CHARACTERIZATION OF PLANT TYPES AND STABILITY ANALYSIS IN PROMISING GENOTYPES OF *Gossypium hirsutum* L. UNDER RAINFED SITUATION

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CERTIFICATE

This is to certify that the thesis entitled "**CHARACTERIZATION OF PLANT TYPES AND STABILITY ANALYSIS IN PROMISING GENOTYPES OF *Gossypium hirsutum* L. UNDER RAINFED SITUATION**" submitted by **Ms. SOUMYA J.**, for the degree of **MASTER OF SCIENCE (AGRICULTURE)** in **GENETICS AND PLANT BREEDING,** to the University of Agricultural Sciences, Dharwad is a record of research work done by her during the period of her study in this university under my guidance and the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar titles.

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Introduction

1. INTRODUCTION

Cotton, the king of fibre, known for its desirable properties is also called White Gold due to its global importance in agriculture as well as industrial economy. In India, it provides direct employment to around 35 million people (Mohankumar and Katageri, 2017). It is an important fibre yielding cash crop with unique spinnable cellulosic textile fibre with 95 per cent cellulose.

Cotton is harvested as ‘seed cotton’ which is then ginned to separate the seed and lint. The long ‘lint’ fibres are further processed by spinning to produce yarn which is knitted or woven into fabrics. Cotton contributes to 35 per cent of the global fabric needs and 60 per cent of clothing in India. Cotton is cultivated by about 80 countries (CICR, 2014).

The major cotton producing countries are USA, China, India, Pakistan, Uzbekistan and Turkey. These countries contribute about 85 per cent to the global cotton production. India is the largest cotton growing country with an area of 126.55 lakh hectares and 400.00 lakh bales (1bale=170 kg lint) production, with productivity of 537 kg/ha. Karnataka produces 28 lakh bales of cotton from an area of 7.60 lakh hectares with a productivity of 626 kg/ha (Anon, 2015).

The cotton species recognized in the world are about 50, of which 4 are cultivated. Two of these (*Gossypium arboreum* and *Gossypium herbaceum*) are diploids, and two (*Gossypium hirsutum* and *Gossypium barbadense*) are tetraploids. More than 80 per cent of the world’s cotton area is covered by tetraploids. However, diploid cottons are cultivated in Asia and the Middle East. India is the only country where all the cultivated species and some of their hybrid combinations are commercially grown (Khadi *et al*. 2001).

In cotton, usually farmers adopt plant spacing and plant density according to their traditional methods of planting rather than the varietal requirement, resulting in yield penalty. Cotton genotypes with a short stature and occupying lesser field space can generally tolerate high density planting. It has been seen that higher planting density with ultra-narrow rows has proved to be a viable cotton production system compared with conventionally grown cotton system with wider rows and low planting density in different cotton genotypes (Witten and Cothren, 2000; Nicholas *et al*. 2004).

In the current Bt. cotton scenario of the country, varieties are hardly being grown. Wherever they are still in cultivation, the productivity is less because of low plant population and non-availability of improved varieties. Plant population is crucial for attaining optimum crop growth and yield. In cotton, plant spacing has effects on the growth and yield characteristics of the plant. One of the options for maintaining yield per unit area is optimum plant population per unit land area. Every variety has its own plant to plant distance requirements. Some plants are of erect nature, requiring less space and with higher planting density can give higher yield. Such a plant type is now called, ‘compact type’. The other type is bushy, occupying more horizontal as well as vertical space resulting in low plant density and lower yields. These are the traditionally grown ‘robust’ types. Maximum yield can be obtained by maintaining optimum plant population according to the plant morphological characteristics (Asghar *et al* 2009).

The compact plant type also seems to bring with it early maturity thus providing comparatively increased economic returns on account of reduced cost of inputs and crop management. Short season cottons can also fit very well in cropping patterns where sequence of other crops succeed the cotton crop for sustainable agriculture (Jatoi *et al* 2012).

Characterization of early maturing upland cotton varieties with morphologically distinguished traits can help breed short season cottons. Kairon and Singh (1996), proposed reduction in monopodia, profuse flowering, higher boll setting and opening at earlier stages of crop growth, less and smaller leaves, short internode length, semi-determinate types, lower sympodial node number, short sympodial branches, cluster fruit bearing types, medium boll size, sub-okra types and dwarf stature plants to determine earliness in cotton. Baloch and Baloch (2004) characterized earliness in 15 phenotypically diversified hirsutum varieties. They observed them as having sympodial branches at lower nodes, short sympodial branches, short internodes, medium or smaller leaves, moderate boll size, higher per cent of boll opening at earlier stages of crop growth which turned out to be very important plant attributes for short season/early maturing cotton varieties. Apart from the above traits, synchronous maturity is also a characteristic of compact cotton genotypes making them ideally suited for machine picking. With these benefits, compact genotypes appear to be a viable option in the coming days.

Assessment of the extent and distribution of genetic variation in a crop species will help in genetic resources conservation and plant improvement. It is a pre-requisite to embark up on any crop improvement program. The genetic variability of traits in the newly developed genotypes is being assessed in the present study.

Yield is a complex character dependent on a number of other characters and is highly influenced by genetic factors as well as environmental fluctuations. The genotype (G) × environment (E) interaction is an important aspect of both plant breeding programs and the introduction of new genotypes. Thus, stability studies quantifying G × E interaction will help identify promising genotypes suited for a specific environment. The present study is on a collection of predominantly compact genotypes which when grown in different planting densities are automatically exposed to differing environmental pressures. The premise was, a truly compact genotype would show less G × E interaction and would be a candidate for high density planting which increases per unit area production.

Keeping all the above in view, an attempt has been made in the present study to evaluate 25 new genotypes with three check varieties under rainfed situation with the following objectives.

1. Assessment of genetic variability among cotton genotypes with differing plant type.
2. Characterization of plant type and stability analysis of these genotypes for yield and yield components.

Review of Literature

2. REVIEW OF LITERATURE

In the present chapter an attempt has been made to review studies on the evaluation of genotypes for yield and its components in different planting densities, assessment of genotypes for genetic variability, correlation and path analyses, characterization of plant type and genotype x environment interaction for identification of stable genotypes. The literature has been reviewed under the following heads.

2.1 Genetic variability
2.2 Heritability and genetic advance
2.3 Association analysis
2.4 Path coefficient analysis
2.5 Plant type characterization
2.6 Stability analysis

2.1 Genetic variability

The genetic variability present in the available genotypes may be utilized either for direct selection or for hybridization programs with an objective to identify promising genotypes for cultivation. In cotton, the available literature on variability is reviewed and presented below.

2.1.1 Plant height

A genotypic and phenotypic coefficient of variability of 10.39 and 11.50 per cent respectively, in *G. hirsutum* was observed by Krishnarao and Mary (1990). Similarly Mane and Bhatade (1992), Sambamurthy *et al.* (1995), Kowsalya and Raveendran (1996), Lavanya Kumar (2004), Kale and Annapurve (2007), Do thi *et al.* (2008), Ravi Kumar Patnaik and Parshuram Sial (2010), Vinodhana Kumari *et al.* (2013), Dahiphale *et al.* (2015), Liaqat *et al.* (2015), Latif *et al.* (2015), Baloch *et al.* (2016) and Manjunath Paloti (2016) observed significant varietal differences for plant height whereas Singh *et al.* (2009), Mohankumar and Katageri (2017), Pujer *et al.* (2014) and Nishanth *et al.* (2015) reported moderate variability. Arega Gashaw (2013) and Ahsan *et al.* (2015) observed narrow variability for plant height.

2.1.2 Number of sympodia per plant

Krishnarao and Mary (1990), Tian *et al.* (1994), Sambamurthy *et al.* (1995), Kowsalya and Raveendran (1996), Sumathi and Nadarajan (1996), Kale and Annapurve

(2007), Shakti *et al.* (2007), Do Thi *et al.* (2008), Khan *et al.* (2009), Singh *et al.* (2009), Ravi Kumar Patnaik and Parshuram Sial (2010), Latif *et al.* (2015), Liaqat *et al.* (2015), Dahiphale *et al.* (2015) and Baloch *et al.* (2016) observed wider genetic variability for this trait. While Reddy and Pradeep (2001) and Girase and Mehetre (2002) reported narrow genetic variability. Vinodhana Kumari *et al.* (2013), Nishanth *et al.* (2015) and Manjunath Paloti (2016) reported moderate genetic variability.

2.1.3 Sympodial length at 50 per cent plant height

Lavanya Kumar (2004) and Gururaj (2006) revealed narrow genetic variability for this trait, while Pradeep and Sumalini (2005) and Manjunath Paloti (2016) reported moderate variability for sympodial length.

2.1.4 Number of bolls per plant

Rokadia *et al.* (1996), Siddiqui (1996), Sumathi and Nadarajan (1996), Jagtap and Mehetre (1998), Reddy and Pradeep (2001), Dheva and Potdhuke (2002), Gururaj (2006), Kale and Annapurve (2007), Do Thi *et al.* (2008), Khan *et al.* (2009), Singh *et al.* (2009), Butool *et al.* (2010), Arega Gashaw (2013), Vinodhana Kumari *et al.* (2013), Pujer *et al.* (2014), Latif *et al.* (2015), Ahsan *et al.* (2015), Dahiphale *et al.* (2015), Baloch *et al.* (2016) and Manjunath Paloti (2016) observed wider genetic variability for this trait. Nishanth *et al.* (2015) reported moderate variability whereas, Girase and Mehetre (2002) observed narrow genetic variability.

2.1.5 Boll weight

Rokadia *et al.* (1996), Sumathi and Nadarajan (1996), Jagtap and Mehetre (1998), Kale and Annapurve (2007), Do Thi *et al.* (2008), Khan *et al.* (2009), Singh *et al.* (2009), Butool *et al.* (2010), Ravi Kumar Patnaik and Parshuram Sial (2010), Vinodhana Kumari *et al.* (2013), Liaqat *et al.* (2015), Latif *et al.* (2015) and Baloch *et al.* (2016) observed wider genetic variability for this trait whereas, Reddy and Pradeep (2001) and Pujer *et al.* (2014) reported narrow genetic variability. Ahsan *et al.* (2015), Singh *et al.* (2009), Nishanth *et al.* (2015) and Manjunath Paloti (2016) observed moderate variability for boll weight.

2.1.6 Ginning out turn

Dedaniya and Pethani (1994), Kowsalya and Raveendran (1996), Dheva and Potdhuke (2002), Verma *et al.* (2006), Ratna Kumari and Subbaramamma (2006), Do Thi *et* *al.* (2008), Latif *et al.*(2015), Dahiphale *et al.* (2015), Ahsan *et al.* (2015) and Baloch *et al.* (2016) reported high genotypic and phenotypic coefficients of variability for this trait. Faqir *et al.* (1984), Rajarathinam *et al.* (1993), Sambamurthy *et al.* (1994), Vinodhana Kumari *et al.*(2013), Nishanth *et al.* (2015) and Manjunath Paloti (2016) observed considerably low amount of variation for ginning outturn.

2.1.7 Seed index

Chhabra *et al.* (1995), Sankarapandian *et al.* (1998), Neelima and Potdhuke (2002), Ratna Kumari and Subbaramamma (2006), Do Thi *et al.* (2008), Kulkarni *et al.* (2011), Liaqat *et al.* (2015), Latif *et al.* (2015) and Baloch *et al.* (2016) reported wider genetic variability. Rao *et al.* (2001), Vinodhana Kumari *et al.* (2013), Ahsan *et al.* (2015) Nishanth *et al.* (2015) and Manjunath Paloti (2016) observed narrow genetic variability for seed index.

2.1.8 Lint index

Siddiqui (1996), Sandhu and Badesha (1997), Sankarapandian *et al.* (1998), Ratna Kumari and Subbaramamma (2006), Do Thi *et al.* (2008), Kulkarni *et al.* (2011), Liaqat *et al.*(2015), Ahsan *et al.* (2015) and Dahiphale *et al.* (2015) reported wider genetic variability. Narrow genetic variability was reported by Mohankumar and Katageri (2017), Jagtap and Mehetre (1998) and Rao *et al.* (2001). Moderate variability was observed by Vinodhana Kumari *et al.* (2013), Nishanth *et al.* (2015) and Manjunath Paloti (2016).

2.1.9 Seed cotton yield

Seed cotton yield is a complex trait as it has several contributing characters. The worth of any cultivar is judged primarily by its potential for giving higher yields. Krishnarao and Mary (1990) reported genotypic coefficient of variance of 24.20 and 22.20 and phenotypic coefficient of variance of 25.44 and 26.6 per cent respectively. Kowsalya and Raveendran (1996) observed highest phenotypic coefficient of variance of 38.67 per cent than the other characters. Rokadia *et al.* (1996), Siddiqui (1996), Sumathi and Nadarajan (1996), Jagtap and Mehetre (1998), Sankarapandian *et al.* (1998), Ahuja and Tuteja (2000), Reddy and Pradeep (2001), Gururaj (2006), Gitte *et al.* (2007), Do Thi *et al.* (2008), Khan *et al.* (2009), Singh *et al.* (2009), Ravi Kumar Patnaik and Parshuram Sial (2010), Vinodhana Kumari *et al.* (2013), Farooq *et al.*(2014), Pujer *et al.* (2014), Mohankumar and Katageri (2017), Dahiphale *et al.* (2015), Nishanth *et al.* (2015), Baloch *et al.* (2016) and Manjunath Paloti (2016) observed wider genetic variability for this character. Ahsan *et al.* (2015) observed moderate variability for seed cotton yield.

2.1.10 Total biomass

Parre Suman (2012) and Manjunath Paloti (2016) observed high variability for this character.

2.1.11 Fibre length

Wider genetic variability was reported by Siddiqui (1996), Sumathi and Nadarajan (1996), Rao *et al.* (2001), Arega Gashaw (2013), Vinodhana Kumari *et al.* (2013), Liaqat *et al.* (2015), Dahiphale *et al.* (2015) and Baloch *et al.* (2016). While narrow genetic variability by Sangeetha (1998), Sankarapandian *et al.* (1998), Kumar *et al.* (2000), Reddy and Pradeep (2001), Neelima and Potdukhe (2002), Herring *et al.* (2004) and Patil Malagouda *et al.* (2014). Moderate genetic variability for this trait was reported by Nizamani *et al.* (2017).

