50 (28.662)
5 Cluster					0.00 (0.00)	745.82 (27.310)	901.05 (30.017)	958.78 (30.964)	501.62 (22.397)	1349.33 (36.733)	1254.20 (35.415)	1222.55 (34.965)	1694.83 (41.168)
6 Cluster						0.00 (0.00)	204.20 (14.290)	297.55 (17.250)	536.94 (23.172)	1051.70 (32.430)	1167.62 (34.170)	534.40 (23.117)	1597.38 (39.967)
7 Cluster							0.00 (0.00)	338.21 (18.390)	747.12 (27.333)	975.61 (31.235)	1011.04 (31.797)	684.02 (26.154)	1552.58 (39.403)
8 Cluster								0.00 (0.00)	717.11 (26.779)	1632.26 (40.401)	1751.16 (41.847)	398.97 (19.974)	2286.11 (47.813)
9 Cluster									611.52 (24.729)	1305.03 (36.125)	1671.10 (40.879)	1020.00 (31.937)	1891.49 (43.491)
10 Cluster										0.00 (0.00)	523.20 (22.874)	1600.65 (40.008)	531.57 (23.056)
11 Cluster											0.00 (0.00)	1977.75 (44.472)	580.55 (24.095)
12 Cluster												0.00 (0.00)	2392.47 (48.913)
13 Cluster													0.00 (0.00)

Table 4.18 Contribution of different grain yield and physiological characters to diversity in foxtail millet

S.No	Character	Times ranked first	Contribution (%)
1	Days to 50% flowering	2	0.11
2	Days to maturity	0	0.00
3	Plant height (cm)	0	0.00
4	Ear bearing tillers per hill	0	0.00
5	Ear head length (cm)	0	0.00
6	Number of grains / ear head	197	11.13
7	Grain yield/plant (g)	4	0.23
8	1000 seed weight (g)	4	0.23
9	Fodder yield (g)	21	1.19
10	Specific leaf area at 30 DAS	49	2.77
11	Specific leaf area at 45 DAS	70	3.95
12	SCMR at 30 DAS	1	0.06
13	SCMR at 45 DAS	10	0.56
14	Canopy leaf temperature at 30 DAS	0	0.00
15	Canopy leaf temperature at 45 DAS	63	3.56
16	Relative membrane injury at 30 DAS	683	38.59
17	Relative membrane injury at 45 DAS	503	28.42
18	Relative water content at 30 DAS	112	6.33
19	Relative water content at 45 DAS	51	2.88

Table 4.14 Cluster composition of 60 foxtail millet genotypes based on Tocher's method

Cluster number	No.of genotypes	Genotypes
I	35	SiA-3581, 3619, 3585, 3583, 3574, 3634, 3628, 3589, 3600, 3595, 3555, 3626, 3637, 3631, 3611, 3558, 3623, 3550, 3563, 3580, 3562, 3543, 3632, 3542, 3584, 3604, 3572, 3570, 3539, 3598, 3615, Krishnadevaraya (Check), Prasad (Check), SiA 3085 (Check)
II	5	SiA 3607, 3608, 3610, 3622, 3625
III	1	SiA 3554
IV	8	SiA 3586, 3605, 3560, 3575, 3578, 3591, 3545, 3156(Check)
V	1	SiA 3559
VI	1	Sri Lakshmi(Check)
VII	1	SiA 3636
VIII	1	SiA 3551
IX	3	Suryanandi(Check), SiA 3613, SiA 3618
X	1	SiA 3569
XI	1	Narasimharaya(Check)
XII	1	SiA 3545
XIII	1	SiA 3596

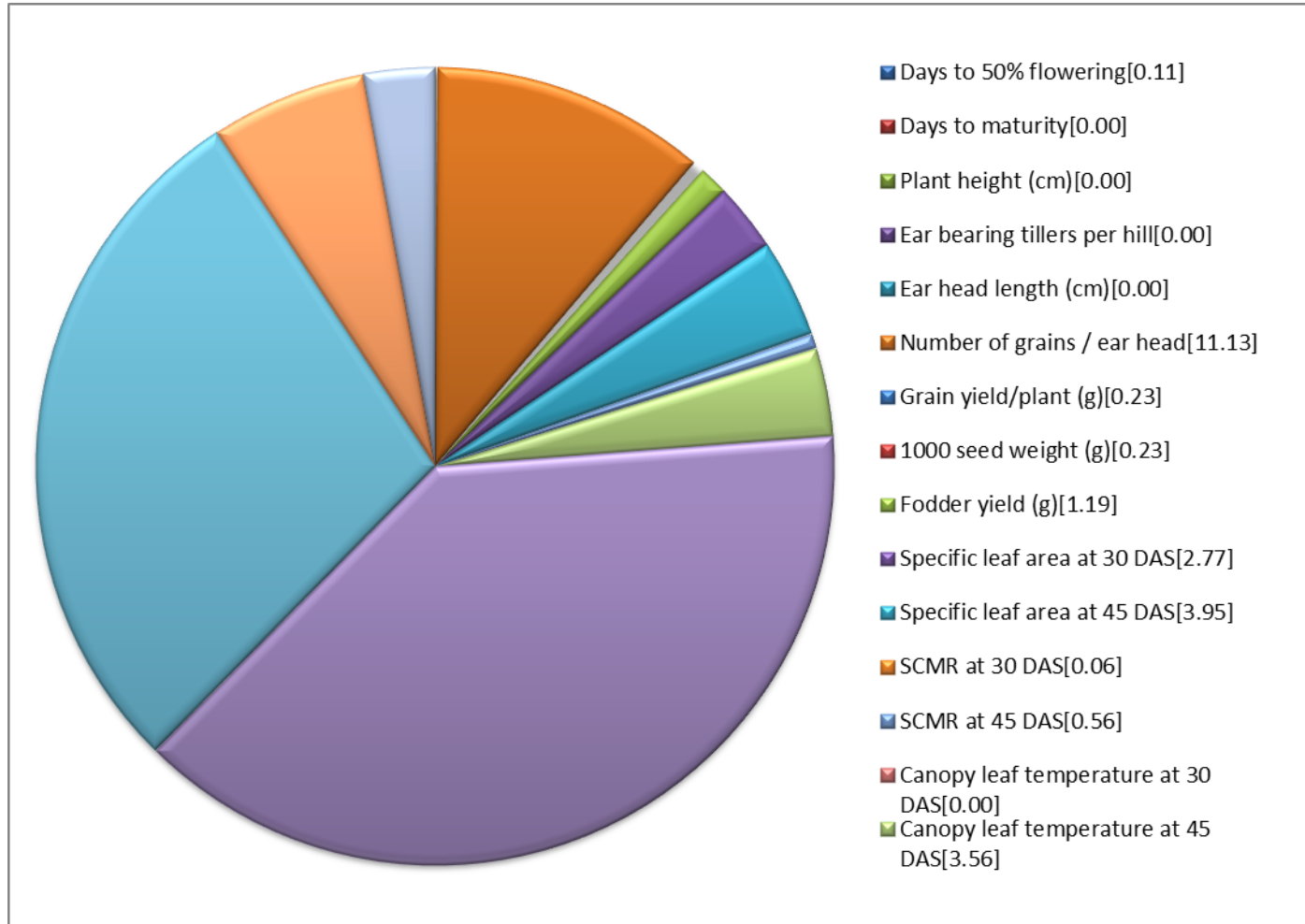


Fig 4.5 Relative contribution of different grain yield and physiological characters to diversity in foxtail millet

Tocher's method

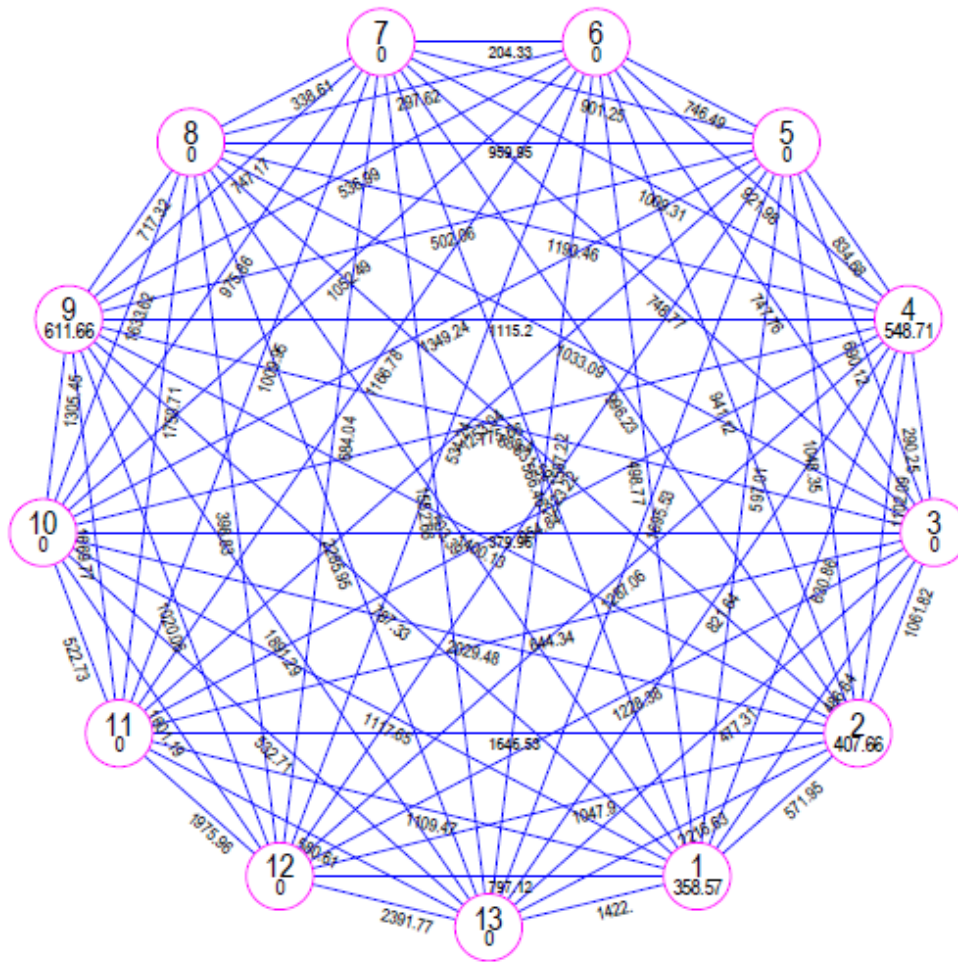


Fig. 4.4. Intra-cluster (D) and inter-cluster distance (D²) among thirteen clusters of foxtail millet

4.5 CANONICAL ROOT ANALYSIS

The canonical root analysis was carried out for sixty genotypes of foxtail millet as per the method suggested by Rao (1952). The values of eight canonical roots and the percentage of variation expressed by them were presented in the Table 4.19. The first canonical root accounted for 21.36, per cent of total variability, followed by 15.62, 10.77, 8.72, 7.97, 6.56, 5.87, 4.84 per cent of total variability respectively. The eight canonical roots accounted for 81.76 per cent of total variability. The mean values of canonical variates for three roots X, Y, Z were furnished in Table 4.20. The amount of contribution of canonical vectors for all the characters towards diversity was presented in Table 4.21.

Grains per ear head contributed maximum to the genetic diversity in the vector Z_1 (0.412) followed by fodder yield (0.384), plant height (0.295), SCMR at 45 DAS (0.295), SCMR at 30 days (0.285), specific leaf area at 45 DAS (0.280), grain yield / plant (0.277), SLA at 30 DAS (0.255), ear bearing tillers per hill (0.188), days to 50% flowering (0.183) and days to maturity (0.143), membrane injury at 30 DAS (0.098), membrane injury at 45 DAS (0.008). On contrary, leaf temperature at 30 DAS (-0.002), RWC at 30 DAS (-0.016), RWC at 45 DAS (-0.018), ear head length (-0.128), leaf temperature at 45 DAS (-0.182) and test weight (-0.232) contributed negatively to the differentiation of genotypes at primary axis level.