2.1.12 Micronaire value

Rao *et al.* (2001), Neelima and Potdukhe (2002), Arega Gashaw (2013), Vinodhana Kumari *et al.* (2013), and Liaqat *et al.* (2015) reported wider genetic variability. Sangeetha (1998), Sankarapandian *et al.* (1998), Kumar *et al.* (2000), Reddy and Pradeep (2001), Herring *et al.* (2004), Patil Malagouda *et al.* (2014) and Manjunath Paloti (2016) reported narrow genetic variability.

2.1.13 Fibre strength

Narrow genetic variability was reported by Sangeetha (1998), Kumar *et al.* (2000), Rao *et al.* (2001), Reddy and Pradeep (2001), Neelima and Potdukhe (2002), Herring *et al.* (2004), Arega Gashaw (2013) and Patil Malagouda *et al.* (2014). Contrastingly Vinodhana Kumari *et al.* (2013), Liaqat *et al.* (2015) and Manjunath Paloti (2016) reported high variability for this character.

2.2 Heritability and genetic advance

Heritability and genetic advance are important selection parameters. Hanson *et al.* (1956) defined heritability in broad sense as the ratio of genotypic variance to the total genetic variance in the non-segregating populations. Thus, heritability is the heritable portion of phenotypic variance. It is a good index of transmission of characters from parents to their offspring (Falconer, 1981). The estimates of heritability help the plant breeder in selection of elite genotypes from diverse genetic populations. Genetic advance measures the amount of progress that could be expected with selection in a character. However, character showing high heritability need not exhibit high genetic advance (Johnson *et al.*, 1955). High heritability coupled with high genetic advance indicates that the improvement in a character could be made by simple selection.

2.2.1 Plant height

Siddiqui (1996), Dheva and Potdhuke (2002), Do Thi *et al.* (2008), Singh *et al.* (2009), Ravi Kumar Patnaik and Parshuram Sial (2010), Pujer *et al.* (2014), Farooq *et al.* (2015) Liaqat *et al.* (2015), Baloch *et al.* (2016) and Manjunath Paloti (2016) reported high heritability for plant height. Sambamurthy *et al.* (1994) and Verma *et al.* (2006) reported moderate heritability. Neelima and Potdhuke (2002) and Kale and Annapurve (2007) reported high heritability combined with high genetic advance for this trait. Vinodhana Kumari *et al.* (2013), Dahiphale *et al.* (2015), Ahsan *et al.* (2015) and Nishanth *et al.* (2015) observed high heritability with moderate genetic advance.

2.2.2 Number of sympodia per plant

Sumathi and Nadarajan (1996), Sangeetha (1998), Neelima and Potdukhe (2002), Kale and Annapurve (2007), Gitte *et al.* (2007), Shakti *et al.* (2007), Ravi Kumar Patnaik and Parshuram Sial (2010), Liaqat *et al.* (2015), Farooq *et al.* (2015), Mohankumar and Katageri (2017), Nishanth *et al.* (2015) and Latif *et al.* (2015) reported high heritability and high genetic advance for number of sympodia per plant, whereas Krishnarao and Mary (1990), Singh *et al.* (2009) and Farooq *et al.* (2014) reported moderate heritability. Reddy and Pradeep (2001) and Manjunath Paloti (2016) observed high heritability with low genetic advance.

2.2.3 Sympodial length at 50 per cent plant height

Lavanya Kumar (2004) and Gururaj (2006) found moderate heritability and moderate GAM. Moderate to high heritability was reported by Pradeep and Sumalini (2005) and Manjunath Paloti (2016).

2.2.4 Number of bolls per plant

High heritability and high genetic advance were reported for number of bolls per plant by Butany *et al.* (1966), Chhabra *et al.* (1995), Rokadia *et al.* (1996), Sumathi and Nadarajan

(1996), Jagtap and Mehetre (1998), Reddy and Pradeep (2001), Girase and Mehetre (2002), Neelima and Potdukhe (2002), Kaushik *et al.* (2003), Kale and Annapurve (2007), Singh *et al.* (2009), Vinodhana Kumari *et al.* (2013), Pujer *et al.* (2014), Latif *et al.* (2015), Farooq *et al.* (2015), Ahsan *et al.* (2015), Nishanth *et al.* (2015) and Manjunath Paloti (2016). Li (1994) and Tian *et al.* (1994) reported moderate to high heritability. Javali (1984), Dahiphale *et al.* (2015) and Mohankumar and Katageri (2017), observed moderate heritability.

2.2.5 Boll weight

Chhabra *et al.* (1995), Rokadia *et al.* (1996), Sumathi and Nadarajan (1996), Jagtap and Mehetre (1998), Reddy and Pradeep (2001), Kale and Annapurve (2007), Gitte *et al.* (2007), Shakti *et al.*(2007), Singh *et al.* (2009), Ravi Kumar Patnaik and Parshuram Sial (2010), Farooq *et al.* (2014), Farooq *et al.* (2015), Ahsan *et al.* (2015) and Nishanth *et al.*(2015) observed high heritability and high genetic advance for boll weight. High heritability and moderate genetic advance were reported by Mane and Bhatade (1992), Sambamurthy (1999) Pujer *et al.* (2014), Manjunath Paloti (2016) and Mohankumar and Katageri (2017). Javali (1984) and Liaqat *et al.* (2015) reported low heritability for boll weight.

2.2.6 Ginning out turn

Neelima and Potdhukhe (2002) reported high heritability and high genetic advance for this trait. Kowsalya and Raveendran (1996), Do Thi *et al.* (2008), Gitte *et al.* (2007), Farooq *et al.* (2014), Liaqat *et al.* (2015), Dahiphale *et al.* (2015), Mohankumar and Katageri (2017), Ahsan *et al.* (2015), Nishanth *et al.* (2015) and Manjunath Paloti (2016) observed high heritability and moderate genetic advance. Butany *et al.* (1966) and Siddiqui (1996) reported low genetic advance.

2.2.7 Seed index

High heritability and high genetic advance were reported by Chhabra *et al.* (1995), Siddiqui (1996), Jagtap and Mehetre (1998), Reddy and Pradeep (2001), Neelima and Potdhuke (2002), Ratna Kumari and Subbaramamma (2006), Do Thi *et al.* (2008), Kulkarni *et al.* (2011), Ahsan *et al.* (2015), Liaqat *et al.* (2015), Nishanth *et al.* (2015) and Manjunath Paloti (2016). Chhabra *et al.* (1995), Sankarapandian *et al.* (1998), Neelima and Potdukhe (2002) and Dahiphale *et al.* (2015) observed high heritability and low genetic advance. Reddy and Pradeep (2001) observed low heritability and low genetic advance. Mohankumar and Katageri (2017) reported high heritability with low genetic advance.

2.2.8 Lint index

Chhabra *et al.* (1995), Siddiqui (1996), Sumathi and Nadarajan (1996), Sankarapandian *et al.* (1998), Reddy and Pradeep (2001), Neelima and Potdukhe (2002), Ratna Kumari and Subbaramamma (2006), Do Thi *et al.* (2008), Kulkarni *et al.* (2011), Dahiphale *et al.* (2015), Liaqat *et al.* (2015), , Ahsan *et al.* (2015), Nishanth *et al.* (2015), Manjunath Paloti (2016) and Mohankumar and Katageri (2017) observed high heritability and high genetic advance. Jagtap and Mehetre (1998), Reddy and Pradeep (2001) and Neelima and Potdukhe (2002) observed high heritability and low genetic advance.

2.2.9 Seed cotton yield

Seed cotton yield is a complex character and highly influenced by environmental fluctuations. Naidu and Katarki (1968) reported low heritability for this character. Moderate heritability with high genetic advance was reported by Krishnarao and Mary (1990). Javali (1984) reported moderate amount of heritability. Sambamurthy *et al.*(1995), Siddiqui (1996), Sambamurthy (1997), Jagtap and Mehetre (1998), Ahuja and Tuteja (2000), Reddy and Pradeep (2001), Neelima and Potdukhe (2002), Kaushik *et al.* (2003), Do Thi *et al.* (2008), Khan *et al.* (2009), Singh *et al.* (2009), Pujer *et al.* (2014), Farooq *et al.* (2015), Dahiphale *et al.* (2015), Ahsan *et al.* (2015), Nishanth *et al.* (2015) and Manjunath Paloti (2016) reported high heritability with high genetic advance for seed cotton yield. High heritability with moderate to high genetic advance was reported by Mohankumar and Katageri (2017).

2.2.10 Total biomass

Parre Suman (2012) and Manjunath Paloti (2016) observed high heritability coupled with high genetic advance for this character.

2.2.11 Fibre length

High heritability and high genetic advance were reported by Sumathi and Nadarajan (1996), Jagtap and Mehetre (1998), Sangeetha (1998), Rao *et al.* (2001), Herring *et al.* (2004), McCarthy *et al.* (2004), Patil Malagouda *et al.* (2014) whereas, high heritability and low genetic advance were reported by Vinodhana Kumari *et al.* (2013). Low heritability with low genetic advance was reported by Sankarpandian *et al.* (1998), Dahiphale *et al.* (2015), Liaqat *et al.* (2015) and Manjunath Paloti (2016).

2.2.12 Micronaire value

Rao *et al.* (2001), Liaqat *et al.* (2015) and Manjunath Paloti (2016) reported high heritability and high genetic advance. High heritability and low genetic advance were reported by Reddy and Pradeep (2001), Herring *et al.* (2004) and Vinodhana Kumari *et al.* (2013).

2.2.13 Fibre strength

High heritability with high genetic advance was reported by Reddy and Pradeep (2001), McCarthy *et al.* (2004), Liaqat *et al.* (2015) and Manjunath Paloti (2016). High heritability with low genetic advance was reported by Rao *et al.* (2001), Herring *et al.* (2004) and Vinodhana Kumari *et al.* (2013).

2.3 Association studies

Improvement in yield largely depends upon the improvement of its component traits. It, therefore, becomes essential to know the association of important yield component characters with yield. Galton (1889) put forward the concept of correlation which was elaborated by Fisher (1918) and Woodworth (1931). He pointed that little is known about the various components that make yield, their relation to one another and their genetic behaviour and it was suggested that yield attributes should be fully analysed before a breeding program is undertaken.

The method of estimation of correlation and their implications in selection program was illustrated by Johanson *et al.* (1955). The correlations are useful in formulating the criteria for indirect selection. Most of the plant breeding programs are aimed at augmentation of yield, which is an intricate character dependent on many other component characters which are further related amongst them. The findings of different workers on this aspect in cotton are listed in Table 1.

2.4 Path co-efficient analysis

As the independent variables influencing a particular dependent variable increase, apart from directly influencing the dependent variable, their indirect effect through other traits also increases. Under such complex situations the total correlation would be insufficient to explain the association of the characters. Path analysis furnishes a method of partitioning the correlation coefficient into direct and indirect effects and measures the relative importance of factors involved. Path coefficient analysis was suggested by Wright (1921) and illustrated by

Table 1: Review of literature on association studies for various character combinations in cotton

Sl. No.	Pair of characters	Correlation	References
1.	**Seed cotton yield with**		
a.	Plant height	Positive	Krishnarao and Mary (1990), Kowsalya and Raveendran (1996), Sambamurthy (1999), Neelima and Potdukhe (2002), Muthuswamy and Vivekanandan (2004), Alkuddsi *et al.* (2013), Baloch *et al*. (2014), Farooq *et al.* (2014) and Pujer *et al.* (2014).
		Negative	Pradeep and Sumalini (2005), Annapurve *et al.* (2007), Leelapratap *et al.* (2007) Hanamaraddi (2010) and Dahiphale *et al.* (2015).
b.	Number of sympodia per plant	Positive	Sumathi and Nadarajan (1995), Kowsalya and Raveendran (1996), Sambamurthy (1997), Ladole and Meshram (2000), Rao *et al.* (2001), Neelima and Potdukhe (2002), Kaushik *et al.* (2003), Gururaj (2006), Annapurve *et al.* (2007), Leelapratap *et al.* (2007), Dahiphale *et al.* (2015), Latif *et al.* (2015), Farooq *et al.*.(2015) and Baloch *et al.* (2016).
		Negative	Muthuswamy and Vivekanandan (2004) and Gururaj (2006)
c.	Sympodial length at 50 per cent plant height	Positive	Parre Suman (2012).
		Negative	Gururaj (2006) and Bharat Kumar (2011).
d.	No of bolls per plant	Positive	Krishnarao and Mary (1990), Rajarathinam *et al.* (1993), Sambamurthy *et al.* (1995), Sumathi and Nadarajan (1995), Kowsalya and Raveendran (1996), Sambamurthy (1997), Sambamurthy and Rao (1998), Ladole and Meshram (2000), Rao *et al.* (2001), Neelima and Potdukhe (2002), Kaushik *et al.* (2003), Muthuswamy and Vivekanandan (2004), Gururaj, (2006) Leelapratap *et al.* (2007), Arega Gashaw (2013), Baloch *et al.* (2014), Farooq *et al.* (2014), Vinodhana Kumari *et al.* (2013), Pujer *et al.* (2014), Latif *et al*. (2015), Bayyapu Reddy *et al.* (2015) and Baloch *et al*. (2016).
e.	Boll weight	Positive	Singh *et al.* (1979), Govila and Sharma (1981), Krishnarao and Mary (1990), Rajarathinam *et al.* (1993), Ramalingam *et al.* (1994), Kowsalya and Raveendran (1996), Sambamurthy (1997), Yadav *et al.* (1998), Ladole and Meshram (2000), Kaushik *et al.* (2003), Muthuswamy and Vivekanandan (2004), Leelapratap *et al.*(2007), Farooq *et al*. (2014), Vinodhana Kumari *et al.* (2013), Latif *et al.* (2015), Bayyapu Reddy *et al.* (2015) and Baloch *et al.* (2016).
		Negative	Rao *et al.* (2001), Annapurve *et al.* (2007) and Pujer *et al.* (2014).
		Independent	Sambamurthy (1999).

Table 1: Contd…..

Sl. No.	Pair of characters	Correlation	References
f.	Ginning out turn	Positive	Singh *et al.* (1979), Krishnarao and Mary (1990), Ramalingam *et al.*(1994), Sambamurthy and Rao (1998), Rao *et al.* (2001), Neelima and Potdukhe (2002), Annapurve *et al.* (2007), Leelapratap *et al.* (2007), Kaushik *et al.* (2003), Ashokkumar and Ravikesavan, (2010), Kale and Annapurve (2007), Naqib *et al.* (2010), Farooq *et al.* (2014), Pujer *et al.* (2014), Dahiphale *et al.* (2015) and Latif *et al.* (2015).
		Negative	Sambamurthy (1999) and Muthuswamy and Vivekanandan (2004).
g.	Seed index	Positive	Krishnarao and Mary (1990), Sambamurthy *et al.* (1995), Sambamurthy (1997), Yadav *et al.* (1998), Neelima and Potdukhe (2002), Gururaj (2006) Ashokkumar and Ravikesavan, (2010), Baloch *et al.* (2014) and Pujer *et al.* (2014).
		Negative	Ramalingam *et al.* (1994), Rao *et al.* (2001), Leelapratap *et al.* (2007) and Dahiphale *et al.* (2015).
		Independent	Govila and Sharma (1981) and Sambamurthy (1999)
h.	Lint index	Positive	Krishnarao and Mary (1990), Rajarathinam *et al.* (1993), Sambamurthy *et al.* (1995), Sambamurthy (1997), Neelima and Potdukhe (2002), Naqib *et al.* (2010) and Dahiphale *et al.* (2015).
		Negative	Muthuswamy and Vivekanandan (2004), Leelapratap *et al.* (2007), Govila and Sharma (1981), Ramalingam *et al.* (1994) and Ashokkumar and Ravikesavan, 2010.
		Independent	Sambamurthy (1999) and Ladole and Meshram (2000).
i.	Lint yield	Positive	Bayyapu Reddy *et al.* (2015).
k.	Root dry weight	Positive	Yadav *et al.* (1998) and Parre Suman (2012).
l.	Shoot dry weight	Positive	Sambamurthy *et al.* (1997) and Yadav *et al.* (1998).
		Negative	Parre Suman (2012).
m.	Fibre length	Positive	Vinodhana Kumari *et al.* (2013), Farooq *et al.* (2014), Bayyapu Reddy *et al.* (2015) and Dahiphale *et al.* (2015).
		Negative	Valarmathi (1996), Ahuja and Tuteja (2000), Ashokkumar and Ravikesavan, (2010) and Pujer *et al.* (2014)
n.	Micronaire value	Positive	Ahuja and Tuteja (2000), Ashokkumar Ravikesavan, (2010) and Bayyapu Reddy *et al.* (2015).
		Negative	Baloch *et al.* (2014) and Pujer *et al.* (2014).
o.	Fibre strength	Positive	Farooq *et al.* (2014) and Bayyapu Reddy *et al.* (2015).
		Negative	Valarmathi (1996), Rao *et al.* (2001) and Pujer *et al.* (2014).

Table 1: Contd…..

Sl. No.	Pair of characters	Correlation	References
II	**Plant height with**		
a.	Number of sympodia	Positive	Kowsalya and Raveendran (1996), Sambamurthy (1999), Muthuswamy and Vivekanandan (2004), Leelapratap *et al.* (2007), Karademir *et al.* (2009), Vinodhana Kumari *et al.* (2013), Alkuddsi *et al.* (2013), Baloch *et al.* (2014) and Liaqat *et al.* (2015).
		Negative	Annapurve *et al.* (2007) and Liaqat *et al.* (2015).
b.	Bolls per plant	Positive	Krishnarao and Mary (1990), Kowsalya and Raveendran (1996), Sambamurthy (1999), Annapurve *et al.* (2007), Leelapratap *et al.* (2007), Karademir *et al.* (2009), Vinodhana Kumari *et al.* (2013), Alkuddsi *et al.* (2013), Baloch *et al.* (2014), Dahiphale *et al.* (2015) and Baloch *et al.* (2016).
		Independent	Tomar and Singh (1991).
c.	Boll weight	Positive	Krishnarao and Mary (1990), Muthuswamy and Vivekanandan (2004), Annapurve *et al.* (2007) and Leelapratap *et al.* (2007)
		Independent	Sambamurthy (1999).
d.	Ginning out turn	Positive	Amrutha *et al.* (1996), Leelapratap *et al.* (2007), Karademir *et al* (2009), Naqib *et al.* (2010) and Dahiphale *et al.* (2015).
		Negative	Sambamurthy (1999), Annapurve *et al.* (2007) and Alkuddsi *et al.* (2013).
		Independent	Krishnarao and Mary (1990) and Tomar and Singh (1991).
e	Seed index	Positive	Krishnarao and Mary (1990), Muthuswamy and Vivekanandan (2004), Annapurve *et al.* (2007) and Vinodhana Kumari *et al.* (2013).
		Negative	Leelapratap *et al.* (2007), Alkuddsi *et al.* (2013) and Liaqat *et al.* (2015).
		Independent	Sambamurthy (1999).
g.	Lint index	Positive	Krishnarao and Mary (1990) and Muthuswamy and Vivekanandan (2004)
		Negative	Leelapratap *et al.* (2007), Alkuddsi *et al.* (2013) and Liaqat *et al.* (2015).
		Independent	Tomar and Singh (1991) and Sambamurthy (1999).
h.	Micronaire value	Positive	Liaqat *et al.* (2015).
		Negative	Baloch *et al.* (2014) and Bayyapu Reddy *et al.* (2015).

Table 1: Contd…..

Sl. No.	Pair of characters	Correlation	References
i.	Fibre length	Positive	Vinodhana Kumari *et al.* (2013).
		Negative	Liaqat *et al*. (2015).
j.	Fibre strength	Negative	Liaqat *et al*. (2015).
III	**Number of monopodia per plant with**		
a.	Number of sympodia per plant	Positive	Ladole and Meshram (2000), Neelima and Potdukhe (2002), Kaushik *et al*. (2003), Annapurve *et al*. (2007), Leelapratap *et al.* (2007), Ekinci *et al.* (2010), Dahiphale *et al.* (2015) and Liaqat *et al*. (2015).
		Negative	Neelima and Potdukhe (2002).
b.	Number of bolls per plant	Positive	Waldia *et al*.(1979), Sambamurthy (1999), Ladole and Meshram (2000), Kaushik *et al.* (2003), Neelima and Potdukhe (2002), Annapurve *et al.* (2007), Leelapratap *et al.* (2007), Karademir *et al.* (2009), Ekinci *et al.* (2010) and Bayyapu Reddy *et al.* (2015).
c.	Boll weight	Positive	Ladole and Meshram (2000), Neelima and Potdukhe (2002), Leelapratap *et al.* (2007), Ekinci *et al*.(2010), Alkuddsi *et al*. (2013) and Bayyapu Reddy *et al*.(2015).
		Negative	Kaushik *et al.* (2003) and Annapurve *et al.* (2007).
		Independent	Waldia *et al.* (1979) and Sambamurthy (1999)
d.	Seed index	Positive	Sambamurthy (1999), Ladole and Meshram (2000) and Neelima and Potdukhe (2002).
		Negative	Sambamurthy (1997) and Neelima and Potdukhe (2002).
		Independent	Annapurve *et al.* (2007) and Sambamurthy (1999).
e.	Lint index	Positive	Ladole and Meshram (2000) and Neelima and Potdukhe (2002).
		Negative	Sambamurthy (1999) and Neelima and Potdukhe (2002).
f.	Ginning out turn	Positive	Ladole and Meshram (2000), Neelima and Potdukhe (2002), Annapurve *et al.* (2007), Leelapratap *et al.* (2007) and Naqib *et al.* (2010).
g.	Lint yield	Positive	Bayyapu Reddy *et al*. (2015) and Dahiphale *et al.* (2015).
h.	Fibre strength	Negative	Liaqat *et al.* (2015).
i.	Micronaire value	Positive	Liaqat *et al.* (2015).
IV	**Number of sympodia per plant with**		
a.	Number of bolls per plant	Positive	Singh *et al.* (1979), Kowsalya and Raveendran (1996), Sangeetha (1998), Sambamurthy (1999), Ladole and Meshram (2000), Rao *et al.* (2001), Neelima and Potdukhe (2002), Kaushik *et al.* (2003), Muthuswamy and Vivekanandan (2004), Annapurve *et al*.(2007), Leelapratap *et al.* (2007), Yashavantha Kumar (2008), Hanamaraddi (2010), Karademir *et a*.. (2009), Baloch *et al.* (2014) and Farooq *et al.* (2015).
		Negative	Waldia *et al.* (1979).

Table 1: Contd…..

Sl. No.	Pair of characters	Correlation	References
b.	Boll weight	Positive	Sambamurthy (1999), Ladole and Meshram (2000), Neelima and Potdukhe (2002), Kaushik *et al*. (2003), Leelapratap *et al.* (2007) and Farooq *et al.* (2015).
		Negative	Kowsalya and Raveendran (1996), Rao *et al.* (2001), Annapurve *et al.* (2007), Muthuswamy and Vivekanandan (2004), Alkuddsi *et al.* (2013) and Baloch *et al.* (2014).
		Independent	Singh *et al.* (1979) and Waldia *et al.* (1979)
c.	Seed index	Positive	Sambamurthy (1999), Ladole and Meshram (2000), Neelima and Potdukhe (2002), Leelapratap *et al*. (2007) and Bayyapu Reddy *et al.* (2015)
		Negative	Annapurve *et al.* (2007), Muthuswamy and Vivekanandan (2004) and Alkuddsi *et al.* (2013).
d.	Lint index	Positive	Ladole and Meshram (2000), Neelima and Potdukhe (2002), Muthuswamy and Vivekanandan (2004), Leelapratap *et al.* (2007) and Bayyapu Reddy *et al.* (2015).
		Negative	Rao *et al.* (2001).
		Independent	Sambamurthy (1999).
e.	Ginning outturn	Positive	Ladole and Meshram (2000), Rao *et al.* (2001), Neelima and Potdukhe (2002), Muthuswamy and Vivekanandan (2004), Annapurve *et al.* (2007), Leelapratap *et al.* (2007), Naqib *et al.* (2010) and Liaqat *et al.* (2015).
		Negative	Kowsalya and Raveendran (1996) and Sambamurthy (1999).
		Independent	Singh *et al.* (1979).
f.	Fibre length	Positive	Bayyapu Reddy *et al.* (2015).
g.	Fibre strength	Positive	Bayyapu Reddy *et al.* (2015).
h.	Micronaire value	Positive	Liaqat *et al.* (2015).
V	**Number of bolls per plant with**		
a.	Boll weight	Positive	Neelima and Potdukhe (2002), Singh *et al.* (1979), Rao *et al.* (2001), Karademir *et al.* (2009) and Bayyapu Reddy *et al.*(2015).
		Negative	Kowsalya and Raveendran (1996), Ladole and Meshram (2000), Kaushik *et al.* (2003), Muthuswamy and Vivekanandan (2004), Annapurve *et al.* (2007), Leelapratap *et al.* (2007), Alkuddsi *et al.*(2013) and Baloch *et al.* (2014).
		Independent	Krishnarao and Mary (1990).

Table 1: Contd…..

Sl. No.	Pair of characters	Correlation	References
b.	Seed index	Positive	Neelima and Potdukhe (2002).
		Negative	Ladole and Meshram (2000), Rao *et al.* (2001), Annapurve *et al.* (2007), Leelapratap *et al.* (2007) and Baloch *et al.* (2014).
c.	Lint index	Positive	Neelima and Potdukhe (2002) and Leelapratap *et al.* (2007).
		Negative	Sambamurthy (1999), Ladole and Meshram (2000), Rao *et al.* (2001) and Alkuddsi *et al.* (2013).
d.	Ginning outturn	Positive	Ladole and Meshram (2000), Rao *et al.* (2001), Neelima and Potdukhe (2002), Muthuswamy and Vivekanandan (2004), Annapurve *et al.* (2007), Leelapratap *et al.* (2007) and Naqib *et al.* (2010).
		Negative	Singh *et al.* (1979), Sambamurthy (1999) and Kowsalya and Raveendran (1996).
		Independent	Govila and Sharma (1981) and Krishnarao and Mary (1990).
e.	Lint yield	Positive	Bayyapu Reddy *et al.* (2015).
VI	**Boll weight with**		
a.	Seed index	Positive	Krishnarao and Mary (1990), Rajarathinam *et al.* (1993), Ramalingam *et al.* (1994), Sumathi and Nadarajan (1995), Sambamurthy (1999), Ladole and Meshram (2000), Rao *et al.* (2001), Neelima and Potdukhe (2002), Annapurve *et al.* (2007) and Vinodhana Kumari *et al.* (2013).
		Negative	Leelapratap *et al.* (2007) and Liaqat *et al.* (2015).
		Independent	Govila and Sharma (1981).
b.	Lint index	Positive	Krishnarao and Mary (1990), Rajarathinam *et al.* (1993), Ramalingam *et al.* (1994), Sumathi and Nadarajan (1995), Sambamurthy (1999), Ladole and Meshram (2000), Rao *et al.* (2001), Neelima and Potdukhe (2002), Muthuswamy and Vivekanandan (2004) and Vinodhana Kumari *et al.* (2013).
		Negative	Leelapratap *et al.* (2007) and Liaqat *et al.* (2015).
c.	Ginning outturn	Positive	Krishnarao and Mary (1990), Kowsalya and Raveendran (1996), Neelima and Potdukhe (2002), Muthuswamy and Vivekanandan (2004), Annapurve *et al.* (2007), Naqib *et al.* (2010) and Alkuddsi *et al.* (2013).
		Negative	Ladole and Meshram (2000), Leelapratap *et al.* (2007) and Liaqat *et al.* (2015).
		Independent	Singh *et al.* (1979), Govila and Sharma (1981), Ramalingam *et al.* (1994) and Sambamurthy (1999).
d.	Lint yield	Positive	Bayyapu Reddy *et al.* (2015).
e.	Micronaire value	Negative	Vinodhana Kumari *et al.* (2013) and Baloch *et al.* (2014).
f.	Fibre length	Negative	Liaqat *et al.* (2015).

Table 1: Contd…..