Days to maturity contributed maximum to the genetic diversity in Z_2 vector (0.436), followed by days to 50% flowering (0.389), RWC at 45 DAS (0.330), membrane injury at 45 DAS (0.297), leaf temperature at 45 DAS (0.083), grain yield (0.062), SLA at 45 DAS (0.034) and test weight (0.006).

Table 4.19 Canonical root values, percent of variation explained and cumulative variation explained for 60 genotypes in foxtail millet

Canonical root	Values of canonical root	Percent of variation accounts for	Cumulative total variation accounted for
Z ₁	4.05	21.36	21.36
Z ₂	2.96	15.62	36.99
Z ₃	2.04	10.77	47.77
Z ₄	1.65	8.72	56.49
Z ₅	1.51	7.97	64.47
Z ₆	1.24	6.56	71.04
Z ₇	1.11	5.87	76.91
Z ₈	0.92	4.84	81.76

All the remaining characters contributed negatively to the diversity at secondary level of differentiation.

SLA at 45 DAS contributed maximum (0.347) to the genetic diversity in Z₃ vector, followed by RWC at 30 DAS (0.255), days to 50% flowering (0.223), plant height (0.222), SLA at 30 DAS (0.217), days to maturity (0.190) and membrane injury at 30 DAS (0.181), leaf temperature at 45 DAS (0.141), ear bearing tillers per hill (0.107), leaf temperature at 30 DAS (0.057) and fodder yield (0.020). The remaining characters contributed negatively to the diversity at tertiary axis of differentiation.

In Z₄ vector, the maximum contribution to the diversity was made by RWC at 30 DAS (0.419), followed by test weight (0.376), grain yield per plant (0.324), days to 50% flowering (0.212), SCMR at 45 DAS (0.165), fodder yield (0.152), days to maturity (0.123), leaf temperature at 30 DAS (0.122) and plant height (0.082).

Table 4.21 Canonical vectors for nineteen characters in 60 genotypes of foxtail millet

S. No	Characters	Z ₁	Z ₂	Z ₃	Z ₄	Z ₅	Z ₆	Z ₇	Z ₈
1	Days to 50 % flowering	0.18381	0.38934	0.22358	0.21243	0.15250	0.14676	0.08988	0.14954
2	Days to maturity	0.14358	0.43637	0.19085	0.12371	0.00518	0.16562	-0.12547	-0.15011
3	Plant height	0.29571	-0.09237	0.22246	0.08213	-0.32391	-0.28843	0.19908	0.16560
4	Ear bearing tillers per hill	0.18807	-0.13710	0.10765	0.00816	-0.28617	-0.43814	0.34483	-0.30513
5	Ear head length	-0.12890	-0.46493	-0.16775	-0.08160	0.10460	-0.09747	-0.22011	-0.07217
6	Grains per ear head	0.41249	-0.12060	-0.19362	-0.02744	-0.04008	0.12157	-0.08009	0.10454
7	Grain yield	0.27756	0.06274	-0.06786	0.32491	0.30814	-0.15692	-0.20783	-0.06119
8	Test weight	-0.23261	0.00609	-0.00411	0.37664	0.40563	-0.28011	-0.06948	-0.18326
9	Fodder yield	0.38476	-0.11540	0.02072	0.15273	0.00470	-0.11289	-0.01461	0.36888
10	Specific leaf area at 30 DAS	0.25588	-0.02553	0.21728	-0.30858	0.24044	0.01389	-0.11989	-0.49034
11	Specific leaf area at 45 DAS	0.28021	0.03445	0.34761	-0.26915	0.15103	-0.14028	-0.11149	-0.12221
12	SCMR at 30 DAS	0.28553	-0.08461	-0.40207	-0.08530	0.07585	0.21769	0.07221	-0.34264
13	SCMR at 45 DAS	0.29568	-0.00071	-0.40132	0.16520	0.11787	0.19437	0.30872	-0.07438
14	Canopy leaf temperature at 30 DAS	-0.00222	-0.22218	0.05754	0.12266	0.52679	-0.16877	0.36018	0.22565
15	Canopy leaf temperature at 45 DAS	-0.18292	0.08368	0.14109	-0.13909	0.13830	0.20608	0.66241	-0.14922
16	Relative membrane injury at 30 DAS	0.09869	-0.27046	0.18146	-0.29520	0.17418	0.36683	0.03040	0.33277
17	Relative membrane injury at 45 DAS	0.00807	0.29783	-0.11740	-0.39148	0.22351	-0.18650	-0.06753	0.26094
18	Relative water content at 30 DAS	-0.01656	-0.21525	0.25561	0.41922	-0.14550	0.42476	-0.05741	-0.09746
19	Relative water content at 45 DAS	-0.01847	0.33034	-0.39473	-0.04266	-0.13960	-0.10009	0.09954	0.07234

Table 4.20 Mean values of canonical vectors for 60 genotypes of foxtail millet

S. No	Genotype	X Vector	Y Vector	Z Vector
1	Suryanandi (Check)	84.860	27.452	26.140
2	SiA-3539	109.530	34.059	27.370
3	SiA-3542	98.475	34.002	24.157
4	SiA-3543	99.723	34.057	29.649
5	SiA-3545	96.371	24.335	29.807
6	SiA-3546	103.003	32.988	8.042
7	SiA-3550	109.527	30.835	16.687
8	SiA-3551	102.749	33.951	13.062
9	SiA-3554	104.239	23.880	25.548
10	SiA-3555	103.454	28.151	25.359
11	Narasimharaya (Check)	121.781	22.917	33.707
12	SiA-3558	106.103	30.125	16.344
13	SiA-3559	94.177	29.503	34.074
14	SiA-3560	98.621	36.798	22.149
15	SiA-3562	97.013	37.493	17.281
16	SiA-3563	104.798	32.777	17.011
17	SiA-3569	114.174	15.347	26.120
18	SiA-3570	100.937	39.679	13.590
19	SiA-3572	91.557	35.478	22.145
20	SiA-3574	98.301	29.784	27.407
21	Prasad (Check)	105.259	24.282	20.469
22	SiA-3575	98.823	26.707	26.749
23	SiA-3578	110.968	25.629	29.556
24	SiA-3580	101.306	27.385	27.408
25	SiA-3581	96.884	28.704	23.846
26	SiA-3582	93.067	31.779	26.705
27	SAI-3583	95.845	31.949	22.227
28	SiA-3584	91.389	34.353	19.941
29	SiA-3585	98.201	32.139	19.222
30	SiA-3586	103.668	30.802	20.600

Contd...

Table 4.20 contd...

S.No	Genotype	X Vector	Y Vector	Z Vector
31	Sri Lakshmi (Check)	104.879	26.554	17.545
32	SiA-3589	106.535	32.788	19.373
33	SiA-3591	101.141	17.531	28.025
34	SiA-3595	102.237	27.636	24.788
35	SiA-3596	113.341	17.053	30.738
36	SiA-3598	112.052	32.419	19.568
37	SiA-3600	102.264	32.984	20.687
38	SiA-3604	95.143	28.738	22.319
39	SiA-3605	103.999	30.995	18.761
40	SiA-3607	93.424	43.212	21.838
41	Krishnadevaraya (Check)	106.243	36.149	16.792
42	SiA-3608	102.930	37.398	19.038
43	SiA-3610	97.316	40.936	19.080
44	SiA-3611	106.191	37.961	18.213
45	SiA-3613	107.410	18.762	29.206
46	SiA-3615	93.186	28.575	25.664
47	SiA-3618	92.199	26.067	21.772
48	SiA-3619	96.037	31.731	21.881
49	SiA-3622	103.616	44.019	14.815
50	SiA-3623	102.515	35.294	17.838
51	SiA-3085 (Check)	108.404	35.371	19.741
52	SiA-3625	102.812	40.056	23.490
53	SiA-3626	104.592	26.260	22.833
54	SiA-3628	102.143	30.958	17.466
55	SiA-3631	96.814	36.172	18.336
56	SiA-3632	104.733	38.526	19.519
57	SiA-3634	98.377	29.782	19.377
58	SiA-3636	113.422	28.906	21.964
59	SiA-3637	104.870	33.795	18.810
60	SiA-3156 (Check)	101.954	23.431	14.488

Leaf temperature at 30 DAS contributed maximum (0.526) to the genetic diversity in Z_5 vector, followed by test weight (0.405), grain yield (0.308), SLA at 30 DAS (0.240), membrane injury at 45 DAS (0.223), membrane injury at 30 DAS (0.174), days to 50% flowering (0.152), SLA at 45 DAS (0.151), leaf temperature at 45 DAS (0.138), SCMR at 45 DAS (0.117), ear head length (0.104), SCMR at 30 DAS (0.075), days to maturity (0.005) and fodder yield (0.004). The remaining characters contributed negatively to the diversity.

The maximum contribution to the diversity was made by number of RWC at 30 DAS (0.424), followed by membrane injury at 30 DAS (0.366), SCMR at 30 DAS (0.217), leaf temperature at 45 DAS (0.206), SCMR at 45 DAS (0.194), days to maturity (0.165), days to 50% flowering (0.146), grains/ ear head (0.121) and SLA at 30 DAS (0.013) in Z_6 vector.

In Z_7 vector, the maximum contribution to the diversity was made by leaf temperature at 45 DAS (0.662), followed by leaf temperature at 30 DAS (0.360), ear bearing tillers per hill (0.344), SCMR at 45 DAS (0.308), plant height (0.199), RWC at 45 DAS (0.099), days to 50% flowering (0.089), SCMR at 30 DAS (0.072) and membrane injury at 30 DAS (0.030).

Fodder yield contributed maximum (0.368) to the genetic diversity in Z_8 vector, followed by membrane injury at 30 DAS (0.332), membrane injury at 45 DAS (0.260), leaf temperature at 30 DAS (0.225), plant height (0.165), days to 50% flowering (0.149), grains per ear head (0.104) and RWC at 45 DAS (0.072). The remaining characters contributed negatively to the diversity.

In the present study, the data collected on the yield and yield components and physiological parameters on 60 genotypes of foxtail millet were subjected to D^2 analysis and the genetic diversity was estimated. Tocher's method of grouping is the most widely used procedure of clustering using Mahalanobis's D^2 statistics. The

genotypes were grouped into thirteen clusters using Tocher's method of clustering. Similar reports were also made by Shanmuganathan *et al.*, (2006).

Among thirteen clusters formed, Cluster I had a large number of thirty six genotypes whereas clusters III, V, VI, VII, VIII, X, XI, XII and XIII had only one genotype in each cluster. Inter-cluster distances were greater in magnitude confirming the presence of diversity among clusters. Minimum inter-cluster distance was observed between the cluster VI and VIII revealing the close relationship and similar magnitude for most of the characters of the genotypes in these clusters. Maximum inter-cluster distance was noticed between cluster XII and cluster XIII followed by the distance between cluster VIII and cluster XIII. The genotypes in these clusters can be utilized as potential parents and crossing between these genotypes would result in high heterotic expression for yield and its components and physiological parameters. Thus, selection of parents from such clusters for hybridization programmes would result in novel recombinants. Sirisha *et al.* (2010), Mahajan and Wadika (2012), Andualem and Ketema (2013), Reddy *et al.* (2015) and Bendi and Sarma (2016) made similar study to identify genotypes resulting in heterotic expression for yield components.

Theoretically, the maximum amount of heterosis will be manifested in cross combinations involving the parents belonging to the most divergent clusters. However, for a practical plant breeder, the objective is not only to gain high heterosis but also to achieve high level of production.

The performance of genotypes and the characters with maximum contribution towards divergence should also be considered for inclusion of genotypes in the selection programmes for genetic improvement of foxtail millet.

Canonical root analysis was used to confirm the clustering pattern obtained by D^2 statistic and to plot 60 foxtail millet genotypes in a two dimensional graph. The eight canonical roots accounted for 81.76 per cent of total variation of uncorrelated

variables, which indicated that the differentiation of these traits was nearly complete in these genotypes in eight phases. The relative distribution of genotypes reflected existence of parallelism between grouping obtained by D^2 analysis and canonical root analysis. The first eight canonical roots contribute to 81.76 per cent for getting a clear two dimensional representation.