Sl. No.	Pair of characters	Correlation	References
VII	**Seed index with**		
a.	Lint index	Positive	Govila and Sharma (1981), Krishnarao and Mary (1990), Rajarathinam *et al.*(1993), Sumathi and Nadarajan (1995), Sambamurthy (1999), Jain and Yadav (2001), Rao *et al.* (2001), Neelima and Potdukhe (2002), Leelapratap *et al.* (2007), Liaqat *et al.* (2015) and Bayyapu Reddy *et al.* (2015).
		Negative	Ramalingam *et al.* (1994).
b.	Boll number	Negative	Dahiphale *et al.* (2015).
c.	Ginning outturn	Positive	Neelima and Potdukhe (2002), Muthuswamy and Vivekanandan (2004), Alkuddsi *et al.* (2013) and Liaqat *et al.* (2015).
		Negative	Rao *et al.* (2001), Ladole and Meshram (2000), Neelima and Potdukhe (2002), Annapurve *et al.* (2007), Karademir *et al.* (2009) and Naqib *et al.* (2010).
d.	Fibre length	Positive	Liaqat *et al.* (2015) and Bayyapu Reddy *et al.* (2015).
		Negative	Dahiphale *et al.* (2015).
e.	Fibre strength	Positive	Liaqat *et al.* (2015) and Bayyapu Reddy *et al.* (2015).
VIII	**Lint index with**		
a.	Ginning outturn	Positive	Sumathi and Nadarajan (1995), Ladole and Meshram (2000), Jain and Yadav (2001), Rao *et al.* (2001), Neelima and Potdukhe (2002), Muthuswamy and Vivekanandan (2004), Leelapratap *et al.* (2007), Naqib *et al.* (2010) and Bayyapu Reddy *et al.* (2015).
b.	Fibre length	Positive	Bayyapu Reddy *et al.* (2015).
IX	**Lint yield with**		
a.	Seed index	Negative	Dahiphale *et al.* (2015).
b.	Micronaire value	Positive	Arega Gashaw (2013).
c.	Ginning outturn	Positive	Bayyapu Reddy *et al.* (2015) and Dahiphale *et al.* (2015).
d.	Fibre length	Positive	Arega Gashaw (2013).
X	**Micronaire value with**		
a.	Fibre length	Negative	Krishnarao and Mary (1990).
b.	Fibre strength	Negative	Basang and Gencer (2007) and Ashokkumar and Ravikesavan (2010).
XI	**Fibre length with**		
a.	Fibre strength	Positive	Ashokkumar and Ravikesavan, (2010), Magadum *et al.* (2012), Vinodhana Kumari *et al.* (2013), Patil Malagouda *et al.* (2014) and Amjid *et al.* (2016).
b.	Micronaire value	Negative	Basang and Gencer (2007), Ashokkumar and Ravikesavan (2010) and Amjid *et al.* (2016).
XII	**Fibre strength with**		
a.	Fibre length	Positive	Ashokkumar and Ravikesavan, (2010).
		Negative	Magadum *et al.* (2012).
b.	Micronaire value	Negative	Ashokkumar and Ravikesavan, (2010), Magadum *et al.* (2012) and Patil Malagouda *et al.* (2014).

Dewey and Lu (1959). The findings of different workers on this aspect in cotton are listed in Table 2.

2.5 Plant type characterization

Despite introduction of a range of laboratory methods for varietal characterization, morphological traits of plants are major components for cultivar characterization because they provide most appropriate information on spot for characterization. There are very few studies in cotton on plant type characterization and hence work in other crops has also been quoted.

Donald (1968) reported effect of leaf angle in rice. He grew the erect leafed rice variety at wide and at close spacing; half the plants were treated by dropping the leaf angle with paper fastener attached at the leaf tips. Carbon assimilation was unaffected in the widely spaced plants, but was depressed by 35 per cent in plants at close spacing. Hayashi and Ito (1962) similarly showed in a collection of rice varieties that the steeper the leaf angle the greater was the light penetration and greater the crop growth rate.

Duncan (1971) reported that leaf angle will have small effects on canopy photosynthesis and also the arrangement of leaf layers and leaf angles were not much affected by leaf type in maize.

Russell (1972) evaluated inbred lines for yield performance at two row width and three stand densities at each row width and he found maximum difference of leaf angle between two hybrids was 36 and average difference between the two groups was eleven degrees which affects the photosynthetic rate of maize plant.

Arianayagam *et al.* (1974) evaluated four generations of bi-directional phenotypic selection for leaf angle in maize and they observed that average change in leaf angle was 10 to 12 per cycle in each direction. Leaf blade and midrib thickness, but not leaf length and width were associated with angle. Erect leaf types were generally shorter in plant height, so relative leaf angle remained constant over stages of growth and position in the plant and also grain yield variations attributable to leaf angle were small and statistically insignificant at planting densities from 40,000 to 80,000 plants per ha.

Lambert and Johnson (1978) reported that leaf angle and leaf area index contributed to high grain yield. The failure of legume leaf types to respond to increased plant densities resulted in almost vertical leaf orientation, which caused upper leaf surface to largely enclose the culm and sheath in maize. Thus only one leaf surface would receive direct radiation.

Table 2. Review of literature on path coefficient analysis for various character combinations

Sl. No	Character	Effect	Reference
1.	Plant height	Positive and direct	Leelapratap *et al.* (2007), Talawar (2008), Karademir *et al.* (2009), Farooq *et al.* (2014), Dahiphale *et al.* (2015) and Farooq *et al.* (2015).
2.	Number of sympodia per plant	Positive and direct	Remzi *et al.* (2010), Chitti *et al.* (2014) Alkuddsi *et al.* (2013), Bhatade (1982), Gulamov *et al.* (1974), Manivasakam (1985), Nazir and Khan (1974), Verma *et al.* (2006) and Muthu *et al.* (2004).
		Negative and direct	Ahuja *et al.* (2006) and Rauf *et al.* (2004).
3.	Sympodial length	Positive and direct	Alkuddsi *et al.* (2013),
4.	Plant diameter	Negative and direct	Bharath kumar *et al.* (2014).
5.	Number of nodes on main stem	Negative and direct	Zhang *et al.* (2015)
6.	Number of bolls per plant	Negative and direct	Farooq *et al.* (2015) and Ashokkumar and Ravikesavan (2010).
7.	Number of bolls per sq.m.	Positive and direct	Linghe Zeng and William Meredith (2009)
8.	Boll weight	Positive and direct	Srinivas *et al.* (2015), Aguado *et al.* (2008), Pujer *et al.* (2014) and Balakrishna *et al.* (2016).
9.	Ginning outturn	Positive and direct	Pujer *et al.* (2014), Mahantesh Shastri (2004), Lavanyakumar (2004), Gururaj (2006) and Hanamaraddi (2010).
10.	Seed index	Positive and direct	Alkuddsi *et al.* (2013), Ashraf *et al.* (2016).
11.	Total biomass	Positive and direct	Geremew *et al.* (2014), Erande *et al.* (2014).
12.	UHML	Negative and direct	Wright (1921) and Muhammad *et al.* (2014)
13.	Fibre strength	Negative and direct	Leela *et al.* (2007), Sambamurthy (1999) and Chandrashekar *et al.* (2016).
14.	Micronaire value	Negative and direct	Srinivas *et al.* (2015) and Ashraf *et al.* (2016).

Tungland *et al.* (1987) compared twenty four erect leaf lines with horizontal leaf Cv. Manqar, Morex, glenn and robust and they gave scores for the leaf angle. Erect leaf populations had lower leaf angle scores, later anthesis dates, more erect spikes and enhanced lodging resistance in barley.

Rasmussen (1987) reported that the biggest challenge in doing ideotype breeding is to decide which traits to include. Only one trait has been demonstrated (long awn) to increase yield in barley. Other traits, which contribute more on yield are kernel number, leaf area, leaf angle and vegetative biomass.

Suma and Virupakshappa (1994) evaluated one hundred and ninety six germplasm accessions of sunflower to study extent of variation in different quantitative traits and the germ accessions were characterized on the basis of qualitative traits.

Ahmmed and Mehra (2000) suggested genetic improvement of field crop varieties axiomatic to a plant breeder through utilizing the genetic variability present in germplasm by direct selection, hybridization or characterization of the genotypes in cotton.

Kanavi *et al.* (2004), based on path of productivity analysis indicated that robust types occupied larger three dimensional space to give high productivity. While compact productive types occupied lesser three-dimensional space but still managed to record high yield by virtue of better packing of bolls.

Varma *et al.* (2005) said despite introduction of a range of laboratory methods for varietal characterization of plants, morphological traits of plants are a major component for cultivar characterization because they provide the appropriate data on the spot. They evaluated twenty-five genotypes in maize for leaf tip, first leaf sheath, leaf attitude and tassel branch for characterization.

Gururaj (2006), studied the comparison of genotypes belonging to the two different plant types revealed high potential and response of compact genotypes to high density planting i.e., in 60 cm x 15 cm spacing. The yields of compact genotypes were high in the high population situation.

2.5.1 Effect of plant population

Plant population has its influence on growth and yield of cotton plants. The optimum population depends on the variety to be grown, soil fertility and climate. Higher population densities restrict growth of branches and reproductive part and yield per plant. But yield may be compensated through increased population densities per unit area.

2.5.1.1 Growth and growth attributes affected by planting densities in cotton

Upadya and Paradkar (1992) conducted a study using thirty hybrids, among them A-51-9 x BC-761 was considered to be a good hybrid as it exhibited superiority over checks (Hy-4, JKHy-1, and Khandwa-2) for seed cotton yield, number of bolls, boll weight, number of sympods and plant height. However, this hybrid utilized longer period for maturity as compared to Hy-4 and Khandwa-2. Increase in yield was associated with increase in number of bolls, number of sympods and boll weight.

Mane *et al.* (1999) reported that most potential compact genotypes showed higher mean values for seed cotton yield and its component characters like number of bolls and seed index when compared to robust genotypes. Compacts showed higher values for the characters lint index and lint yield than robust genotypes.

Hussain *et al.* (2000) and Boquet (2005) reported that by increasing plant density, average boll weight decreases. It is evident from the data that average boll weight was affected significantly by plant spacing. Statistically same average boll weight (3.78 g) was obtained in 30 cm plant spacing and 22.50 cm plant spacing (3.77 g) against the minimum value of (3.60 g) in case of 15 cm plant spacing. So, the greater average boll weight at higher plant spacing might be due to less competition and availability of resources, they reasoned.

Kasliwal (2000) compared potential robust genotypes and compact genotypes and reported that the mean plant height was higher in robust lines compared to compact types. Robust genotypes recorded higher values for the number of monopodia, number of sympodia, inter boll distance, plant diameter, boll weight, halo length, leaf area index and ginning out turn, as compared to compacts.

Nehra and Chandra (2001) observed that the significantly higher number of picked bolls per plant and seed cotton yield per plant were under wider plant spacing due to better development of individual plant in wider plant spacing crop. The widely spaced plant received optimum microclimate and had beneficial influence on plant development.

Nehra and Kumawat (2003) found that increase in sympodial length contributes to increase in both boll number and diameter of the plant. Thus, increase in sympodial number with minimum inter boll distance is the ideal path of contribution to boll number. Productive compact types revealed increased boll number and reduced horizontal growth by facilitating accommodation of more plants per unit area.

Bednarz *et al.* (2005) reported on how lint yield, fibre quality and profitability of cotton may be manipulated through plant density. Two cotton cultivars were over seeded and hand-thinned to 3.6, 9.0, 12.6 and 21.5 plants per m^2. While ginning, six lint samples were collected per plot for fibre quality analyses. Net returns were then calculated from yield, quality, and seed cost data. Lint yields were greatest at 12.6 plants per m^2 and lowest at 3.6 plants per m^2. Of the fibre properties investigated, micronaire and fineness were most affected by plant density. Thus, to maximize fibre quality, cultivar selection is of greatest importance while management of plant density to maintain or maximize genetic potential is secondary.

Bednarz *et al.* (2006) reported alterations in yield components in cotton through plant density management. Two cotton cultivars were over seeded and hand thinned to 3.6, 9.0, 12.6, and 21.5 plants per m^2 in 2001 and 2000. Lint mass per boll, individual seed mass, and seed number/boll decreased as plant density increased while total seed surface area per m^2 of land area increased, which resulted in increased lint yield per m^2 of land area. Lint mass per cm^2 of seed surface area and fibre number per seed did not consistently respond to plant density. The results indicate that plant density management may influence total seed surface area per unit land area. Most within-boll yield components, however, appear to be controlled more by cultivar than crop management.

Dong *et al.* (2006) studied that normal planted cotton (NPSS) at a plant density of 3.0 -4.5 plants per m^2, and late-planted cotton at 7.5 plants per m^2 produced higher lint yield than other planting date and density combinations. Another experiment compared NPPS with a late planting production system (LPPS) which involves planting in early May at 7.5 plants per m^2 over 2 years. The NPPS and LPPS had similar lint yields in both years. Cotton plants in both systems produced approximately 75 per cent of total lint in the first two harvests, indicating no significantly delayed earliness in LPPS relative to NPPS. Fibre from late-season bolls exhibited reduced strength and micronaire in both systems.

Siebert *et al.* (2006) reported a significant reduction in plant height with populations under 51,000 plants per ha when compared to 152,833 plants per ha. Several researchers have also shown that plant density is inversely related to main stem node number. These plant growth characteristics suggest that reducing plant population may be used as an additional management tool in conjunction with plant growth regulators to help control plant height.

Giri and Gore (2006) revealed that the sowing of cotton at 45 x 15 cm^2 plant spacing produced considerably highest seed cotton yield, the maximum gross monetary return and net monetary returns and B: C ratio as compared to wider spacing due to more number of picked bolls per unit area. At 60 x 10 cm^2 spacing, seed cotton yield per plant was decreased because of the reduction in yield per plant due to both interplant and intra-plant competition for resources. This was however more than compensated by increase in the number of plants per unit area.

Moola and Giri (2006) reported that the minimum height of crop was recorded with 45 x 30 cm of plant spacing. Among varieties, PA 528 had significantly highest plant height (140.74 cm) as compared to others. At harvesting stage, total dry matter accumulation per plant was influenced due to different spacing and it was maximum (78.64 g) in wider plant spacing 45 x 30 cm^2 as compared to 45 x 22.5, 45 x 15 and 60 x 10 cm^2 plant spacing which was mainly due to the larger ground area, maximum moisture, more nutrients and more light interception resulting in more photosynthetic activity and more biomass accumulation through the process of plant metabolism. With respect to varieties, maximum dry matter accumulation was observed from PA 528 (76.49 g).

Saeed *et al.* (2008) assessed the yield-related morphological measures for earliness by evaluating 13 upland cotton genotypes. All the varieties differed significantly for sympodial branch length, boll weight and seed cotton yield per plant showing a variation range of 14.2 to 35.7 cm, 2.7 to 4.5g, 126.0 to 196.3g, respectively. The new strain VH-144 and VH-156 exhibited great yield potential at 120 days after planting.