Grains per ear head and fodder yield contributed maximum to the genetic diversity in first vector whereas, days to 50% flowering contributed maximum followed by days to maturity in second vector. Similarly, SLA at 45 DAS followed by RWC at 30 DAS contributed maximum towards divergence in third vector, RWC at 30 DAS followed by test weight contributed maximum towards divergence in fourth vector, leaf temperature at 30 DAS followed by test weight contributed maximum divergence in fifth vector, RWC at 30 DAS followed by membrane injury at 30 DAS contributed maximum in sixth vector. Leaf temperature at 45 DAS followed by leaf temperature at 30 DAS contributed maximum in seventh vector. Fodder yield followed by membrane injury at 30 DAS contributed maximum in eighth vector. Relative water content at 30 DAS contributed maximum towards genetic divergence. Similarly, Relative injury at 30 DAS followed by Relative injury at 45 DAS, grains per ear head and relative water content at 30 DAS had high contribution towards divergence and for discerning the genotypes into various clusters. This was in agreement with the relative contribution of characters through D^2 analysis.

In the present study, the maximum distance ($D=48.91$) existed between cluster XII (SiA 3546) and XIII (SiA 3596) followed by cluster VIII (SiA 3551) and XIII (SiA 3596) ($D=47.81$). It is to advocate that crosses involving the parents from the cluster VIII and XIII exhibit high heterosis. Keeping this view, it is to conclude that crosses between the genotypes belonging to clusters II and XIII and clusters II and X are selected to realize exhibit high heterosis as well as higher level of production.

Cluster means for different characters showed considerable differences between the clusters for all the characters. Cluster VII registered maximum values for days to 50% flowering, days to maturity, ear bearing tillers per hill, grain yield and fodder yield. Cluster XI recorded maximum values for plant height, ear head length, SLA at 30 and 45 DAS, SCMR at 30 and 45 DAS and leaf temperature at 30 DAS. Cluster X recorded maximum values for grains/ear head and leaf temperature at 45 DAS. Further, Cluster IX recorded maximum values for relative water content at 30 DAS. Cluster VIII recorded maximum mean values for SCMR at 30 DAS and RWC at 45 DAS. Inter-crossing the genotypes from these clusters could be suggested to generate wide range of variability subsequently followed by effective selection for these characters.

Among all the characters studied, relative injury at 30 and 45 DAS contributed the maximum to the diversity followed by grain yield, relative water content, specific leaf area at 45 DAS, leaf temperature at 45 DAS and RWC at 45 DAS. The characters viz., SLA 30 DAS, fodder yield, SCMR at 45 DAS, grain yield, test weight, days to 50% flowering and SCMR at 30 DAS contributed to the genetic divergence in decreasing order. The characters viz., days to maturity, plant height, ear bearing tillers, ear head length and leaf temperature at 30 DAS had similar contribution towards the genetic divergence. The performance of genotypes and the characters with maximum contribution towards divergence should also be considered for inclusion of genotypes in the hybridization programmes for genetic improvement of foxtail millet.

Similar results were recorded by the earlier researchers for days to 50% flowering (Geethanjali *et al.*, 2016 and Bendi and Sarma, 2016), for days to maturity (Lakshmana *et al.*, 2010 and Reddy *et al.*, 2015), for plant height (Shanmuganathan *et al.*, 2006; Veena *et al.*, 2010, Lin *et al.*, 2012 and Gangurde *et al.*, 2016), for ear bearing tillers per hill (Reddy *et al.*, 2015), for ear head length (Govindaraj *et al.*, 2011), for test weight (Veena *et al.*, 2010), for grain yield per plant (Kumar *et al.*, 2010 and Geethanjali *et al.*, 2016), for fodder yield (Reddy *et al.*, 2015).

The following genotypes with outstanding mean performance from the selected clusters may serve as potential source for hybridization programme to obtain high yielding recombinant genotypes of foxtail millet hybrids for rainfed environment.

S. No.	Cluster number	Selected genotypes for hybridization	Promising characters in genotypes
1	Cluster VII	SiA 3636	Early to days to 50% flowering, Early to days to maturity, High ear bearing tillers per hill, High grain yield, High fodder yield
2	Cluster XI	Narasimharaya	Dwarf plant height, Long Ear head length, Low Specific leaf area, High SCMR at 45 DAS, Low Leaf temperature at 30 DAS
3	Cluster X	SiA 3569	High grains per ear head, Low Leaf temperature at 45 DAS
4	Cluster VIII	SiA 3551	High SCMR at 30 DAS, High Relative water content at 45 DAS
5	Cluster IX	Suryanandi, SiA 3613, SiA 3618	High Relative water content at 30 DAS

4.6 CHARACTER ASSOCIATION OF YIELD AND YIELD COMPONENTS

Yield is a complex character, which is the product of multiplicative interactions of a number of characters (Grafius, 1959). Hence, yield cannot be improved to a greater extent on its own. Yield is influenced by a set of other characters known as yield components which are correlated among themselves and with yield either favourably or unfavourably. The study of genetic correlation gives an idea about the extent to which the characters are under the control of the same set of genes. If the correlation is high, then probably the pleiotropy is more important, if the correlation is low then it may be inferred that the traits are inherited independently. Hence, knowledge of the association between yield and yield components and other traits is essential for effective selection. In the present study also, a number of yield components were investigated and their relationship with yield as well as among themselves was studied using correlation analysis.

The phenotypic and genotypic correlation coefficients were worked out to assess the direction and magnitude of association existing between grain yield and yield components. The results of phenotypic and genotypic correlation analyses are furnished in Table 4.22. In general, genotypic correlations were higher than their corresponding phenotypic correlations for almost all the characters. Further, the magnitude and direction of association of their corresponding phenotypic and genotypic correlations are also matched.

Table 4.22 Phenotypic (r_p) and genotypic (r_g) correlation coefficients among grain yield per plant and other yield attributing characters in 60 genotypes of Foxtail millet

Characters		Days To Maturity	Plant Height	Ear Bearing Tillers / Hill(No.)	Ear Head Length(Cm)	Grains / Ear Head (No.)	Test Weight (gm)	Fodder Yield / Plant(gm)	Grain Yield / Plant
Days To 50% Flowering	r_p	0.5639**	0.0929	0.1208	0.1150	-0.0001	0.0986	0.1221	0.2176*
	r_g	0.7039	0.1155	0.1639	0.0735	0.0111	0.1163	0.1494	0.2453
Days To Maturity	r_p		0.1147	0.1477	0.1799*	-0.1063	0.0581	0.0934	0.2612*
	r_g		0.1206	0.1528	0.1011	-0.1156	0.0402	0.1043	0.2076
Plant Height	r_p			0.3072**	0.7207**	0.3101**	-0.0486	0.3779**	0.1507
	r_g			0.4919	0.8549	0.3477	-0.0583	0.4376	0.1569
Ear Bearing Tillers / Hill(No.)	r_p				0.3114**	0.0782	0.2765**	0.3088**	0.3122**
	r_g				0.3998	0.1045	0.3305	0.3433	0.3458
Ear Head Length(Cm)	r_p					0.3528**	0.1944*	0.3356**	0.2237*
	r_g					0.4602	0.2481	0.4635	0.2867
Grains / Ear Head (No.)	r_p						0.2173*	0.1044	0.4278**
	r_g						0.2257	0.1235	0.4997
Test Weight (g)	r_p							0.1449	0.3338**
	r_g							0.1806	0.3979
Fodder Yield / Plant(g)	r_p								0.4886**
	r_g								0.5274

* Significant at 5% level; ** Significant at 1% level

4.6.1 Correlation between Grain Yield per Plant and its Yield Components

Fodder yield/ plant had highly significant positive phenotypic and very strong positive genotypic correlation with grain yield per plant ($r_p=0.4886^{**}$; $r_g =0.5274$) followed by number of grains per ear head ($r_p=0.4278^{**}$; $r_g =0.4997$), test weight ($r_p=0.3338^{**}$; $r_g =0.3979$), ear bearing tillers per hill ($r_p= 0.3122^{**}$; $r_g =0.3458$), days to maturity ($r_p=0.2612^*$; $r_g =0.2894$), ear head length ($r_p=0.2237^*$; $r_g=0.2867$), days to 50% flowering ($r_p=0.2176^*$; $r_g =0.2453$) in the decreasing order of correlations. Similarly, the significant association of grain yield per plant with ear bearing tillers/ hill was earlier reported by Aruselvi *et al.* (2008), Nirmalakumari and Vetriventhan (2010) and Ganapathy *et al.* (2011); with ear head length by Maloo and Philip (2001), Meena *et al.* (2008), Govindaraj *et al.* (2009) and Ganapathy *et al.* (2011); with test weight by Anarase and Ugale (2001), Yadav *et al.* (2003) and Prasanna *et al.* (2013); with number of grains per ear head by Yadav *et al.* (2003); with fodder yield per plant by Anarase and Ugale (2001), Yadav *et al.* (2003), Lakshmi *et al.* (2013) and Brunda *et al.* (2015). Positive association of grain yield per plant with days to 50% flowering was reported earlier by Prasanna *et al.* (2013).

4.6.2 Inter-se Correlation Among Yield and Yield Components

The studies on *inter se* association among yield components will reveal the favourable or unfavourable association among themselves as well as with yield. The improvement in favourable components will in turn cause the improvement in yield. Results on association among the yield components in the present breeding material are detailed hereunder.

4.6.2.1 Fodder yield/ plant (g)

The dry fodder yield/ plant recorded highly significant positive association with plant height ($r_p=0.3779^{**}$; $r_g =0.4376$) followed by ear head length ($r_p= 0.3356^{**}$; $r_g =0.4365$) and number of ear bearing tillers per hill ($r_p=0.3088^{**}$; $r_g =0.3433$). Similarly, it showed non-significant association with test weight ($r_p=0.1449$; $r_g =0.1806$), days to 50% flowering ($r_p=0.1221$; $r_g =0.1494$), number of grains per ear head ($r_p=0.1044$; $r_g =0.1235$), days to maturity ($r_p=0.0934$; $r_g =0.1043$). Similar kind of positive significant association of plant height was confirmed by Brunda *et al.* (2015). The observed correlations are in consonance with the findings of Anarase and Ugale (2001) and Brunda *et al.* (2015) for plant height, ear head length, test weight and ear bearing tillers per hill.

4.6.2.2 Number of grains per ear head

The number of grains/ ear head had high and significant positive association with ear head length ($r_p=0.3528^{**}$; $r_g =0.4602$) followed by plant height ($r_p=0.3101^{**}$; $r_g =0.3477$), whereas days to 50% flowering had non-significant positive association with ear bearing tillers per hill ($r_p=0.0782$; $r_g =0.1045$). On contrary, it registered negative non significant association with days to maturity ($r_p=-0.1063$; $r_g =-0.1156$) and days to 50% flowering ($r_p=-0.0001$; $r_g =-0.0111$).

4.6.2.3 Test weight (g)

The test weight exhibited highly significant positive association with ear bearing tillers per hill ($r_p=0.2765^{**}$; $r_g =0.3305$) followed by number of grains per ear head ($r_p=0.2173^*$; $r_g =0.2257$) and ear head length ($r_p=0.1944^*$; $r_g =0.2481$). These results are in consonance with the findings of Meena *et al.* (2008b) and Vetriventhan and

Nirmalakumari (2007) for ear head length; Prasanna *et al.* (2013), Vetriventhan and Nirmalakumari (2007) for ear bearing tillers per hill.

4.6.2.4 Ear bearing tillers per hill

This character registered significant positive association with plant height ($r_p=0.3072^{**}$; $r_g = -0.4919$). Similarly, it recorded non-significant positive association with days to maturity ($r_p=0.1477$; $r_g = 0.1528$) and days to 50% flowering ($r_p=0.1208$; $r_g = 0.1639$).

4.6.2.5 Ear head length (cm)

The trait, ear head length expressed highly significant positive association with plant height ($r_p=0.7207^{**}$; $r_g = 0.8549$) followed by number of ear bearing tillers per hill ($r_p=0.3114^{**}$; $r_g = 0.3998$) and days to maturity ($r_p=0.1799^*$; $r_g = 0.2353$) indicating that longer ear heads are observed in long duration taller genotypes. Similar kind of associations were revealed earlier by Ezeaku *et al.* (2006) and Aruselvi *et al.* (2008) for plant height; Prasanna *et al.* (2013) and Brunda *et al.* (2015) for days to maturity.

4.6.2.6 Plant height (cm)

Plant height showed positive non-significant association with days to maturity ($r_p=0.1147$; $r_g = 0.1206$) and days to 50% flowering ($r_p=0.0929$; $r_g = 0.1155$).

4.6.2.7 Days to maturity

The days to maturity showed highly significant positive association with days to 50% flowering ($r_p=0.5639$; $r_g = 0.7039$). This was in conformity with the findings of Abuali *et al.* (2012).

To sum up, grain yield per plant could be increased by indirect selection for fodder yield per plant followed by number of grains per ear head, test weight, ear bearing tillers per hill, days to maturity, ear head length and days to 50% flowering.

Hence, simultaneous selection based on these characters could be suggested for further improvement of grain yield in foxtail millet genotypes.

4.6.3 CHARACTER ASSOCIATION OF YIELD AND PHYSIOLOGICAL CHARACTERS

The phenotypic and genotypic correlation coefficients were worked out to assess the direction and magnitude of association existing between grain yield and physiological traits and furnished in Table 4.23.

4.6.3.1 Correlation between grain yield per plant and physiological characters

SCMR at 30 DAS had highly significant phenotypic and large genotypic association with grain yield per plant ($r_p=0.3655^{**}$; $r_g=0.4010$) followed by SCMR at 45 DAS ($r_p=0.2960^{**}$; $r_g=0.3210$). Similarly, it registered significant positive association with relative water content at 30 DAS ($r_p=0.1818^*$; $r_g=0.1910$) whereas, non significant positive association was found with specific leaf area at 30 DAS ($r_p=0.1701$; $r_g=0.1823$), leaf temperature at 30 DAS ($r_p=0.0765$; $r_g=0.1053$), relative water content at 45 DAS ($r_p=0.0750$; $r_g=0.0608$) and specific leaf area at 45 DAS ($r_p=0.0389$; $r_g=0.0635$). On contrary, the association of leaf temperature at 45 DAS existed with grain yield ($r_p=-0.0838$; $r_g=-0.0829$) and membrane injury at 30 DAS ($r_p=-0.0954$; $r_g=-0.1045$) was negative and non significant. Similar kind of highly positive association of SCMR with grain yield per plant was reported by Kumari and Ganesamurty (2010) and Ravi *et al.* (2016). The significant positive association of relative water content with grain yield was earlier reported by Ayub *et al.* (2012) and Awol *et al.* (2013) with grain yield were reported earlier and corroborates the findings of the present study.

Table 4.23 Phenotypic (r_p) and genotypic (r_g) correlation coefficients among grain yield per plant and physiological traits in 60 genotypes of foxtail millet

Characters		SLA 45	SCMR 30	SCMR 45	LT 30	LT 45	MI 30	MI 45	RWC 30	RWC 45	Gy
Specific Leaf Area At 30 DAS	r_p	0.4641**	-0.0852	-0.0861	0.0121	-0.0593	0.1543	0.0301	0.0379	0.0369	0.1701
	r_g	0.4939	-0.0845	-0.0895	0.0243	-0.0536	0.1577	0.0306	0.0320	0.0185	0.1823
Specific Leaf Area At 45 DAS	r_p		0.1429	-0.0317	-0.0175	-0.0586	0.1922*	0.0821	0.1012	-0.0403	0.0389
	r_g		0.1449	-0.0485	-0.0210	-0.0629	0.1998	0.0876	0.1009	-0.0341	0.0635
SCMR At 30 DAS	r_p			0.6067**	-0.0519	0.2210*	0.0730	0.0166	-0.0972	-0.0482	0.3655**
	r_g			0.7246	-0.2353	0.2359	0.0783	0.0220	-0.1285	-0.0011	0.4010
SCMR At 45 DAS	r_p				0.1320	0.4747**	-0.0133	-0.0134	-0.1672	-0.0182	0.2960**
	r_g				0.2609	0.5080	-0.0144	-0.0089	-0.1720	-0.0080	0.3210
Leaf Temperature At 30 DAS	r_p					0.0835	0.0447	0.0367	0.0549	0.0943	0.0765
	r_g					0.1716	0.0569	0.0419	0.0566	0.2251	0.1053
Leaf Temperature At 45 DAS	r_p						0.0335	-0.0248	-0.0608	0.0428	-0.0838
	r_g						0.0368	-0.0204	-0.0652	0.0504	-0.0829
Relative membrane Injury At 30 DAS	r_p							0.0895	0.0426	-0.2346**	-0.0954
	r_g							0.0891	0.0443	-0.2506	-0.1045
Relative membrane Injury At 45 DAS	r_p								0.0584	-0.1057	0.0195
	r_g								0.0534	-0.1111	0.0208
Relative Water Content At 30 DAS	r_p									-0.0658	0.1818*
	r_g									-0.0780	0.1910
Relative Water Content At 45 DAS	r_p										0.0750
	r_g										0.0608

* Significant at 5% level; ** Significant at 1% level

4.6.3.2 *Inter-se* correlation among physiological traits

The studies on *inter se* association among physiological traits will reveal the favourable or unfavourable association among themselves as well as with grain yield. The improvement in favourable components will in turn cause the improvement in grain yield and are presented hereunder.

4.6.3.2.1 Relative water content at 45 DAS

The relative water content at 45 DAS displayed highly significant negative association with membrane injury at 30 DAS ($r_p = -0.2346$; $r_g = -0.2506$). Similarly, it recorded non significant positive association with leaf temperature at 30 DAS ($r_p = 0.0943$; $r_g = 0.2251$), leaf temperature at 45 DAS ($r_p = 0.0428$; $r_g = 0.0504$), specific leaf area at 30 DAS ($r_p = 0.0369$; $r_g = 0.0185$). On contrary, the negative and significant association of water content existed with SCMR at 45 DAS ($r_p = -0.0182$; $r_g = -0.0080$), SLA at 45 DAS ($r_p = -0.0403$; $r_g = -0.0341$), SCMR at 30 DAS ($r_p = -0.0482$; $r_g = -0.0011$), RWC at 30 DAS ($r_p = -0.0658$; $r_g = -0.0780$) and membrane injury at 45 DAS ($r_p = -0.1057$; $r_g = -0.1111$).

4.6.3.2.2 Relative water content at 30 DAS

The relative water content at 30 DAS displayed non significant positive association with SLA at 45 DAS ($r_p = 0.1012$; $r_g = 0.1009$), membrane injury at 45 DAS ($r_p = 0.0584$; $r_g = 0.0534$), leaf temperature at 30 DAS ($r_p = 0.0549$; $r_g = 0.0566$), membrane injury at 30 DAS ($r_p = 0.0426$; $r_g = 0.0443$) and SLA at 30 DAS ($r_p = 0.0379$; $r_g = 0.0320$). On contrary, the association of RWC at 30 DAS with SCMR at 45 DAS ($r_p = -0.1672$; $r_g = -0.1720$), SCMR at 30 DAS ($r_p = -0.0972$; $r_g = -0.1285$) and leaf temperature at 45 DAS ($r_p = -0.0608$; $r_g = -0.0652$) was negative and non significant.

4.6.3.2.3 Membrane injury at 45 DAS

The membrane injury at 45 DAS displayed non significant positive association with membrane injury at 30 DAS ($r_p=0.0895$; $r_g =0.0891$), SLA at 45 DAS ($r_p=0.0821$; $r_g =0.0876$), leaf temperature at 30 DAS ($r_p=0.0367$; $r_g =0.0419$), SLA at 30 DAS ($r_p=0.0301$; $r_g =0.0306$) and SCMR at 30 DAS ($r_p=0.0166$; $r_g =0.0220$). On contrary, the association of membrane injury at 45 DAS with SCMR at 45 DAS ($r_p=-0.0134$; $r_g =-0.0089$) and leaf temperature at 45 DAS ($r_p=-0.0248$; $r_g =-0.0204$) was negative and non significant.

4.6.3.2.4 Membrane injury at 30 DAS

The membrane injury at 30 DAS displayed significant positive association with SLA at 45 DAS ($r_p=0.1922$; $r_g =0.1998$). Similarly, it recorded non significant positive association with SLA at 30 DAS ($r_p=0.1543$; $r_g =0.1577$), SCMR at 30 DAS ($r_p=0.0730$; $r_g =0.0783$), leaf temperature at 30 DAS ($r_p=0.0447$; $r_g =0.0569$) and leaf temperature at 45 DAS ($r_p=0.0335$; $r_g =0.0368$). On contrary, the association of membrane injury at 30DAS with SCMR at 45 DAS ($r_p=-0.0133$; $r_g =-0.0144$) was negative and non significant.

4.6.3.2.5 Leaf temperature at 45 DAS

The leaf temperature at 45 DAS displayed highly significant positive association with SCMR at 45 DAS ($r_p= 0.4747$; $r_g =0.5080$) and significant positive association with SCMR at 30 DAS ($r_p= 0.2210^*$; $r_g =0.2359$). Similarly, it recorded non-significant positive association with leaf temperature at 30 DAS ($r_p=0.0835$; $r_g =0.1716$). The association of leaf temperature at 45 DAS with SLA at 45 DAS ($r_p=-0.0586$; $r_g =-0.0629$) and SLA at 30 DAS ($r_p=-0.0593$; $r_g =-0.0536$) was negative and non significant.

4.6.3.2.6 Leaf temperature at 30 DAS

The leaf temperature at 30 DAS displayed non significant positive association with SCMR at 45 DAS ($r_p=0.1320$; $r_g =0.2609$) and SLA at 30 DAS ($r_p=0.0821$; $r_g =0.0876$), leaf temperature at 30 DAS ($r_p=0.0367$; $r_g =0.0419$), SLA at 30 DAS ($r_p=0.0301$; $r_g =0.0306$) and SCMR at 30 DAS ($r_p=0.0166$; $r_g =0.0220$). While, the association of membrane injury at 45 DAS with SCMR at 45 DAS ($r_p=-0.0134$; $r_g =-0.0089$) and leaf temperature at 45 DAS ($r_p=-0.0248$; $r_g =-0.0204$) was negative and non significant.

4.6.3.2.7 SPAD chlorophyll meter reading at 45 DAS

The association of SCMR at 45 DAS ($r_p=0.6067$; $r_g =0.7246$) and SCMR at 30 DAS was positive and highly significant. On contrary, the association of SLA at 45 DAS ($r_p=-0.0317$; $r_g =-0.0485$) and SLA at 30 DAS ($r_p=-0.0861$; $r_g =-0.0895$) was negative and non significant with SPAD chlorophyll meter reading. Significant negative correlation of SLA with SCMR was reported by Reddy *et al.* (2003).

4.6.3.2.8 SPAD chlorophyll meter reading at 30 DAS

The association of SLA at 45 DAS ($r_p=0.1429$; $r_g =0.1449$) was positive and non significant, SLA at 30 DAS ($r_p=-0.0852$; $r_g =-0.0845$) was negative and non significant with SPAD chlorophyll meter reading.

4.6.3.2.9 Specific leaf area at 45 DAS (cm^2g^{-1})

Specific leaf area displayed highly significant positive association with SLA at 30 DAS ($r_p=0.4611$; $r_g =0.4939$).

The above results indicated that grain yield per plant under rainfed conditions could be increased through selection for increased SPAD chlorophyll meter reading followed by high relative water content and low relative membrane injury. Hence, simultaneous selection based on these physiological characters could be suggested for further improvement of grain yield in foxtail millet genotypes under rainfed conditions.

4.7 PATH CO-EFFICIENT ANALYSIS OF YIELD AND YIELD COMPONENTS

Path coefficient analysis is unique in partitioning the association in to direct and indirect effects *via* other component characters. Hence, correlation in conjunction with path coefficient analysis will give a clear idea of the nature of association between yield and yield attributes and also gives information on relative contribution of various yield components to yield.