Asghar *et al.* (2009) investigated the effect of plant spacing (15 cm, 22.5 cm and 30 cm) on the yield of three recently approved varieties of cotton CIM-496, CIM-534 and MNH-786. Plant height, number of sympodial branches per plant, monopodial branches per plant, number of bolls per plant and average boll weight were significantly higher in CIM496.

Yang *et al* (2014) conducted a two year field experiment on cotton, to determine the effects of soil salinity and plant density on plant biomass and harvest index in relation to cotton yield. Plant biomass and harvest index were greatly affected by salinity, plant density and their interaction. They concluded that optimal yield can only be obtained with proper coordination of total biomass and harvest index by modification of plant density.

Tamilselvam and Anbarasan (2013) compared robust and compact *hirsutum* cotton varieties. They reported that robust types occupied larger three dimensional space to give high productivity, while compact productive types occupied lesser three dimensional space but still managed to record high yield by virtue of better packing of bolls. This was ensured by a shorter horizontal interval (inter boll distance) and vertical distance (inter branch) contributed by packing of more sympodial branches in a shorter plant.

Zhi Xiao-yu *et al.* (2016) observed that plant densities of 51,000 and 87,000 plants per ha. increased lint yield by 61.3 and 65.30 per cent in 2012 and 17.8 and 15.5 per cent in 2013 relative to low plant density (15000 plants per ha.). The number of bolls (boll density) increased while boll weight decreased as plant density rose, and no significant changes occurred in lint percentage in 2013 but increased with plant density in 2012. The number of bolls in upper nodes, number of seeds per boll and seed vigour index increased with decreasing plant density.

Pradeep *et al.* (2017) conducted an experiment, laid out in split plot design consisting of four levels of plant densities *viz*., 45 × 15 cm^2 (148148 plants/ha), 45 × 22.5 cm^2 (98765 plants/ha), 45 × 30 cm^2 (74074 plants/ha) and 60 × 10 cm^2 (166666 plants /ha) in main plots and three levels of desi cotton varieties *i.e.,* PA 08, PA 528 and PA 255 in sub plots, results of which indicated that the quality parameters were not influenced significantly with plant densities. However, highest seed index (5.36 g) was obtained with 45 × 30 cm^2. The desi cotton variety PA 528 produced highest seed cotton yield than PA 08 and PA 255 varieties. Halo length was not affected considerably with desi cotton varieties.

2.6 Stability analysis

2.6.1 Reviews on Genotype × Environment interaction by Eberhart and Russell stability model

In the study of genotype × environment interactions, the main difficulty is found in fixing the environmental index for comparing varietal performance. There were only few studies found assessing the G × E interactions for seed cotton yield using the Eberhart and Russell model with differing planting densities (environments). No previous studies on G × E interactions were found for the traits *viz*., plant diameter, bolls per sq.m. and harvest index. However, the following are few reviews related to the present study where Eberhart and Russell stability model was used.

Patel *et al*. (2000) evaluated nine pure breeding genotypes developed through multi species crosses in four distinct environments and stated that environment and variety X environment interaction was significant for seed cotton yield there by indicating that variation in performance of nine cotton genotypes over four locations was due to unpredictable factors.

Pavasia *et al*. (2000) studied eight parental lines of cotton during *kharif* season in three different environments (sowing date) and reported that presence of variation among genotypes as well as environments and G X E interactions was significant for all the characters, thereby indicating that genotypes behaved differently under varying environments.

Arshad *et al*. (2016) evaluated four varieties of upland cotton and estimated their genetic stability by Eberhart and Russell method. The results revealed that Lachata variety recorded significant increase in plant height, number of monopodia branches per plant, number of bolls per plant, boll weight, seed index, lint index and lint percentage. Lachata variety revealed genetic stability for plant height, number of monopodia per plant, number of sympodia per plant, number of bolls per plant, boll weight, seed index and seed cotton yield. The variety Ashoor ranked second in genetic stability for seed cotton yield, followed by Koker-310 variety in genetic stability for the number of sympodia per plant, seed index and lint percentage.

William *et al*. (2013) evaluated the performance of obsolete and modern cotton genotypes grown under reduced and traditional plant population densities using six genotypes representing five decades of release grown at either five plants m-2 (low) or 10 plants m^{-2} (high) densities, during the years 2009 through 2012. Genotypes did not interact with plant densities for any trait except for few consistent dry-matter partitioning or growth differences among the genotypes, large genotypic differences were detected in lint yield and fiber quality production. Increased light interception by the high density treatment was offset by the ability of the leaves of the low density canopy to more efficiently intercept and utilize sunlight. These counteracting traits resulted in no yield or fibre quality differences between the two densities. Yield success can be achieved with a reduced seeding rate if uniform seedling spacing is also achieved, possibly regardless of the cultivar planted, they said.

Venugopalan *et al.* (2014) studied the effect of spacing, genotype and genotype x spacing interaction on seed cotton yield. The genotype x spacing interaction was also significant and unlike other genotypes PKV 081 produced almost thrice the number of bolls/m^2 at 45 cm × 13.5 cm over the currently recommended spacing of 60 cm × 30 cm. In general the boll weight declined at closer spacing. There was significant variation among genotypes. Genotypes Anjali, PKV 081 and NISC 50 produced significantly bigger bolls than CNH 120MB and CCH 724. Number of bolls per m^2 and boll weight were significant. Averaged across genotypes, the seed cotton yield was significantly higher in the spacings of 45 cm × 13.5 cm and 30 cm × 20 cm, both accommodating 166000 plants per ha.

Rekha and Pradeep (2015) evaluated ten short and compact (multiple cross derivatives) of cotton genotypes in randomized block design. The stability analysis of the genotypes following the Eberhart and Russel model was performed for two years. On the basis of mean performance, over all fertility levels, genotypes ADB 159, ADB 160 and ADB 164 were dwarf and high yielders with high boll weight and had less than one monopodia per plant, average sympodia per plant and bolls per plant suggesting that their performance was stable even at high fertility level and hence can be amenable for high density planting.

Islam *et al.* (2015) tested five cotton genotypes *viz.,* BC-0165, BC0406, JA/54, JA/08/C, JA/08/B along with two cultivated checks *viz.* CB-9 and CB-12 to determine the effect of different environments on seed cotton yield and to understand its adaptation to varying environments. Analysis of variance revealed that genotype, location and genotype × environment interactions were highly significant ($P < 0.05$), an indication of variability among genotypes and their response to changing environments. Regression coefficient and deviation from regression differed from each other indicating the genotypes' diversity in adaptability and stability.

Zhi Xiao-yu *et al.* (2016) evaluated cotton hybrid cultivar CRI75 and conventional cultivar SCRC28 as the main plots, and three plant densities (15,000, 51,000 and 87,000 plants per ha) as the sub plots in 2012 and 2013 at Anyang, Henan Province, China. They showed that plant densities of 51,000 and 87,000 plants per ha increased lint yield by 61.3 and 65.3 per cent in 2012 and 17.8 and 15.5 per cent in 2013 relative to low plant density (15,000 plants per ha), however, no significant difference was observed between 51,000 and 87,000 plants per ha. As the number of fibers per seed area is genetically determined, adjusting plant density to produce more seeds and greater seed area can be a potentially promising alternative to improve lint yield in cotton.

Zakaria (2017) tested Egyptian cotton cultivar planted at three different densities (1,66,000, 2,22,000 and 3,33,000 plants per ha). Planting density had no significant effect on lint yield and fibre properties. It was found that when cotton was grown at 2, 3 and 4 plants per hill (1,66,000, 2,22,000 and 3,33,000 plants per ha, respectively), increasing the plant density decreased the number of bolls per plant and seed cotton yield per plant but increased yield per ha.

2.6.2 Genotype × Environment interaction by AMMI stability model

No previous studies on assessment of G × E interactions using Additive Main Effects and Multiplicative Interactions (AMMI) model in cotton with different environments created by differing planting densities for the traits *viz*., plant height, plant diameter, bolls per sq. m., seed cotton yield per plant and harvest index were found. But there were some studies in cotton using AMMI stability model over environments for seed cotton yield and are presented below.

Shinde *et al*. (2004) reported on seed cotton yield of ten *Gossypium hirsutum* varieties tested over 15 environments (years/locations) subjected to AMMI analysis. The results indicated a significant genotype-environment interaction (GEI) that influenced the relative ranking of the varieties across the environments. AMMI analysis indicated that genotype X environment and the first principal component of interaction effect accounted for 81.13 per cent of treatment sum of squares and first three principal components of interaction effect were found significant. As per the AMMI model two varieties *viz.,* RHC-1694 and RHC 688, were identified as having general adaptability. Further, the environments Summer, 1998 (Rahuri) and Summer, 1999 (Kopergaon) were found ideal for stable performance of the varieties tested.

Naveed *et al*. (2007) conducted an experiment to determine the yield stability, adaptability and G × E interaction of 18 cotton genotypes across seven different environments. The AMMI analysis of variance for seed cotton yield indicated that genotypes, environments and G × E interaction were significantly different ($p < 0.01$) and it also revealed that the environments, genotypes and G × E accounted for 70.41, 10.70 and 18.89 per cent of the treatment sum of squares, respectively. The sum of squares for genotypes, environments and IPCA 1 provided 91.03 per cent of treatment sum of squares. The result indicated that the proportion of environmental and G × E interaction variation for seed cotton yield was much larger than that due to genotypes' main effects. It also implied that yield was affected by both the environment and G × E interaction effects.

Riaz *et al.* (2013) conducted a study to determine the yield stability, adaptability and to analyze the G × E interaction of 9 cotton genotypes at six locations. AMMI analysis revealed that the major contributions to treatment sum of squares were environments (38.51 %), GE interaction (35.27 %) and genotypes (26.22 %) suggesting that the seed cotton yield of genotypes was under major environmental effects of G × E interactions. The first two principal component axes (PCA 1 and 2) cumulatively contributed to 64.34 per cent of the total GE interaction and were significant ($p \leq 0.01$). The biplot technique was used to identify appropriate genotypes for special locations / environments. Results showed that genotypes BH-172, MNH814 and NIAB-2009 with the lowest interaction, and genotypes FH-4243, FH-113, CIM-496, CIM-573, VH-289 and MNH-886 with the highest interaction were the most stable and unstable genotypes, respectively.

A study conducted by Gul *et al.* (2014) characterized the GEI by using eight upland cotton cultivars *viz.,* SLH-284, CIM-446, CIM-473, CIM-496, CIM-499, CIM-506, CIM-544 and CIM-707. Significant ($p \leq 0.01$) mean squares for genotypes, environments and G × E interactions revealed genetic variability among cotton genotypes as well as environmental inconsistency. The environment accounted for 61.86 per cent, 26.99 per cent and 18.64 per cent of total variation for bolls per plant, seed cotton yield and sympodia per plant, respectively, considering the larger effects of environment in combination with genotypes on plant growth and morphology. Based on two-year studies, CIM-496 exhibited the best performance followed by CIM-554 and SLH-284 for improvement in seed cotton and lint yields.

Mukoyi *et al.* (2015) evaluated genotypes using AMMI model and GGE biplot software. The environment effect was significant ($p < 0.05$) for seed cotton yield. The genotype x environment interaction was not significant for two seasons. SZ 9314 showed wide adaptation to all environments, a well known recommended characteristic of the commercial variety. The results showed that 644-98-11, 915-5-7 and SZ-95-7 are promising genotypes that can be registered for production in upland cotton ecologies worldwide and they can be incorporated in future cotton improvement program.

Pretorius *et al.* (2015) evaluated five genotypes over three seasons (2003 to 2006) at six locations. The AMMI statistical model was used to investigate the cultivar x environment interaction, yield stability and adaptation to environments. AMMI analysis indicated that cotton yield showed highly significant differences ($p < 0.01$) affected by environments, genotypes and genotype × environment interaction. Environmental fluctuations accounted for 84.0 per cent of the total sum of squares showing that the environments were diverse, with large differences among environmental means accounting for most of the variation in cotton yield. Results showed that Nu OPAL was the best performing cultivar in 15 out of 18 observations in fibre yields.

Farias *et al.* (2016) conducted an experiment with 16 genotypes in eight environments across Mato Grosso State. Data for seed cotton productivity were analyzed by AMMI and GGE biplot methods. Both methods were concordant in the discrimination of environments and genotypes for phenotypic stability. The genotypes BRS ARAÇÁ and LD 05 CV had high seed cotton productivity and phenotypic stability, and could be grown in all environments across Mato Grosso State.

Djaboutou *et al.* (2017) evaluated five genotypes in three regions during two years. The results indicated that density and cotton seed yield (CSY) were significantly affected by environment ($p < 0.000$). Significant effect of genotypes was observed with boll average weight. However, there was no significant difference among genotypes for variables, density and CSY ($p > 0.05$). In addition, the effect of genotypes × environments interaction on density was highly significant ($p \leq 0.01$). The genotypes Djougou 8/5, H-279-1, Kandi 3/4 and Okpara 3/5 were adapted to the environments of Kandi and Savalou and were more stable in the production of bolls and cotton seeds yield.

Material and Methods

3. MATERIAL AND METHODS

The present investigation was carried out in upland cotton (*G. hirsutum* L.) during *kharif,* 2016-17 at Agricultural Research Station, Dharwad Farm under rainfed conditions. The material used in the present investigation and techniques followed for collection, analysis and interpretation of data are described in this chapter.

3.1 Experimental location and weather condition

The experiment was conducted at Agricultural Research Station, Dharwad Farm, which is situated in the northern transitional zone (Zone 8) of Karnataka with latitude of 25°17' N, longitude of 71°46' E and an altitude of 678 m above the mean sea level. The experiments were laid out in black cotton soil and plots were homogeneous with respect to nutrient status. All agronomic management practices were followed according to recommended package of practices for Zone 8.

3.2 Description of the experimental material

The experimental material comprised of twenty eight new *G. hirsutum* L. genotypes along with three commercial check varieties. The list of genotypes and their pedigree is given below.

Sl. No.	Genotypes	Pedigree/Salient features
1	N-45	Super compact genotype derived from the double cross VBCH 2303 × JKCH 2245,
2	N-30	Super compact genotype derived from the double cross RAHH 246 × JKCH 2245
3	N-57	Super compact genotype derived from an elite interspecific hybrid E-221
4	N-59	Super compact genotype derived from an elite interspecific hybrid E-312
5	F-17	Super compact genotype derived from the cross L-761 × R-221
6	F-21	Super compact genotype derived from the cross L-761 × 1-2-1
7	F-22	Compact genotype derived from the cross L-761 × 1-2-1
8	F-25	Compact genotype derived from the cross R-100 × IC-6
9	F-31	Compact genotype derived from the cross DC-12 IPS × 8-1-2
10	U-16	Super compact genotype derived from the double cross RAHH 246 × JKCH 2245
11	U-20	Compact genotype derived from a double cross NNDC-93 Bulk
12	U-21	Compact genotype derived from a double cross NNDC-95 Bulk

Sl. No.	Genotypes	Pedigree/Salient features
13	U-31	Super compact genotype derived from the double cross VBCH 2303 × JKCH 2245
14	S-32	Compact genotype derived from composite cross of JK-97 and JK-44 and 36 other cotton strains. A sister line of Sahana.
15	S-34	Compact genotype derived from composite cross of JK-97 and JK-44 and 36 other cotton strains. A sister line of Sahana.
16	A-2	Compact genotype derived from the population of multiple crosses used to derive ARBH-813
17	A-11	Compact genotype derived from the population of multiple crosses used to derive ARBH-813
18	A-16	Compact genotype derived from the population of multiple crosses used to derive ARBH-813
19	A-31	Compact genotype derived from the population of multiple crosses used to derive ARBH-813
20	BRCC-1601	An early compact genotype obtained from Breeder, KSSC Research Farm, Dharwad
21	BRCC-1602	An early compact genotype obtained from Breeder, KSSC Research Farm, Dharwad
22	SCS-1206	A high yielding compact type obtained from Breeder, MARS, UAS Raichur
23	Suraj	A compact variety released from CICR, Coimbatore for Central and South Zone
24	ARBC-19	A compact variety from UAS Dharwad released for North Zone of India
25	ARBC-64	A promising compact genotype from UAS Dharwad in advanced trials
26	Sahana	Released robust variety from UAS Dharwad
27	ARBH-813	Released robust variety from UAS Dharwad
28	RAH-100	Released robust variety from UAS Dharwad

3.3 Particulars of the experiment

The set of 28 genotypes was evaluated in randomized complete block design with two replications each in three different planting densities, representing 3 environments. Three released varieties *viz*., Sahana, ARBH-813 and RAH-100 were also included in each environment. Each genotype was sown in a three row plot of 4.20 m length.

Environment	Planting geometry	Plants/hectare	Planting density	Date of sowing
1	60 cm × 15 cm	1,11,111	High	09.06.2017
2	60 cm × 30 cm	55,555	Recommended	09.06.2017
3	60 cm × 60 cm	27,777	Low	09.06.2017

3.4 Observations recorded

Five plants in each entry were selected randomly and tagged. These tagged plants were used for recording observations on the following characters.

3.4.1 Plant height

Plant height was measured in centimeters (cm) from the base of the plant to apex of the plant at maturity.

3.4.2 Number of sympodia per plant

The total number of sympodial branches *i.e.*, number of fruiting branches present in the plant at maturity, was counted.

3.4.3 Sympodial length at 50 per cent plant height

Sympodial branch length at 50 per cent plant height was measured and expressed in centimeters (cm).

3.4.4 Number of bolls per plant

The number of bolls on a plant, which contributed to seed cotton yield were counted and recorded at the time of harvest.

3.4.5 Number of bolls per square meter

The number of bolls in 11, 6 and 5 tagged plants from each entry in the three different planting densities E1, E2 and E3 respectively was recorded at the time of harvest. The number of plants is those accommodated in 1 square meter of land in each environment.

3.4.6 Boll weight

Seed cotton obtained from a random sample of 20 bolls per plant was used to determine single boll weight in grams (g).

3.4.7 Sympodial angle

Sympodial angle was measured at 50 per cent plant height with the help of a protractor and expressed in degrees.

3.4.8 Diameter of the plant

Diameter of the plant at different planting densities was calculated by using the sympodial angle and sympodial length at 50 per cent plant height. It can be worked out in the following manner.

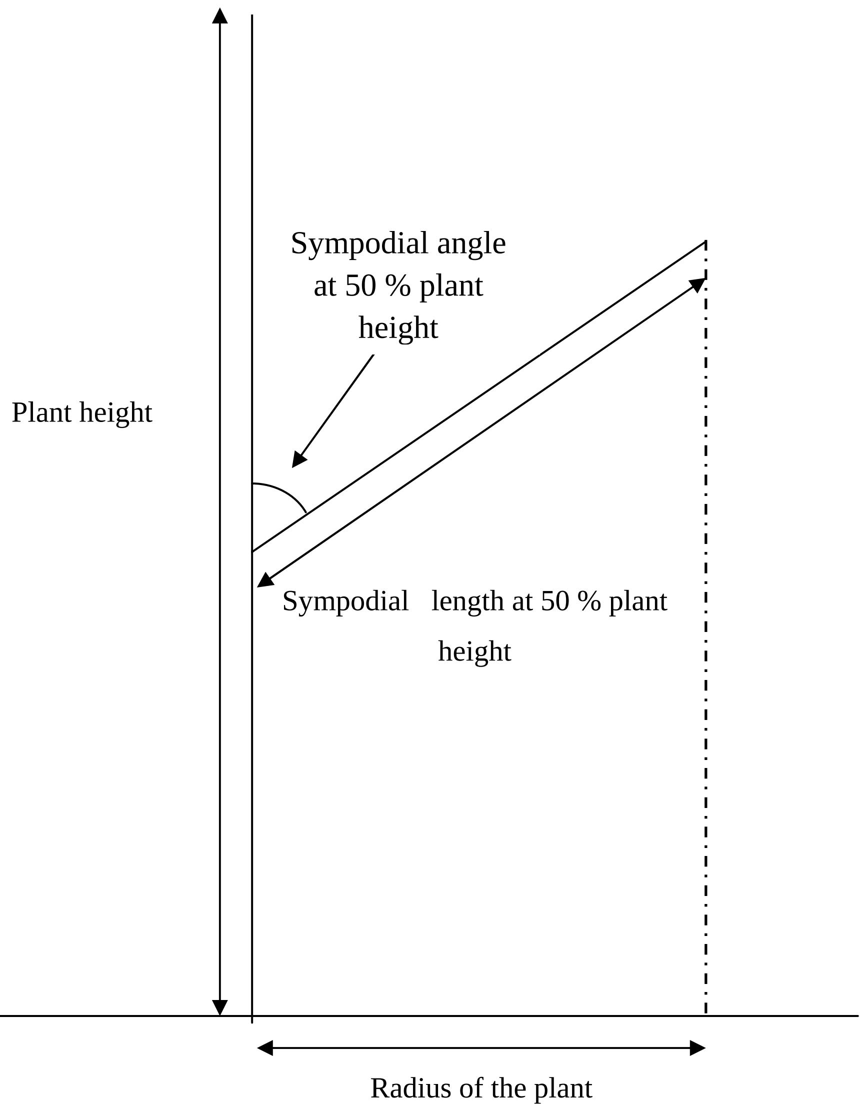

Fig. 1. Determination of plant diameter

Firstly the sympodial angle is to be converted to radian using the following formula.

$$\text{Radian} = \frac{\text{Sympodial angle} \times 3.14159}{180}$$

The radian is converted into Sin of radian. The radius is then converted using the following formula.

Radius = Sin (radian) × Sympodial length at 50 per cent plant height.

The diameter can be then obtained by doubling the radius and is expressed in centimetres (cm).

3.4.9 Seed index

Hundred good and bold seeds were weighed to determine the seed index in grams (g).

3.4.10 Ginning outturn (GOT)

A known quantity of random sample of seed cotton from each entry was ginned and the lint yield obtained from it was utilized for working out the ginning outturn as per cent (%) in the following manner.

$$\text{Ginning outturn (\%)} = \frac{\text{Weight of lint (g)}}{\text{Weight of seed cotton (g)}} \times 100$$

3.4.11 Lint index

It is the weight of the lint obtained from hundred seeds and expressed in grams (g). This was calculated by using the formula.

$$\text{Lint Index (g)} = \frac{\text{Weight of 100 seeds (g)} \times \text{Ginning outturn (\%)}}{100 - \text{Ginning outturn (\%)}}$$

3.4.12 Total biomass

It is the total weight in grams (g) obtained from both dry root and shoot weight. This was calculated in the following manner.

Total biomass (g) = Dry root weight (g) + Dry shoot weight (g)

3.4.13 Seed cotton yield per plant

Total weight of seed cotton in grams (g) obtained from the 11, 6 and 5 tagged plants from each entry in the three different planting densities E1, E2 and E3 respectively, was used to derive mean seed cotton yield per plant.

3.4.14 Harvest index

Harvest index is an important trait in plant breeding, which describes plant capacity to allocate biomass (assimilates) into the formed reproductive parts. Harvest index was determined by using the following formula.

$$\text{Harvest index} = \frac{\text{Economical yield}}{\text{Biological yield}} \times 100$$

Fibre quality traits

The following fibre quality characters were analyzed under high volume instrument (HVI). And the observations were recorded under HVI mode.

3.4.15 Upper half mean length

It is the average length by number of longer half (50 %) of the fibres distributed by weight and expressed in millimeters (mm).

3.4.16 Fibre strength

It is the force required to break fibre of unit linear density expressed in grams per tex (g/tex), and computed as below

$$\text{Fibre strength (g/tex)} = \frac{\text{Breaking strength (kg)}}{\text{Weight of tuff (mg)}} \times \text{Length of sample (mm)}$$

3.4.17 Micronaire value

It is the average weight per unit length of fibre. It is used in determining the fibre fineness. Linear density of fibre is expressed in micrograms per inch (μg/inch).

3.4.18 Rainfall

The rainfall received during 2016-17 was recorded in milliliters (mm) using the rain guaze and is presented in Appendix-II.

3.5 Plant type characterization

The categories of plant diameter and plant height were based on the Index Score method of Singh and Chaudhary (1985) where in the range of the traits were equally divided in to 3 and 2 categories, respectively in each environment. The chequer board developed had 6 plant type categories *viz.*, super compact, compact, compact spreading, tall compact, robust and highly robust. Each genotype was then assigned to a plant type category based on its diameter and height, in each environment separately.

3.6 Statistical analysis

The statistical methods applied during the analysis of data are as follows. For statistical analysis mean values for each character were taken.

3.6.1 Analysis of variance for design of experiment

The analysis of variance (ANOVA) was done to test the significance of differences among the genotypes for each character. The 'F' values were obtained for assessing the significance of mean sum of squares of treatments and CD was calculated for comparing the treatment means. Model is

$$Y_{ij} = \mu + a_i + b_j + e_{ij}$$

Where,

Y_{ij} = Observation in i^{th} treatment and j^{th} block

μ = Grand mean

a_i = i^{th} treatment effects

b_j= j^{th} block effect

e_{ij} = Random error associated with the i^{th} treatment and j^{th} block.

The assumptions of the model are:

1. All the observations should be independent.
2. The different effects in the model should be additive.
3. Error involved in the population should be normally and independently distributed with mean zero and variance.

The variance and co-variance matrices for calculating genotypic and phenotypic correlation coefficients were obtained from the mean sum of squares and mean sum of products of genotypes and error for different character were measured in replicated experiment. The analysis of variance table for all the characters under study were constructed as follows:

ANOVA TABLE

Source	**d.f**	**MSS**	**Expectations**	**F cal**
Replications	(b-1)	M_b	$\sigma^2_e + g\,\sigma^2_b$	M_b/M_e
Genotypes	(g-1)	M_g	$\sigma^2_e + r\,\sigma^2_g$	M_g/M_e
Error	(b-1)(g-1)	M_e	σ^2_e	
Total	(bg-1)			

Where,

b = Number of replications

g = Number of genotypes

σ^2_g = Variance due to genotypes

σ^2_b = Variance due to replications

σ^2_e = Error variance

M_b, M_g and M_e stand for mean sum of squares due to replications, genotypes and error, respectively.

3.6.2 Basic statistics

a) Mean ($\overline{X}$)

The mean value of each character was worked out by dividing the total value by corresponding number of observations.

$$\overline{X} = \frac{\Sigma X_{ij}}{N}$$

Where,

X_{ij} = any observation in ith genotypes and jth replication

N = Total number of observations

b) Range

The lowest and the highest values for each character were recorded.

c) Standard error (SE)

It is the measure of uncontrolled variation present in a sample which is estimated by dividing the standard deviation by the square root of the observations in the sample and is denoted by SE.

Thus, **SE = SD /** $\sqrt{n}$

Where,

S. D = Standard deviation

n = Number of observations

3.6.3 Estimation of genetic parameters

In order to assess and quantify the genetic variability among the genotypes for the characters under study, the following parameters were estimated.

3.6.3.1 Estimation of variance components

Genotypic and phenotypic variance and coefficients of variances were computed based on the expected mean sum of squares from the ANOVA table as follow.

The treatment mean sum of squares due to genotypes is made up of environmental variance along with 'r' times the genetic variance.

$$\sigma^2_g = \frac{M_t - M_e}{r}$$

$$\sigma^2_p = \frac{M_t - M_e}{r} + M_e \text{ or } \sigma^2_g + \sigma^2_e$$

Where,

M_t = Mean sum of squares due to treatments

M_e = Mean sum of squares due to error

r = Number of replications

σ^2_g = Genotypic variance

σ^2_p = Phenotypic variance

σ^2_e = Environmental variance

3.6.3.2 Genotypic and phenotypic co-efficients of variance

Both phenotypic and genotypic coefficients of variation for all the characters were estimated using the formulae of Burton and De Vane (1953).

1. Genotypic coefficient of variance (GCV) = $\dfrac{\sigma_g}{\overline{X}} \times 100$

2. Phenotypic coefficient of variation (PCV) = $\dfrac{\sigma_p}{\overline{X}} \times 100$

Where,

σ_g = Genotypic standard deviation
σ_p = Phenotypic standard deviation
$\overline{X}$ = General mean of the character

GCV and PCV values were categorized as low, moderate and high by Shivasubramanian and Menon (1973) as given below.

0-10%	: Low
10-20%	: Moderate
20% and above	: High

3.6.3.3 Heritability (h^2_{bs})

Heritability in broad sense was estimated as the ratio of genotypic variance to the total phenotypic variance as suggested by Hanson *et al.* (1956) and expressed as percentage (%).

$$\text{Heritability } (h^2_{bs}) = \sigma^2_g / \sigma^2_p \times 100$$

Where,

σ^2_g = Genotypic variance

σ^2_p = Phenotypic variance

The heritability percentage was categorized as low, moderate and high as per Robinson *et al*. (1949).