If the direct effect is equal to correlation co-efficient, then correlation explains the true relationship and direct selection for this trait will be effective. If the correlation co-efficient is positive, but the direct effect is negative or negligible the indirect effects seem to be the cause of correlation. In such situations, the other factors have to be considered simultaneously. If correlation is negative, but the direct effect is positive and high, a restricted simultaneous selection model is to be followed *i.e.*, restrictions are to be imposed to nullify the undesirable indirect effects in order to make use of the direct effect.

In the present study, the phenotypic correlation coefficients between grain yield and yield components were partitioned into the corresponding direct and indirect effects through path analysis and the results are presented in Table 4.24, Fig 4.6 and 4.7.

4.7.1 Direct effects of yield components on grain yield per plant

Among nine yield components, the highest positive direct effect on grain yield per plant was exerted by fodder yield per plant ($P=0.4709$; $G=0.5389$) followed by test weight ($P=0.1610$; $G=0.2065$) and number of grains per ear head ($P=0.0916$; $G=0.0912$). Hence, selection based on these traits would be effective in increasing the grain yield per plant.

Table 4.24 Phenotypic (P) and genotypic (G) path coefficients among grain yield per plant and other yield components in 60 genotypes of Foxtail millet

Characters		Days To 50% Flowering	Days To Maturity	Plant Height	Ear Bearing Tillers / Hill(No.)	Ear Head Length(Cm)	Grains / Ear Head (No.)	Test Weight (g)	Fodder Yield / Plant(g)	Grain Yield / Plant
Days To 50% Flowering	P	0.0877	0.0494	0.0081	0.0106	0.0101	0.0000	0.0086	0.0107	0.2176*
	G	0.0051	0.0036	0.0006	0.0008	0.0004	0.0001	0.0006	0.0008	0.2453
Days To Maturity	P	-0.0132	-0.0235	-0.0027	-0.0035	-0.0039	0.0025	-0.0014	-0.0022	0.2612*
	G	0.0235	0.0333	0.0040	0.0051	0.0034	-0.0039	-0.0013	0.0036	0.2076
Plant Height	P	0.0038	0.0048	0.0414	0.0127	0.0299	0.0129	-0.0020	0.0157	0.1507
	G	0.0036	0.0037	0.0309	0.0152	0.0264	0.0107	-0.0018	0.0135	0.1569
Ear Bearing Tillers / Hill(No.)	P	-0.0104	-0.0127	-0.0265	-0.0861	-0.0268	-0.0067	-0.0041	-0.0066	0.3211**
	G	-0.0125	-0.0116	-0.0374	-0.0761	-0.0304	-0.0080	-0.0029	-0.0116	0.3458
Ear Head Length(Cm)	P	0.0030	0.0044	0.0189	0.0082	0.0263	0.0093	0.0051	0.0088	0.2237*
	G	-0.0032	-0.0043	-0.0367	-0.0172	-0.0429	-0.0197	-0.0106	-0.0199	0.2867
Grains / Ear Head (No.)	P	0.0000	-0.0097	0.0284	0.0072	0.0323	0.0916	0.0199	0.0096	0.4278**
	G	0.0010	-0.0105	0.0317	0.0095	0.0420	0.0912	0.0206	0.0133	0.4997
Test Weight (g)	P	0.0159	0.0094	-0.0078	0.0077	0.0313	0.0350	0.1610	0.0233	0.3338**
	G	0.0240	0.0083	-0.0120	0.0077	0.0512	0.0466	0.2065	0.0373	0.3979
Fodder Yield / Plant(g)	P	0.0575	0.0440	0.1780	0.0363	0.1580	0.0492	0.0682	0.4709	0.4886**
	G	0.0805	0.0578	0.2358	0.0820	0.2498	0.0666	0.0973	0.5389	0.5274

Phenotypic residual effect: 0.7614; Genotypic residual effect: 0.7069

* Significant at 5% level; ** Significant at 1% level; Diagonal: Direct effects

The positive direct effects of component traits observed with grain yield were in accordance with the reports of Maloo and Philip (2001), Chikurte *et al.* (2003), Kebere *et al.* (2006) and Aruselvi *et al.* (2008) for test weight and Anarase and Ugale (2001) for fodder yield; Maloo and Philip (2001), Aruselvi *et al.* (2008), Nirmalakumari and Vetriventhan (2010) for days to 50% flowering; Anarase and Ugale (2001), Priyadharshini *et al.* (2011) Sharma (1987), Chikurte *et al.* (2003), Meena *et al.* (2008) and Govindaraj and Selvi (2012) for ear head length.

On contrary, the traits *viz.*, ear bearing tillers per hill ($P=-0.0861$; $G=-0.0761$) followed by days to maturity ($P=-0.0235$; $G=-0.0333$) exerted negative direct effect on grain yield per plant. These findings were in accordance with the earlier reports by Abuali *et al.* (2012) for ear bearing tillers per hill; Govindaraj and Selvi (2012) for days to maturity.

4.7.2 Indirect effects of yield components on grain yield per plant

4.7.2.1 Days to 50 per cent flowering

Days to 50 per cent flowering exhibited significant positive association with grain yield per plant ($P=0.2176$; $G =0.02453$). The direct effect of this trait on grain yield per plant was positive and negligible ($P=0.0877$; $G=-0.0051$). It showed negligible positive indirect effects via other traits *viz.*, days to maturity ($P=0.0494$; $G=0.0036$) followed by fodder yield per plant ($P=0.0107$; $G=0.0008$), number of ear bearing tillers per hill ($P=0.0106$; $G=0.0008$), ear head length ($P=0.0101$; $G=0.0004$), test weight ($P=0.0086$; $G=0.0006$), plant height ($P=0.0081$; $G=0.0006$) and number of grains per ear head ($P=0.0000$; $G=0.0004$).

4.7.2.2 Days to maturity

Days to maturity had significant positive association with grain yield per plant ($P=0.2612$; $G =0.2076$). It exhibited negative direct effect ($P =-0.0235$; $G =0.0333$) on grain yield per plant coupled with negative indirect effects through days to 50% flowering ($P=-0.0132$; $G =0.0235$) ear head length ($P=-0.039$; $G =0.0034$), ear bearing tillers per hill ($P=-0.0035$; $G =0.0051$), plant height ($P=-0.0027$; $G =0.0040$) fodder yield per plant ($P=-0.0022$; $G =0.0036$) and test weight ($P=-0.0014$; $G =-0.0013$) which ultimately resulted in highly significant negative association with grain yield per plant.

On the other hand, days to maturity exerted positive indirect effect on grain yield per plant via number of grains per ear head ($P= 0.0025$; $G = -0.0039$). The negative correlation of this trait with grain yield per plant indicated that selection for early maturing types would be useful to escape drought for sustaining increased yield in the genotypes under rainfed conditions.

4.7.2.3 Plant height (cm)

Plant height registered non significant positive correlation with grain yield per plant ($P=0.1507$, $G=0.1569$). The direct effect of this trait on grain yield per plant was positive ($P=0.0414$; $G =0.0309$). It showed positive indirect effect on grain yield per plant via ear head length ($P=0.0299$; $G =0.0264$), followed by fodder yield per plant ($P=0.0157$; $G =0.0135$), number of grains per ear head ($P=0.0129$; $G =0.0107$), number of ear bearing tillers per hill ($P=0.0127$; $G =0.0152$), days to maturity ($P=0.0048$; $G =0.0037$) and days to 50% flowering ($P=0.0038$; $G =0.0036$). On contrary, it had negative indirect effect on grain yield per plant exerted through test weight ($P=-0.0020$; $G =-0.0018$).

4.7.2.4 Ear bearing tillers per hill

Ear bearing tillers per hill displayed highly significant positive association with grain yield per plant ($P = 0.3211$; $G = 0.3458$). It expressed negative direct effect on grain yield per plant ($P = -0.0861$; $G = -0.0761$) and showed negative indirect effect via ear head length ($P = -0.0268$; $G = -0.0304$) followed by via plant height ($P = -0.0265$; $G = -0.0374$), days to maturity ($P = -0.0127$; $G = -0.0116$), days to 50% flowering ($P = -0.0104$; $G = -0.0125$), number of grains per ear head ($P = -0.0067$; $G = -0.0080$), fodder yield per plant ($P = -0.0066$; $G = -0.0116$) and test weight ($P = -0.0041$; $G = -0.0029$) on grain yield per plant.

4.7.2.5 Ear head length (cm)

Ear head length exhibited significant positive association with grain yield per plant ($P = 0.2237$, $G = 0.2867$). The direct effect of this trait on grain yield per plant was positive but very low ($P = 0.0263$, $G = -0.0429$). It showed positive indirect effect via plant height ($P = 0.0189$; $G = -0.0367$) followed by number of grains per ear head ($P = 0.0093$; $G = -0.0197$), fodder yield per plant ($P = 0.0088$; $G = -0.0199$), ear bearing tillers per hill ($P = 0.0082$; $G = -0.0172$), test weight ($P = 0.0051$; $G = -0.0106$), days to maturity ($P = 0.0044$; $G = -0.0043$) and days to 50% flowering ($P = 0.0030$; $G = -0.0032$).

4.7.2.6 Number of grains per ear head

Number of grains per ear head exhibited highly significant positive association with grain yield per plant ($P = 0.4278$; $G = 0.4997$). The direct effect of this trait on grain yield per plant was positive ($P = 0.0916$; $G = 0.0912$). It showed positive indirect effect on grain yield per plant via ear head length ($P = 0.0323$; $G = 0.0420$) followed via plant height ($P = 0.0284$; $G = 0.0317$), test weight ($P = 0.0199$; $G = 0.0206$), fodder yield per plant ($P = 0.0096$; $G = 0.0133$), ear bearing tillers per hill ($P = 0.0072$; $G = 0.0095$) and days to 50% flowering ($P = 0.0000$; $G = 0.0010$). On contrary, it registered negative indirect effect via days to maturity ($P = -0.0097$; $G = -0.0105$).

4.7.2.7 Test weight (g)

Test weight recorded highly significant positive association with grain yield per plant ($P=0.3338$; $G=0.3979$). The direct effect of this trait on grain yield per plant was highly positive ($P=0.1610$; $G=0.2065$). It showed positive indirect effect on grain yield per plant via number of grains per plant ($P=0.0350$; $G=0.0466$) followed by ear head length ($P=0.0313$; $G=0.0512$), fodder yield/ plant ($P=0.0233$; $G=0.0373$), days to 50% flowering ($P=0.0159$; $G=0.0240$), days to maturity ($P=0.0094$; $G=0.0083$) and ear bearing tillers per hill ($P=0.0077$; $G=0.0077$). On contrary, it registered negative indirect effect via plant height ($P=-0.0078$; $G=-0.0120$). Selection for higher weight is effective to realize high yield potential under rainfed condition.

4.7.2.8 Fodder yield per plant (g)

Fodder yield per plant displayed highly significant positive association with grain yield per plant ($P=0.4886$; $G=0.5274$). The direct effect of this trait on grain yield per plant was highly positive ($P=0.4709$; $G=0.5389$). It showed positive indirect effect on grain yield per plant via plant height ($P=0.1780$; $G=0.2358$) followed by ear head length ($P=0.1580$; $G=0.2498$), test weight ($P=0.0682$; $G=0.0973$), days to 50% flowering ($P=0.0575$; $G=0.0805$), number of grains per ear head ($P=0.0492$; $G=0.0666$), days to maturity ($P=0.0440$; $G=0.0578$) and ear bearing tillers per hill ($P=0.0363$; $G=0.0820$). Since the trait expressed high positive direct effect, selection for this trait would be effective in increasing the grain yield under rainfed condition.

From the foregoing results, it is to note that high positive direct effect on grain yield per plant was exerted by fodder yield per plant followed by test weight, number of grains per ear head, days to 50% flowering, plant height, ear head length and ear bearing tillers per hill in the decreasing order of magnitude. Hence, selection based on these traits would be effective in increasing the grain yield under moisture stress.

In the present study, the residual effect was of high magnitude (0.7614), suggesting there might be few more important components contributing to grain yield other than those studied in the present investigation.