0-30% : Low

30-60% : Moderate

60% and above : High

3.6.3.4 Genetic advance (GA)

Genetic advance was estimated by using the formula given by Johnson *et al*. (1955).

$$GA = h^2_{bs} k \sigma_p$$

Where,

h^2_{bs} = Heritability in broad sense

k = Selection differential which is equal to 2.06 at 5% intensity of selection

σ_p= Phenotypic standard deviation

3.6.3.5 Genetic advance as per cent of mean (GAM)

$$GAM = \frac{GA}{\overline{X}} \times 100$$

Where,

GA = Genetic advance

$\overline{X}$ = General mean of the character

Genetic advance as per cent mean was categorized as low, moderate and high by Johnson *et al*. (1955).

0-10% : Low

10-20% : Moderate

20% and above : High

3.6.4 Estimation of correlation coefficient

Across the genotypes, the simple correlation coefficients were calculated to determine the direction and magnitude of association among different characters and tested against table ‘r’ values (Fisher and Yates, 1963) at (n-2) degree of freedom, both at 0.05 and 0.01

probability levels for their significance. Simple correlations were calculated by using the formula as given by Webber and Murthy (1952).

$$r = \frac{\text{Cov (x.y)}}{\sigma_x \, \sigma_y}$$

Where,

Cov (x.y) = Covariance of x and y

σ_x = Standard deviation of x

σ_y = Standard deviation of y

3.6.5 Path coefficient analysis

Path coefficient analysis suggested by Wright (1921), Dewey and Lu (1959) were carried out to know the direct and indirect effect of the morphological and physiological traits on plant yield. The following set of simultaneous equations were formed and solved for estimating various direct and indirect effects.

r1.y = P1y + r1.2 P2y + r1.3 P3y+ ………………....R1.k + Pky

r2.y = r2.1 P1 y + r2.2 P2 y + r2.3 P3y ……………..r2.k Pky.

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rk-1.y = rk-1.1 P1y + rk-1.2 +P2y + rk-1.3 + P3y + ... Pk-1y

Where,

r1.y to rk-1.y denote the correlation coefficients between independent characters, 1 to k-1 and dependent characters ‘y’, r1.2 to rk-2, k-1 denote the correlation coefficient between all possible combinations of independent characters. P1y to pk-1y denote the direct effects of characters 1 to k-1on character Y.

3.6.6 Analysis of variance

3.6.6.1 Two way analysis of variance

The data obtained for all the characters on all genotypes across locations were subjected to two way analysis of variance. This was done for each character in order to find out the variation due to genotypes and environments and to reveal the existence of genotype x environment interaction, if any. Only after ascertaining the existence of genotype x environment interaction in the two way analysis of variance, the data were further subjected to stability analysis.

Pooled analysis of variance

Source of variation	**d.f.**	**MSS**	**Expected value of MSS**	**Cal F.**
Environment	$(e-1)$		-	-
Genotype	$(g-1)$	M_1	$\sigma^2_e + \sigma^2_{ge} + e\sigma^2_g$	-
Genotype × Environment	$(g-1)(e-1)$	M_2	$\sigma^2_e + \sigma^2_{ge}$	-
Pooled error	M*	M_3	σ^2_e	-

*Degrees of freedom pooled over environments

3.6.7 Stability analysis

Additive Main effects and Multiplicative Interaction effects (AMMI) model of analysis of variance for stability was followed in this study.

3.6.7.1 Additive Main effects and Multiplicative Interaction effects (AMMI)

Statistical analysis using AMMI model was done in Window stat 8 program. The AMMI statistical model is a hybrid which makes use of standard ANOVA procedure to separate the additive variance from the multiplicative variance (genotype by environment interaction) and then uses a multiplicative procedure – Principal Component Analysis (PCA) to extract the pattern from the G × E portion of ANOVA analysis. The resulting statistical model is a hybrid of the two models and results in a least squares analysis which with further graphical representation of the numerical results (Biplot analysis) often allows interpretation of the underlying causes of G × E interaction (Gollob, 1968; Zobel *et al.* 1988; Gauch, 1993).

The mathematical model for AMMI is

$$Y_{ger} = \mu + \alpha_g + \beta_e + \sum \lambda_n \gamma_{gn} \delta_{en} + \rho_{ge} + \varepsilon_{ger}$$

Where,

g = genotypes

e = environments

r = replications

Y= character of a genotype in environment e

μ = grand mean

α_g= mean of the gth genotype minus the grand mean

β_e= mean of the eth genotype minus the grand mean

n = number of ICPAs (Interaction Principal Component axis) retained in the model

λ_n = singular value or square root of the Eigen value of the PCA axis n

γ_{gn}= principal component score for PCA axis of the gth genotype

δ_{en}= principal component score for PCA axis 'n' of the eth environment

ε_{ger} = residual

AMMI analysis procedure

Format

The AMMI analysis is the two factor analysis of variance (ANOVA) where the variance due to factor mean deviation from the grand mean is removed from the data matrix cells along with the grand mean, and the resulting matrix is subjected to matrix algebra procedure called Singular Value Decomposition (SVD). This process is followed by presenting the results on a two – factor scatter diagram called AMMI biplot, where the factor mean deviation from grand mean is represented on the X – axis and their interaction with each other (PCA 1) on Y axis.

Mathematical basis for AMMI analysis

Additive model

Two factor data are represented as a matrix with columns representing the different levels of one factor and rows representing the different levels of second factor. In a replicated experiment each replicate is represented as separate matrix and then the means of each cell across all replicate cell values from the mean and is assumed to be removed.

Mathematical representation of the additive model is

$$Y_{ge}= \mu + \alpha_g + \beta_e + \varepsilon_{ge}$$

Where,

Y_{ge} = actual cell value

μ = grand mean

α_g = row mean deviation from grand mean

β_e = column mean deviation from grand mean

Singular Value Decomposition (SVD)

Singular value decomposition is a matrix algebra procedure that is effective in characterizing a data matrix. Mathematical representation of a complete SVD of the data matrix is

$$Y_{ir} = \sum_{r=1}^{N} \rho_i \gamma_{ir} + \delta_{ci}$$

Where,

N = smaller of the number of rows or column

ρ_i= singular value (square root of the eigen value which in turn, is the sum of squares divided by number of replication) for axis i

γ_{ir}= eigen vector for row r in axis i

δ_{ci}= eigen vector for column c in axis i

Principal component analysis (PCA)

Principal component analysis is the application of singular value decomposition (SVD) to a matrix after the removal of the grand mean from each cell. The removal results in so called covariance matrix.

Mathematical representation of PCA

$$Y_{ir} = \sum_{r=1}^{N} \rho_i \gamma_{ir} + \delta_{ci}$$

Experimental Results

4. EXPERIMENTAL RESULTS

The results of the present investigations on genetic variability, character association, path analysis involving different traits and yield, characterization of plant type and genotype × environment interactions for identifying stable genotypes of cotton across three different planting densities (environments) are presented in the following sections :

4.1 Analysis of variance
4.2 Analysis of genetic variability parameters
4.3 Association analysis
4.4 Path co-efficient analysis
4.5 Plant type characterization
4.6 Stability analysis

4.1 Analysis of variance

The analysis of variance pertaining to the set of 28 *G. hirsutum* genotypes sown in three different planting densities (environments E1, E2 and E3) and evaluated in randomized block design is presented in Table 3. Significant treatment mean sum of squares for all the 19 characters studied, in each environment, indicated considerable amount of variation for most traits among the genotypes. The material selected for the present investigation was thus quite appropriate for further genetic analysis.

In case of E1 and E3, the analysis of variance indicated significant treatment mean sum of squares for plant height, number of sympodia, internode distance, sympodial angle, plant diameter, number of bolls per sq.m., boll weight, boll capsule weight, GOT, seed index, lint index, total biomass and harvest index. In addition to the above traits, significant treatment mean sum of squares for sympodial length at 50 per cent plant height and seed cotton yield was noticed in E2.

4.2 Analysis of genetic variability parameters

The data collected on eleven traits in the twenty eight genotypes of cotton were analysed to find out their performance in the recommended planting density (60 cm x 30 cm: E2 environment). The value of mean, range and genetic parameters for the different traits are presented in Table 4.

Table 3: ANOVA for various quantitative characters in cotton genotypes in three different environments evaluated at ARS, Dharwad during *kharif*, 2016-17

Characters	Mean sum of squares								
	E1			E2			E3		
	Rep	Genotype	Error	Rep	Genotype	Error	Rep	Genotype	Error
Plant height (cm)	1087.68	78.24*	29.99	159.13	100.68*	10.62	518.87	153.91*	51.07
Days to first flowering	98.6	9.53	6.95	56.3	7.29	5.24	74.5	5.86	6.21
Days to 50 per cent flowering	110.2	17.9	10.25	65.9	14.26	7.63	26.8	13.28	3.98
Number of sympodia	17.49	2.49*	0.79	6.45	2.90*	2.74	3.40	2.95*	1.29
Sympodial length at 50 per cent plant height (cm)	104.91	10.41	7.33	12.35	16.77*	6.06	11.89	14.27	7.89
Internode distance (cm)	0.49	0.33*	0.09	0.15	0.26*	0.06	0.45	0.38*	0.13
Interboll distance (cm)	0.14	0.06	0.05	0.01	0.10	0.06	0.06	0.12	0.07
Sympodial angle (degree)	161.84	20.03*	12.84	0.01	12.77*	11.67	0.09	16.48*	6.99
Plant diameter (cm)	7.19	37.48*	5.41	0.41	64.91*	5.46	7.02	58.07*	10.04
Number of bolls per plant	0.64	1.24	0.75	0.11	4.16*	1.71	21.25	9.66	6.99
Number of bolls per sq.m.	91.84	161.84*	68.07	22.10	122.41*	46.23	40.22	76.34*	40.07
Boll weight (g)	0.21	1.02*	0.08	0.01	1.83*	0.10	0.14	1.25*	0.08
Boll capsule weight (g)	1.37	7.69*	2.31	0.64	12.32*	1.62	2.57	6.91*	3.33
GOT (%)	15.56	47.22*	32.76	7.84	134.46*	31.34	1696.32	966.84*	873.87
Seed index (g)	0.43	1.53*	0.14	0.06	1.28*	0.31	0.77	1.28*	0.12
Lint index (g)	4.83	15.93*	6.59	16.98	50.69*	12.14	0.48	12.64*	4.77
Total biomass/plant (g)	2613.98	1765.10*	185.14	305.98	8560.21*	858.63	305.98	8560.21*	858.63
Seed cotton yield/plant (g)	35.01	12.66	7.43	666.56	271.07*	30.85	13.16	104.66	56.38
Harvest index (%)	154.08	18.00*	8.79	55.50	113.79*	21.39	464.17	1040.0*	332.73

E1: Spacing of 60 cm × 15 cm –1,11,111 plants/ha * Significance at 0.05 probability ** Significance at 0.01 probability.
E2: Spacing of 60 cm × 30 cm –55,555 plants/ha
E3: Spacing of 60 cm × 60 cm –27,777 plants/ha

Table 4: Means, range and genetic parameter values of eleven characters in *G. hirsutum* L estimated in the recommended planting density (60 cm × 30 cm of E2 environment) at ARS, Dharwad during *kharif* 2016-17

SL. No	Character	Mean	Range		Variance		Coefficient of Variation		GA	GAM (%)	h^2_{bs}(%)
			Min	Max	Genotypic	Phenotypic	Genotypic (%)	Phenotypic (%)			
1.	Plant height (cm)	63.30	49.90	76.50	45.03	55.65	10.60	11.78	12.43	19.64	80.92
2.	Number of sympodia	12.38	10.00	14.30	0.08	2.82	2.22	13.57	11.23	14.10	46.69
3.	Sympodial length at 50 per cent plant height (cm)	18.21	12.95	26.30	5.35	11.42	12.71	18.56	3.26	17.93	46.89
4.	Internode distance (cm)	3.83	3.16	4.47	0.1	0.16	8.18	10.54	0.50	13.10	60.36
5.	Plant diameter (cm)	35.94	25.27	51.95	29.73	35.19	15.17	16.51	10.32	28.73	84.48
6.	Number of bolls per plant	8.07	5.50	12.00	1.23	2.93	13.72	21.21	1.48	18.28	41.83
7.	Number of bolls per sq.m.	43.91	26.85	64.35	38.09	84.32	14.05	20.91	8.54	19.46	45.17
8.	Boll weight (g)	3.54	1.60	5.62	0.86	096	26.29	27.72	1.82	51.31	89.92
9.	Boll capsule weight (g)	14.52	10.75	20.25	5.35	6.97	15.94	18.18	4.18	28.78	76.83
10.	Ginning outturn (%)	57.25	39.89	80.24	51.56	82.90	12.54	15.90	11.67	20.38	62.20
11	Seed index (g)	8.96	7.41	10.74	0.49	0.79	7.78	9.93	1.13	12.56	61.39
12.	Lint index (g)	12.95	6.43	34.01	19.28	31.42	33.90	43.28	7.08	54.70	61.36
13.	Total biomass (g)	213.12	134.95	261.25	673.46	1255.17	12.18	16.62	39.16	8.37	63.65
14.	Seed cotton yield per plant (g)	59.02	32.91	83.71	120.11	150.96	18.57	20.82	19.14	34.12	79.56
15.	Harvest index (%)	31.15	16.57	50.23	46.20	67.59	21.82	26.40	21.58	37.17	68.36