4.7.3 Path Coefficient Analysis of Physiological Traits

In the present study, the phenotypic correlation coefficients between grain yield and physiological characters were partitioned in to the corresponding direct and indirect effects through path analysis and the results are presented in Table 4.25, Fig 4.6 and Fig 4.7.

4.7.3.1 Direct effects of physiological traits on grain yield per plant

Among ten physiological traits, the highest positive direct effect on grain yield per plant was shown by SCMR at 30 DAS ($P=0.3655$; $G=0.4010$) followed by SCMR at 45 DAS ($P=0.2960$; $G=0.3210$) and relative water content at 30 DAS ($P=0.1818$; $G=0.1910$). Hence, selection based on these physiological traits would be effective in increasing the grain yield per plant under moisture stress.

The positive direct effects of yield components observed with grain yield were in accordance with the earlier reports of Sudhakar *et al.* (2006), Kumari and Ganesamurthy (2010) for SPAD chlorophyll meter reading; Seenaiyah *et al.* (2015) for relative water content.

Table 4.25 Phenotypic (P) and genotypic (G) path coefficients among grain yield per plant and physiological traits in 60 genotypes of foxtail millet

Characters		SLA 30	SLA 45	SCMR 30	SCMR 45	LT 30	LT 45	MI 30	MI 45	RWC 30	RWC 45	GY
Specific Leaf Area At 30 DAS	P	0.1580	0.0733	-0.0135	-0.0136	0.0019	-0.0094	0.0244	0.0048	0.0060	0.0058	0.1701
	G	0.1438	0.0710	-0.0122	-0.0129	0.0035	-0.0077	0.0227	0.0044	0.0046	0.0027	0.1823
Specific Leaf Area At 45 DAS	P	-0.0385	-0.0830	-0.0119	0.026	0.0015	0.0049	-0.0160	-0.0068	-0.0084	0.0033	0.0389
	G	0.0018	0.0037	0.0005	-0.0002	-0.0001	-0.0002	0.0007	0.0003	0.0004	-0.0001	0.0635
SCMR At 30 DAS	P	-0.0045	0.0076	0.0531	0.0322	-0.0028	0.0117	0.0039	0.0009	-0.0052	-0.0026	0.3655**
	G	0.0032	-0.0055	-0.0380	-0.0275	0.0089	-0.0090	-0.0030	-0.0009	0.0049	0.0000	0.4010
SCMR At 45 DAS	P	-0.0148	-0.0055	0.1044	0.1721	0.0227	0.0817	-0.0023	-0.0023	-0.0288	-0.0031	0.2960**
	G	-0.0259	-0.0141	0.2101	0.2900	0.0757	0.1473	-0.0042	-0.0026	-0.0499	-0.0023	0.3210
Leaf Temperature At 30 DAS	P	0.0010	-0.0015	-0.0044	0.0112	0.0852	0.0071	0.0038	0.0031	0.0047	0.0080	0.0765
	G	0.0011	-0.0009	-0.0102	0.0114	0.0435	0.0075	0.0025	0.0018	0.0025	0.0098	0.1053
Leaf Temperature At 45 DAS	P	0.0088	0.0087	-0.0327	-0.0702	-0.0123	-0.1479	-0.0049	0.0037	0.0090	-0.0063	-0.0838
	G	0.0090	0.0106	-0.0396	-0.0852	-0.0288	-0.1678	-0.0062	0.0034	0.0109	-0.0085	-0.0829
Relative membrane Injury At 30 DAS	P	-0.0281	-0.0350	-0.0133	0.0024	-0.0081	-0.0061	-0.1820	-0.0163	-0.0078	0.0427	-0.0954
	G	-0.0312	-0.0396	-0.0155	0.0029	-0.0133	-0.0073	-0.1980	-0.0176	-0.0088	0.0496	-0.1045
Relative membrane Injury At 45 DAS	P	0.0017	0.0047	0.0009	-0.0008	0.0021	-0.0014	0.0051	0.0573	0.0033	-0.0061	0.0195
	G	0.0015	0.0043	0.0011	-0.0004	0.0020	-0.0010	0.0043	0.0486	0.0026	-0.0054	0.0208
Relative Water Content At 30 DAS	P	0.0062	0.0166	-0.0160	-0.0275	0.0090	-0.0100	0.0070	0.0096	0.1644	-0.0108	0.1818*
	G	0.0061	0.0192	-0.0245	-0.0327	0.0108	-0.0124	0.0084	0.0102	0.1905	-0.0149	0.1910
Relative Water Content At 45 DAS	P	0.0018	-0.0020	-0.0023	-0.0009	0.0046	0.0021	-0.0114	-0.0052	-0.0032	0.0487	0.0750
	G	0.0009	-0.0016	-0.0001	-0.0004	0.0109	0.0024	-0.0121	-0.0054	-0.0038	0.0482	0.0608

Phenotypic residual effect: 0.7614; Genotypic residual effect: 0.7069 * Significant at 5% level; ** Significant at 1% level, Diagonal: Direct effect

4.7.3.2 Indirect effects of physiological traits on grain yield per plant

4.7.3.2.1 Specific leaf area at 30 DAS

Specific leaf area at 30 DAS registered non significant positive correlation with grain yield per plant ($P=0.1701$; $G = 0.1823$). The direct effect of this trait on grain yield per plant was highly positive ($P=0.1580$; $G =0.1438$). It showed positive indirect effect on grain yield per plant via SLA at 45 DAS ($P=0.0733$; $G =0.0710$), relative injury at 30 DAS ($P=0.0244$; $G =0.0227$), RWC at 30 DAS ($P=0.0060$; $G =0.0046$), RWC at 45 DAS ($P=0.0058$; $G =0.0027$), membrane injury at 45 DAS ($P=0.0048$; $G =0.0044$) and leaf temperature at 30 DAS ($P=0.0019$; $G =0.0035$). Contrarily, it exerted negative indirect effect on grain yield per plant via leaf temperature at 45 DAS ($P=-0.0094$; $G =-0.0077$) followed by SCMR at 45 DAS ($P=-0.0136$; $G =-0.0129$) and SPAD chlorophyll meter reading at 30 DAS ($P=-0.0135$; $G =-0.0122$).

4.7.3.2.2 Specific leaf area at 45 DAS

Specific leaf area at 45 DAS registered non significant positive correlation with grain yield per plant ($P=0.0389$; $G = 0.0635$). The direct effect of this trait on grain yield per plant was negative ($P=-0.0830$; $G =0.0037$). It showed positive indirect effect on grain yield per plant via leaf temperature at 45 DAS ($P=0.0049$; $G =-0.0002$), relative water content at 45 DAS ($P=0.0033$; $G =-0.0001$), SCMR at 45 DAS ($P=0.0026$; $G =-0.0002$), leaf temperature at 30 DAS ($P=0.0015$; $G =-0.0001$). On contrary, it exerted negative indirect effect on grain yield per plant via SLA at 30 DAS ($P=-0.0385$; $G =0.0018$) followed by SCMR at 30 DAS ($P=-0.0119$; $G =-0.0005$), membrane injury at 30 DAS ($P=-0.0160$; $G =0.0007$), RWC at 30 DAS ($P=-0.0084$; $G =0.0004$) and membrane injury at 45 DAS ($P=-0.0068$; $G =0.0003$).

4.7.3.2.3 SPAD chlorophyll meter reading at 30 DAS

SPAD chlorophyll meter reading had highly significant positive association with grain yield per plant ($P=0.3655$; $G =0.4010$). The direct effect of this trait on grain yield per plant was positive but low ($P=0.0531$; $G =-0.0380$). It showed positive indirect effect on grain yield per plant via SCMR at 45 DAS ($P=0.0322$; $G =-0.0275$) followed by leaf temperature at 45 DAS ($P=0.0117$; $G =-0.0090$), SLA at 45 DAS ($P=0.0076$; $G =-0.0055$), membrane injury at 30 DAS ($P=0.0039$; $G =-0.0030$) and membrane injury at 45 DAS ($P=0.0009$; $G =-0.0009$). On contrary, it registered negative indirect effect via leaf temperature at 30 DAS ($P=-0.0028$; $G =0.0089$), specific leaf area at 30 DAS ($P=-0.0045$; $G =0.0032$), RWC at 30 DAS ($P=-0.0052$; $G =0.0049$) and RWC at 45 DAS ($P=-0.0026$; $G =0.0000$).

4.7.3.2.4 SPAD chlorophyll meter reading at 45 DAS

SPAD chlorophyll meter reading had highly significant positive association with grain yield per plant ($P=0.2960$; $G =0.3210$). The direct effect of this trait on grain yield per plant was positive ($P=0.1721$; $G =0.2900$). It showed positive indirect effect on grain yield per plant via leaf temperature at 45 DAS ($P=0.0817$; $G =0.1473$) followed by leaf temperature at 30 DAS ($P=0.0227$; $G =0.0757$), SCMR at 30 DAS ($P=0.1044$; $G =0.2101$). On contrary, it registered negative indirect effect via RWC at 30 DAS ($P=-0.0288$; $G =-0.0499$), specific leaf area at 30 DAS ($P=-0.0148$; $G =-0.0259$), SLA at 45 DAS ($P=-0.0055$; $G =-0.0141$), RWC at 45 DAS ($P=-0.0031$; $G =-0.0023$), membrane injury at 30 DAS ($P=-0.0023$; $G =-0.0042$) and membrane injury at 45 DAS ($P=-0.0023$; $G =-0.0026$).

4.7.3.2.5 Leaf temperature (°C) at 30 DAS

Leaf temperature exhibited non significant positive association with grain yield per plant ($P=0.0765$; $G =0.1053$). The direct effect of this trait on grain yield per plant was positive ($P=0.0852$; $G =0.0435$). It showed positive direct effect on grain yield per

plant via SCMR at 45 DAS ($P=0.0112$; $G =0.0114$), leaf temperature at 45 DAS ($P=0.0071$; $G =0.0075$), RWC at 45 DAS ($P=0.0080$; $G =0.0098$), RWC at 30 DAS ($P=0.0047$; $G =0.0025$), membrane injury at 30 DAS ($P=0.0038$; $G =0.0025$), membrane injury at 45 DAS ($P=0.0031$; $G =0.0018$) and SLA at 30 DAS ($P=0.0010$; $G =0.0011$). On contrary, it registered negative indirect effect via SLA at 45 DAS ($P=-0.0015$; $G =-0.0009$) and SCMR at 30 DAS ($P=-0.0044$; $G =0.0102$).

4.7.3.2.6 Leaf temperature ($^{\circ}\text{C}$) at 45 DAS

Leaf temperature exhibited non significant negative association with grain yield per plant ($P=-0.0838$; $G =-0.0829$). The direct effect of this trait on grain yield per plant was negative ($P=-0.1479$; $G =-0.1678$). It showed positive direct effect on grain yield per plant via RWC at 30 DAS ($P=0.0090$; $G =0.0109$), SLA at 30 DAS ($P=0.0088$; $G =0.0090$), SLA at 45 DAS ($P=0.0087$; $G =0.0106$) and membrane injury at 45 DAS ($P=0.0037$; $G =0.0034$). On contrary, it registered negative indirect effect via SCMR at 45 DAS ($P=-0.0702$; $G =-0.0852$) and SCMR at 30 DAS ($P=-0.0327$; $G =-0.0396$), leaf temperature at 30 DAS ($P=-0.0123$; $G =-0.0288$), RWC at 45 DAS ($P=-0.0063$; $G =-0.0085$) and membrane injury at 30 DAS ($P=-0.0049$; $G =-0.0062$).

4.7.3.2.7 Relative membrane injury (%) at 30 DAS

Relative membrane injury exhibited non significant negative association with grain yield per plant ($P=-0.0954$; $G =-0.1045$). The direct effect of this trait on grain yield per plant was negative ($P=-0.1820$; $G =-0.1980$). It showed positive direct effect on grain yield per plant via relative water content at 45 DAS ($P=0.0427$; $G =0.0496$) and SCMR at 45 DAS ($P=0.0024$; $G =0.0029$). On contrary, it registered negative indirect effect via SLA at 45 DAS ($P=-0.0350$; $G =-0.0396$), SLA at 30 DAS ($P=-0.0281$; $G =-0.0312$), membrane injury at 45 DAS ($P=-0.0163$; $G =-0.0176$), SCMR at 30 DAS ($P=-0.0133$; $G =-0.0155$), leaf temperature at 30 DAS ($P=-0.0081$; $G =-0.0133$), RWC at 30 DAS ($P=-0.0078$; $G =-0.0088$) and leaf temperature at 45 DAS ($P=-0.0061$; $G =-0.073$).

4.7.3.2.8 Relative membrane injury (%) at 45 DAS

Relative membrane injury exhibited non significant positive association with grain yield per plant ($P=0.0195$; $G =0.0208$). The direct effect of this trait on grain yield per plant was positive ($P=0.0573$; $G =0.0486$). It showed positive direct effect on grain yield per plant via membrane injury at 30 DAS ($P=0.0051$; $G =0.0043$), SLA at 45 DAS ($P=0.0047$; $G =0.0043$), RWC at 30 DAS ($P=0.0033$; $G =0.0026$), leaf temperature at 30 DAS ($P=0.0021$; $G =0.0020$), SLA at 30 DAS ($P=0.0015$; $G =0.0017$) and SCMR at 30 DAS ($P=0.0009$; $G =0.0011$). On contrary, it registered negative indirect effect via RWC at 45 DAS ($P=-0.0061$; $G =-0.0054$), leaf temperature at 45 DAS ($P=-0.0014$; $G =-0.0010$) and SCMR at 45 DAS ($P=-0.0008$; $G =-0.0009$).

4.7.3.2.9 Relative water content (%) at 30 DAS

Relative water content exhibited significant positive association with grain yield per plant ($P=0.1818$; $G =0.1910$). The direct effect of this trait on grain yield per plant was highly positive ($P=0.1644$; $G =0.1905$). It showed positive direct effect on grain yield per plant via SLA at 45 DAS ($P=0.0166$; $G =0.0192$), membrane injury at 45 DAS ($P=0.0096$; $G =0.0102$), leaf temperature at 30 DAS ($P=0.0090$; $G =0.0108$), membrane injury at 30 DAS ($P=0.0070$; $G =0.0084$) and SLA at 30 DAS ($P=0.0061$; $G =0.0062$). On contrary, it registered negative indirect effect via SCMR at 45 DAS ($P=-0.0275$; $G =-0.0327$), SCMR at 30 DAS ($P=-0.0160$; $G =-0.0245$), RWC at 45 DAS ($P=-0.0108$; $G =-0.0149$), and leaf temperature at 45 DAS ($P=-0.0100$; $G =-0.0124$).

4.7.3.2.10 Relative water content (%) at 45 DAS

Relative water content exhibited significant positive association with grain yield per plant ($P=0.0750$; $G =0.0608$). The direct effect of this trait on grain yield per plant was highly positive ($P=0.0487$; $G =0.0482$). It showed positive direct effect on grain yield per plant via leaf temperature at 30 DAS ($P=0.0046$; $G =0.0109$), leaf temperature

at 45 DAS ($P=0.0021$; $G =0.0024$) and SLA at 30 DAS ($P=0.0018$; $G =0.0009$). On contrary, it registered negative indirect effect via membrane injury at 30 DAS ($P=-0.0114$; $G =-0.0121$), membrane injury at 45 DAS ($P=-0.0052$; $G =-0.0054$), RWC at 30 DAS ($P=-0.0032$; $G =-0.0038$), SLA at 45 DAS ($P=-0.0020$; $G =-0.0016$) and SCMR at 45 DAS ($P=-0.0009$; $G =-0.0012$).

Path coefficient analysis revealed that the highest positive direct effect on grain yield per plant was exerted by SPAD chlorophyll meter reading followed by relative water content. Hence, selection based on these traits would be effective in increasing the grain yield per plant under rainfed conditions. Hence for increasing the grain yield per plant in Foxtail millet, indirect selection based on these two physiological traits would be rewarding.

In the present study, the residual effect was of high magnitude (0.7614), suggesting there might be few more important physiological traits contributing to grain yield other than those studied in the present investigation.

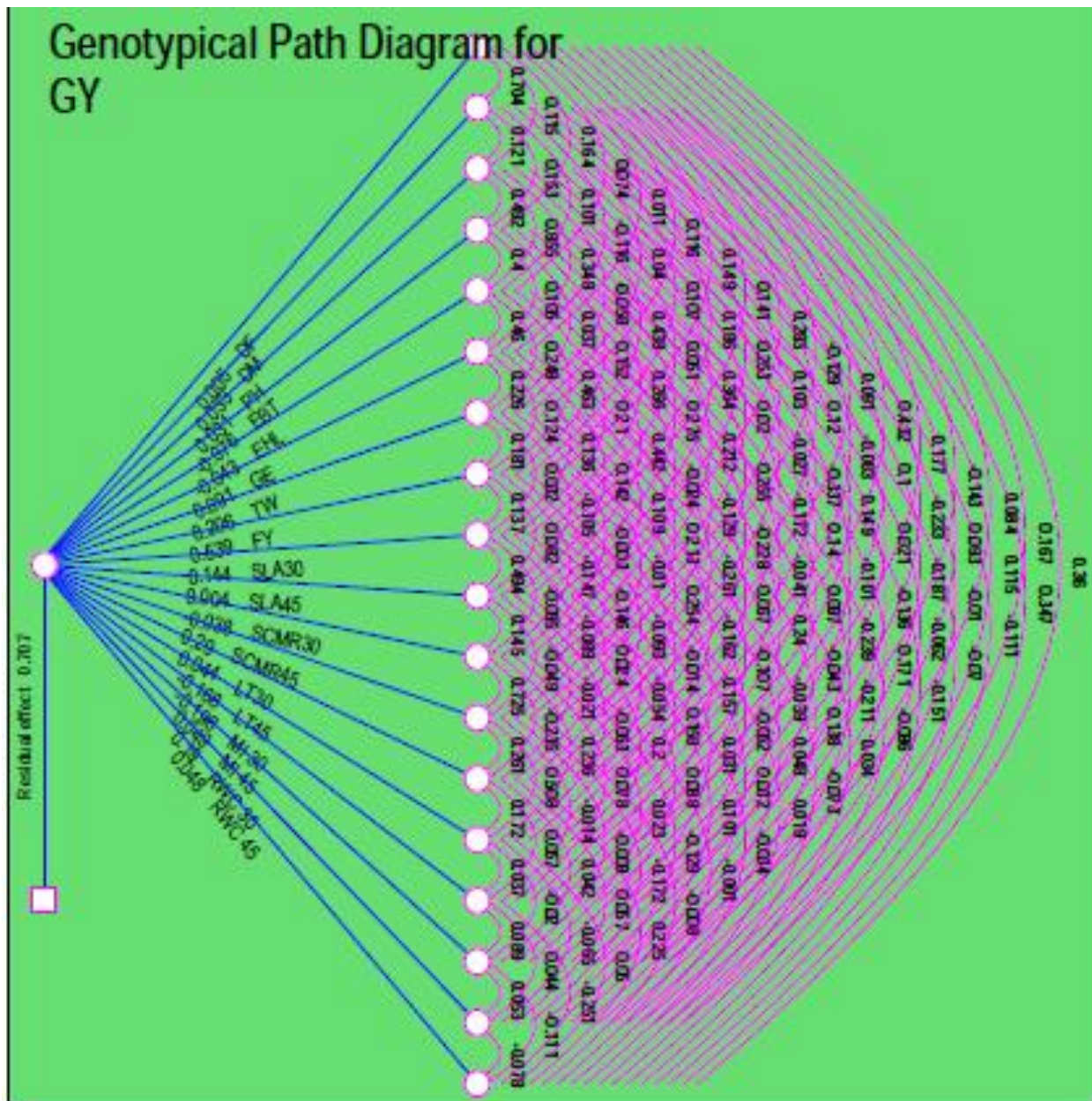


Fig. 4.7. Genotypic path diagram of grain yield, yield and physiological components in 60 genotypes of foxtail millet

Chapter V

SUMMARY AND CONCLUSIONS

Foxtail millet, a nutritionally superior and one of the most drought tolerant warm season cereal crop is predominantly used as staple food grain as source of feed and fodder in drier areas, where low, erratic rainfall, nutrient poor soils prevail. It is well adapted to temperate, sub-tropical and tropical Asia. It is essentially dry land crop on marginal and sub marginal lands all through the world.

The present investigation entitled “**Studies on genetic divergence and character association for yield and drought related traits in foxtail millet (*Setaria italica* L.)**” was carried out to identify the elite genotypes for drought situation which can serve as donors for hybridization programme. The required information on the following objectives has been obtained in the present investigation *viz.*,

- a) Nature and magnitude of genetic variability for yield, yield attributes and physiological traits.
- b) Screening of thermo tolerant foxtail millet genotypes at seedling stage using TIR technique.
- c) Screening of stress tolerant foxtail millet genotypes at germination stage using polyethylene glycol (PEG) solution.
- d) Extent of genetic divergence among yield, yield components and physiological characters.
- e) Extent of correlation and path analysis among yield, yield attributes and physiological parameters.

The field experiment was conducted at Agricultural Research Station, Perumallapalle, Tirupati, Andhra Pradesh. The experimental material consisting of 60 lines including seven checks were grown under rainfed condition during *kharif*, 2016 in a Randomized Block Design (RBD) with two replications. The observations were recorded on randomly selected five plants for nine yield components *viz.*, plant height, ear bearing tillers/ hill, ear head length, test weight, grains/ ear head, grain yield/ plant, fodder yield/ plant and plot basis for days to 50% flowering, days to maturity and five physiological traits *viz.*, leaf temperature at 30 and 45 DAS, SPAD chlorophyll meter reading at 30 and 45 DAS, specific leaf area at 30 and 45 DAS, relative injury at 30 and 45 DAS and relative water content at 30 and 45 DAS.

The analysis of variance revealed the existence of highly significant differences among the genotypes for all the traits studied. The genotypes, SiA 3636 followed by sri Lakshmi (Check), Narasimharaya (Check), SiA 3598, SiA 3604, SiA 3539, SiA 3584, SiA 3628, SiA 3611 and Prasad (Check) registered high *per se* performance for most of the traits.

From the studies of Temperature Induction Response (TIR) technique, out of 60 genotypes evaluated, Prasad (Check), SiA 3580, SiA 3604, SiA 3618 and SiA 3623 showed the highest thermo tolerance in terms of 75 to 100 per cent seedlings survival without considerable reduction in root and shoot growth. These varieties are able to survive even when they were exposed to lethal temperature (59°C).

From the experiment using polyethylene glycol (PEG) induced drought stress technique, among 60 genotypes, Suryanandi (Check), Prasad (Check), SiA 3551 and SiA 3615 showed the highest germination per cent, lower reduction of plumule and radicle length during germination on different concentrations of polyethylene glycol *viz.*, control, 15%, 20%, 25%, and 30% in 100 ml water solution. These genotypes showed the higher tolerance to water stress conditions without considerable reduction

in root and shoot growth. These varieties are able to survive even when they were exposed to high drought conditions.

Prasad was promising for highest thermotolerance and tolerance to water stress conditions.

The estimates of GCV and PCV were high for test weight, membrane injury at 30 DAS, fodder yield per plant, ear bearing tillers per hill, number of grains per ear head, grain yield per plant, membrane injury at 45 DAS, specific leaf area at 30 DAS, leaf temperature at 45 DAS and specific leaf area at 45 DAS indicating the presence of high genetic variability for these traits and were less influenced by the environment. Thus, direct selection for these traits would result in further improvement of yield under rainfed condition. Moderate estimates of GCV and PCV were recorded for plant height, SCMR at 30 DAS, ear head length and SCMR at 45 DAS. Hence, direct selection for these traits may be misleading if adopted for improvement programme through these traits.

The results of Mahalanobis's D^2 analysis revealed considerable variability among the sixty genotypes and were grouped into thirteen clusters. Among, thirteen clusters formed, cluster I contained maximum number of 36 genotypes whereas Clusters, III, V, VI, VII, VIII, X, XI, XII and XIII comprised of only one genotype in each cluster. The inter-cluster distance was maximum between cluster IX and IV followed by between cluster II and I. Selection of parents from such clusters for hybridization programme would result in generation of novel recombinants. It revealed that among the nineteen characters, relative membrane injury at 30 DAS followed by relative membrane injury at 45 DAS, number of grains per ear head, relative water content at 30 DAS, specific leaf area at 45 DAS and leaf temperature at 45 DAS contributed maximum towards genetic divergence.

The correlation of yield, yield components and physiological traits revealed strong positive association of fodder yield per plant followed by number of grains per ear head, test weight, ear bearing tillers per hill, days to maturity, ear head length and days to 50% flowering whereas SPAD chlorophyll meter reading followed by relative water content, relative injury with grain yield per plant at both phenotypic and genotypic levels. *Inter se* associations revealed that fodder yield per plant, number of grains per ear head, test weight, ear bearing tillers per hill, days to maturity, ear head length and days to 50% flowering and physiological traits *viz.*, SPAD chlorophyll meter reading, relative water content and relative injury exhibited strong positive inter correlations among themselves as well as with grain yield per plant. Hence, these traits should be considered in formulating selection procedures for the improvement of elite genotypes for grain yield in foxtail millet.

A perusal of path coefficient analysis revealed that high positive direct effect on grain yield per plant was exerted by fodder yield per plant followed by test weight, number of grains/ ear head, days to 50% flowering, plant height, ear head length and ear bearing tillers per hill in the decreasing order of magnitude whereas among physiological characters SPAD chlorophyll meter reading followed by relative water content contributed positive direct effects on grain yield. The maximum positive indirect effects on grain yield per plant was exerted by the yield attributing traits, fodder yield per plant, test weight, grains per ear head, days to 50% flowering, plant height, ear head length and ear bearing tillers per hill respectively, while among physiological traits studied by SPAD chlorophyll meter reading and relative water content. Hence, selection based on these traits would be effective in increasing the grain yield per plant.

FUTURE LINE OF WORK

1. Based on *per se* performance among 60 germplasm lines, SiA 3636 and Sri Lakshmi (Check) were found to be desirable for development of drought tolerant foxtail millet genotypes with high grain yield potential.
2. Based on D²-analysis, SiA 3551, SiA 3545 and SiA 3596 lines were highly divergent while SiA 3636, Narasimharaya (Check), SiA 3569, SiA 3551, Suryanandi (Check), SiA 3613 and SiA 3618 registered high cluster mean values for most of the traits hence, these genotypes serve as potential source for hybridization programme to obtain high yielding foxtail millet genotypes for rainfed environment.
3. The drought inherent traits of promising identified genotypes may be subjected to further testing under multi-drought environment conditions to testify their intrinsic nature of drought adaptation features.

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APPENDIX –I

Weekly mean meteorological data during the period of crop growth

Standard Week	Date		Temperature (°C)				Mean relative humidity (RH %)		Rainfall (mm)		No. of rainy days	
	From	To	Max.		Min.		A	DN	A	DN	A	DN
			A	DN	A	DN						
31	30-07-16	05-08-16	33.2	-0.3	25.3	-0.2	56.00	0.0	0	20.1	0	1
32	06-08-16	12-08-12	35.6	-0.2	26	-0.3	57.00	0.0	0	19.3	0	1
33	13-08-16	19-08-16	35.9	-1.6	26.2	-1.4	57.80	4.8	0	43.5	0	3
34	20-08-16	26-08-16	35.5	-1.7	26.9	-2.3	58.90	6.1	0	44.3	0	2
35	27-08-16	02-09-16	33.2	6.4	25.5	-1.2	65.80	-1.5	90.3	-55.8	3	-1
36	03-09-16	09-09-16	34.2	0	24.9	-0.6	56.60	8.0	3	38	1	1
37	10-09-16	16-09-16	32	-0.8	25	-1.1	65.30	2.2	0	30.4	0	2
38	17-09-16	23-09-16	33.3	1.2	24.3	-0.3	65.90	-1.0	22.4	-4.1	3	-2
39	24-09-16	30-09-16	34.5	0	25.9	-1.8	60.30	4.6	1	29.5	0	1
40	01-10-16	07-10-16	34.4	-1	25.8	-2.2	62.90	2.8	6.2	26.1	1	0
41	08-10-16	14-10-16	35.8	-2.2	25.1	-2.3	55.30	11.1	0	25.1	0	2
42	15-10-16	21-10-16	35.6	-2.5	21.9	0.5	53.90	15.8	0	28	0	2
43	22-10-16	28-10-16	35.3	-3.9	20.5	1.5	52.20	20.9	0	52.1	0	3
44	29-10-16	04-11-16	32.5	-2	22.24	-10.8	68.30	8.1	11.2	54.3	2	0

A: Actual DN: Deviation from decennial mean

* Dry spells for more than a week at seedling stage, vegetative stage and flowering stage

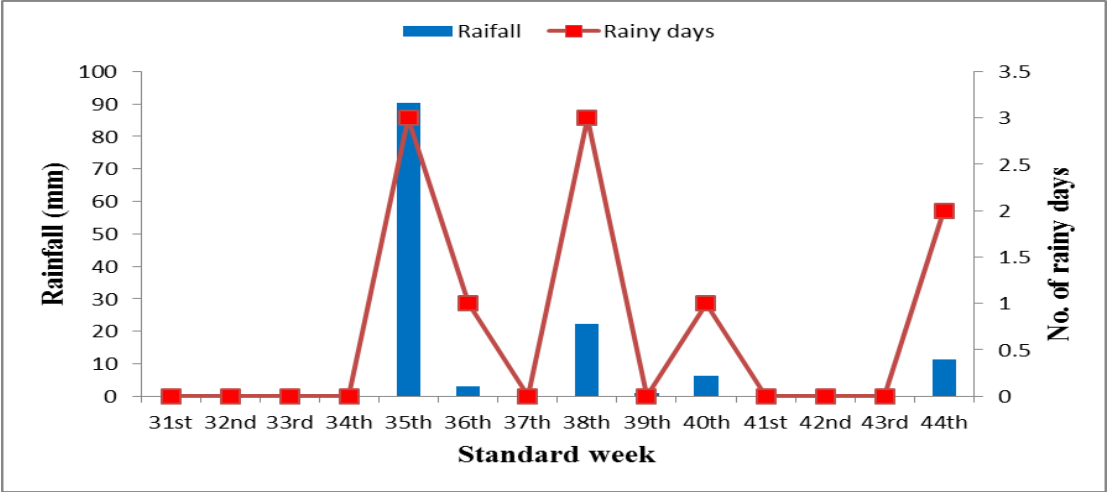
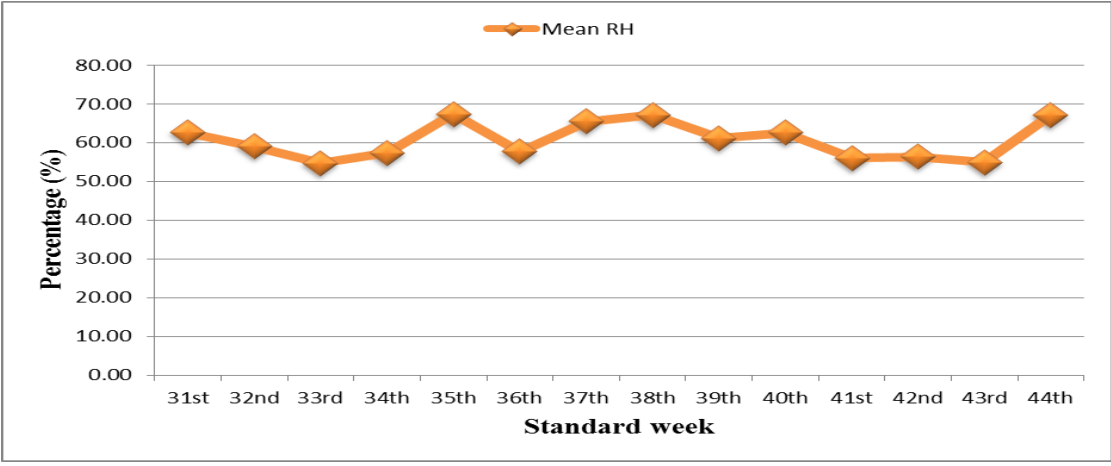
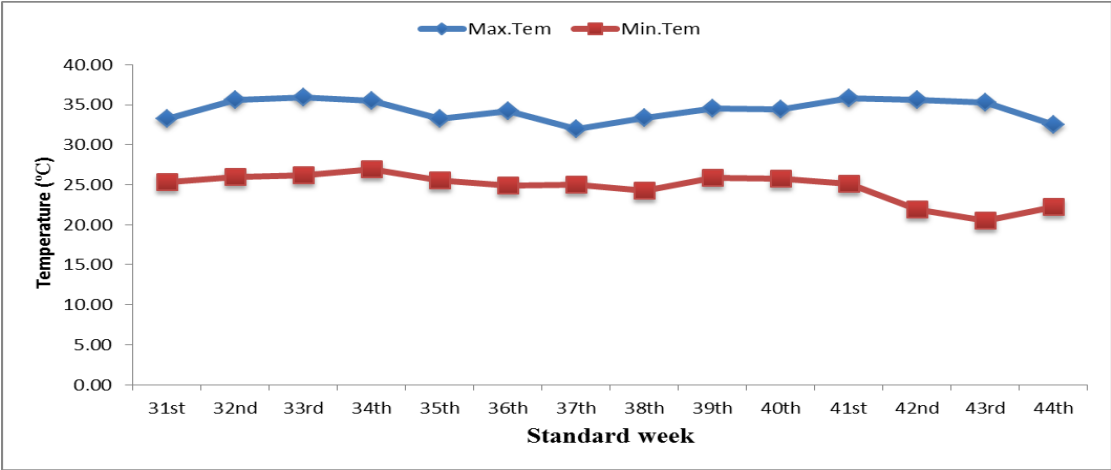


Fig. 1. Standard week wise meteorological data during the crop period

**STUDIES ON GENETIC DIVERGENCE AND CHARACTER
ASSOCIATION FOR YIELD AND DROUGHT RELATED TRAITS IN
FOXTAIL MILLET (*Setaria italica* L.)**

Name of the student : S. J. BHEEMESH

Major advisor : Dr. M. SUBBA RAO

ABSTRACT

The present investigation was undertaken in Foxtail millet during *kharif*, 2016 to study genetic variability, genetic divergence, character association and path analysis of sixty germplasm lines including seven checks for different morpho-physiological characters related to drought tolerance along with yield and yield components.

The genotypes SIA 3636, Sri Lakshmi, Narasimharaya, SIA 3598 and SIA 3604 recorded superiority for most of the traits. Five genotypes *viz.*, Prasad, SIA 3580, SIA 3604, SIA 3618 and SIA 3623 showed the highest thermo tolerance in terms of 75 to 100 per cent seedlings survival with minimal reduction in root and shoot growth. From the experiment polyethylene glycol (PEG) induced drought stress technique, Suryanandi, Prasad, SIA 3551 and SIA 3615 showed the highest germination per cent, lower reduction of plumule and radicle length. These varieties are able to survive even when they were exposed to high drought conditions.

Higher GCV, PCV, heritability and genetic advance as per cent mean were recorded for test weight, membrane injury at 30 DAS, fodder yield, ear bearing tillers per hill and grains per ear head indicating that simple selection could be practiced for improving these traits under rainfed condition.

All the genotypes were grouped into 13 clusters based on D^2 analysis. The inter-cluster distance was maximum between cluster IX and IV followed by cluster II and I. Selection of parents from such clusters for hybridization programmes would result in novel recombinants. Relative membrane injury contributed maximum towards genetic divergence.

Fodder yield/ plant, number of grains per ear head, test weight, ear bearing tillers/ hill, days to maturity, SPAD chlorophyll meter reading and relative water content exhibited highly significant positive association with grain yield per plant. Fodder yield per plant, test weight, number of grains/ ear head, SPAD chlorophyll meter reading, relative water content exerted maximum positive direct effect on grain yield besides other traits. Hence, emphasis should be made on these traits in the selection programme to evolve high yielding genotypes in foxtail millet under rainfed condition.