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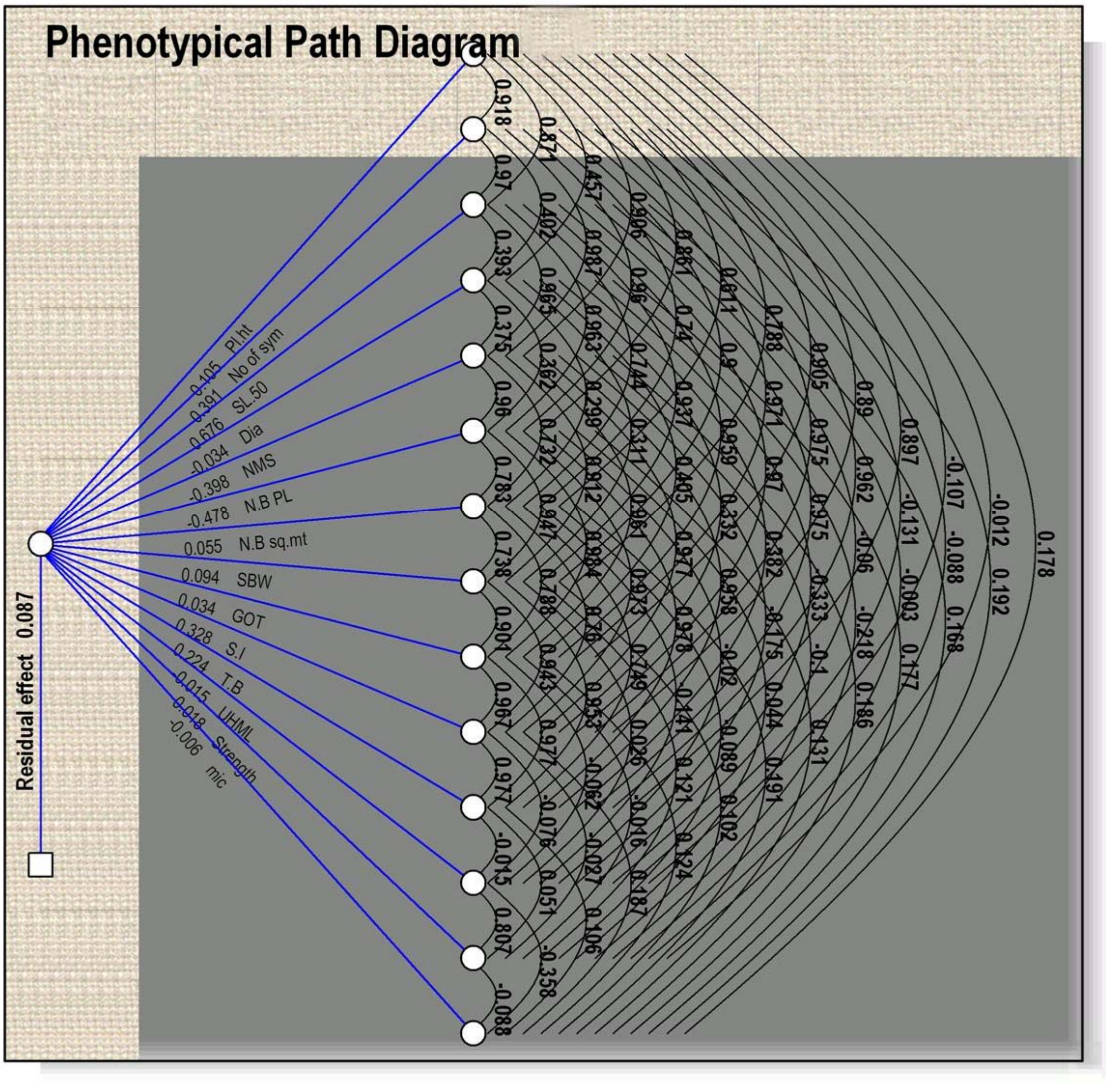

Fig. 2. Phenotypical path diagram for seed cotton yield (g/plant)

PH – Plant height, **NSP** – Number of sympodia per plant, **SL.50** – Sympodial length at 50 per cent plant height, **D** – Diameter, **NMS** – Number of nodes on main stem, **NBP** – Number of bolls per plant, **NBSM**– Number of bolls per sq.m. **BW** – Boll weight, **GOT** – Ginning outturn **S.I** – Seed index, **T.B** – Total biomass, **SCY** – Seed cotton yield, **UHML** – Upper half mean length, **FS** – Fibre strength, **Mic** – Micronaire value

4.2.1 Plant height

The overall mean of the genotypes for plant height was 63.30 cm. The genotypic variance was 45.03 and phenotypic variance was 55.65. The genotypic and phenotypic coefficients of variation were 10.60 and 11.78, respectively. Genetic advance and genetic advance as per cent of mean were 12.43 and 19.64 per cent, respectively. Heritability estimate was 80.92 per cent.

4.2.2 Number of sympodia

The mean of the genotypes for number of sympodia was 12.38. The genotypic variance was 0.08 and phenotypic variance was 2.82. The genotypic and phenotypic coefficients of variation were 2.22 and 13.57, respectively. Genetic advance and genetic advance as per cent of mean were 11.23 and 14.10 per cent, respectively. Heritability estimate was 46.69 per cent.

4.2.3 Sympodial length at 50 per cent plant height

The overall mean of the genotypes for plant height was 18.21 cm. The genotypic variance was 5.35 and phenotypic variance was 11.42. The genotypic and phenotypic coefficients of variation were 12.71 and 18.56, respectively. Genetic advance and genetic advance as per cent of mean were 3.26 and 17.93 per cent, respectively. Heritability estimate was 46.89 per cent.

4.2.4 Internode distance

The observed mean internode distance was 3.83 cm with a range of 3.16 to 4.47 cm. The estimated genotypic and phenotypic variances were 0.10 and 0.16, respectively. Genotypic and phenotypic coefficients of variation for internode distance were 8.18 and 10.54 per cent, respectively. The genetic advance was 0.50 per cent, as per cent of that mean was 13.10 with heritability estimate of 60.36 per cent.

4.2.5 Plant diameter

Range for this character was 25.27 to 51.95 cm with a mean of 35.94 cm. The trait exhibited genotypic and phenotypic variances of 29.73 and 35.19, respectively. The genotypic and phenotypic coefficients of variation were 15.17 and 16.51 per cent, respectively. The genetic advance observed was 10.32 and per cent of mean was 28.73 per cent, with heritability estimate of 84.48 per cent.

4.2.6 Number of bolls per plant

The observed mean for number of bolls per plant was 8.07. The estimated genotypic and phenotypic variances were 1.23 and 2.93, respectively. Genotypic and phenotypic coefficients of variation were 13.72 and 21.21 per cent, respectively. The genetic advance was 1.48 per cent, as per cent of that mean was 18.28 with heritability estimate of 41.83 per cent.

4.2.7 Number of bolls per sq.m.

The mean recorded for the number of bolls per sq.mt was 43.91 with a range of 26.85 to 64.35. The genotypic and phenotypic variances were 38.09 and 84.32, respectively. Genotypic and phenotypic coefficients of variation for this character were 14.05 and 20.91 per cent, respectively. The genetic advance was 8.54 per cent with per cent of that mean being 19.46. The estimated heritability was 45.17 per cent.

4.2.8 Boll weight

The recorded mean boll weight was 3.54 g with a range of 1.60 to 5.62 g. The genotypic and phenotypic variances for this trait were 0.86 and 0.96, respectively. The genotypic and phenotypic coefficients of variation were 26.29 and 27.72, respectively. The estimated heritability was 89.92 per cent. The genetic advance and genetic advance as per cent of mean were 1.82 and 51.35 per cent, respectively.

4.2.9 Boll capsule weight

The overall mean of the genotypes for boll capsule weight was 14.52 g with a range of 10.75 to 20.25 g. The estimated genotypic and phenotypic variances were 5.35 and 6.97, respectively. Genotypic and phenotypic coefficients of variation were 15.94 and 18.18 per cent, respectively. The genetic advance was 4.18 per cent, as per cent of mean was 28.78 with heritability estimate of 76.83 per cent.

4.2.10 Ginning outturn

The observed mean for ginning outturn was 57.25. The estimated genotypic and phenotypic variances were 51.56 and 82.90, respectively. Genotypic and phenotypic coefficients of variation were 12.54 and 15.90 per cent, respectively. The genetic advance was 11.67 per cent, as per cent of that mean was 20.38 with heritability estimate of 62.20 per cent.

4.2.11 Seed index

The mean seed index was 8.96 g and the range for this character was 7.41 to 10.74 g. The trait exhibited genotypic and phenotypic variances of 0.49 and 0.79, respectively. The genotypic and phenotypic coefficients of variation were 7.78 and 9.93, respectively. The heritability was 61.39 per cent. The genetic advance and genetic advance as per cent of mean were 1.13 and 12.56 per cent, respectively.

4.2.12 Lint index

The recorded lint index was 12.95 g. with a range from 6.43 to 34.01 g. The estimated genotypic and phenotypic variances were 19.28 and 31.42, respectively. Genotypic and phenotypic coefficients of variation were 33.90 and 43.28 per cent, respectively. The genetic advance was 7.08 per cent and as per cent of that mean was 54.70, with heritability estimate of 61.36 per cent.

4.2.13 Total biomass per plant

The range for the total biomass per plant was 134.95 to 261.25 g with a mean of 213.12 g. The trait exhibited genotypic and phenotypic variances of 673.46 and 1255.17, respectively. The genotypic and phenotypic coefficients of variation were 12.18 and 16.62 per cent, respectively. The genetic advance and per cent of that mean were 39.16 and 53.65 per cent, respectively with heritability estimate of 63.65 per cent.

4.2.14 Seed cotton yield per plant

The mean seed cotton yield per plant was 59.02 g. with a range of 32.91 to 83.71 g. The genotypic and phenotypic variances for this trait were 120.11 and 150.96, respectively. The genotypic and phenotypic coefficients of variation estimated were 18.57 and 20.82, respectively. The genetic advance and genetic advance as per cent of mean were 20.14 and 34.12 per cent, respectively with heritability of 79.56 per cent.

4.2.15 Harvest index

The recorded mean for harvest index was 31.15 per cent with a range of 16.57 to 50.23 per cent. The genotypic and phenotypic variances were 46.20 and 67.59, respectively. Genotypic and phenotypic coefficients of variation for this character were 21.82 and 26.40 per cent, respectively. The genetic advance was 11.58 per cent with per cent of that mean being 37.17. The heritability estimated was 68.36 per cent.

4.3 Association studies

Improvement in the seed cotton yield is an important goal of plant breeding. The ultimate seed yield is a complex process that will be affected by many genetic and non genetic factors. In order to know the magnitude of association of the seed cotton yield with other yield influencing traits, correlation analysis is an effective tool. The association studies give us an idea about how the traits are associated with each other as well as with the seed yield. The results of the association studies (Table 5) are presented here under.

The seed cotton yield per plant was positively and significantly correlated with plant height (0.89), number of sympodia per plant (0.97), sympodial length at 50 per cent plant height (0.98), plant diameter (0.37), number of nodes on main stem (0.95), number of bolls per plant (0.94), number of bolls per sq.m. (0.75), boll weight (0.92), ginning outturn (0.95), seed index (0.97) and total biomass (0.97). The fibre traits, upper half mean length (-0.07) and fibre strength (-0.03) were negatively, and micronaire value (0.17) positively, but non-significantly correlated with the seed cotton yield per plant.

Plant height had positive significant correlation with number of sympodia per plant (0.91), sympodial length at 50 per cent plant height (0.87), plant diameter (0.45), number of nodes on main stem (0.90), number of bolls per plant (0.86), number of bolls per sq.m. (0.61), boll weight (0.78), ginning outturn (0.90), seed index (0.89) and total biomass (0.89). Fibre traits, upper half mean length (-0.10) and fibre strength (-0.01) were negatively and non-significantly correlated with plant height.

Number of sympodia per plant had positive significant correlation with sympodial length at 50 per cent plant height (0.96), plant diameter (0.40), number of nodes on main stem (0.98), number of bolls per plant (0.95), number of bolls per sq.m. (0.73), boll weight (0.90), ginning outturn (0.97), seed index (0.97) and total biomass (0.96). Fibre traits, upper half mean length (-0.13) and fibre strength (-0.08) were negatively but non-significantly correlated with number of sympodia per plant and micronaire value (0.19) had no correlation with it.

Sympodial length at 50 per cent plant height had positive significant association with plant diameter (0.39), number of nodes on main stem (0.96), number of bolls per plant (0.96), number of bolls per sq.m. (0.74), boll weight (0.93), ginning outturn (0.95), seed index (0.97) and total biomass (0.97). Fibre traits, upper half mean length (-0.06) and fibre strength (-0.00)

Table 5: Phenotypic correlations among fifteen quantitative characters in the recommended planting density of *G. hirsutum* genotypes at ARS, Dharwad during *kharif* 2016-17

Characters	PH	NSP	SL50	PD	NMS	NBP	NBS	BW	GOT	S I	TB	UHML	FS	Mic	SCY
PH	1	0.91**	0.87**	0.45**	0.90**	0.86**	0.61**	0.78**	0.90**	0.89**	0.89**	-0.10	-0.01	0.17	0.89**
NSP		1	0.96**	0.40**	0.98**	0.95**	0.73**	0.90**	0.97**	0.97**	0.96**	-0.13	-0.08	0.19	0.97**
SL50			1	0.39**	0.96**	0.96**	0.74**	0.93**	0.95**	0.97**	0.97**	-0.06	-0.00	0.16	0.98**
PD				1	0.37**	0.36**	0.29*	0.31*	0.40**	0.33*	0.38**	-0.33*	-0.21	0.17	0.37**
NMS					1	0.95**	0.73**	0.91**	0.96**	0.97**	0.95**	-0.17	-0.10	0.18	0.95**
NBP						1	0.78**	0.94**	0.98**	0.97**	0.97**	-0.01	0.04	0.13	0.94**
NBS							1	0.73**	0.78**	0.75**	0.74**	-0.14	-0.08	0.19	0.75**
BW								1	0.90**	0.94**	0.95**	0.02	0.12	0.10	0.92**
GOT									1	0.96**	0.97**	-0.06	-0.01	0.12	0.95**
S I										1	0.97**	-0.07	-0.02	0.18	0.97**
TB											1	-0.01	0.05	0.10	0.97**
UHML												1	0.80**	-0.35**	-0.07
FS													1	-0.08	-0.03
Mic														1	0.17

PH – Plant height, **NSP** – Number of sympodia per plant, **SL.50** – Sympodial length at 50 per cent plant height, **PD** – Plant diameter, **NMS** – Number of nodes on main stem, **NBP** – Number of bolls per plant, **NB**– Number of bolls per sq.m. **BW** – Boll weight, **GOT** – Ginning outturn, **S.I** – Seed index, **T.B** – Total biomass, **UHML** – Upper half mean length of fibre, **FS-** Fibre strength, **Mic** – Micronaire value, **SCY-** Seed cotton yield.

* Significance at 0.05 probability ** Significance at 0.01 probability.

were negatively and non-significantly correlated with sympodial length at 50 per cent plant height and micronaire value (0.16) had no correlation with it.

Significant positive correlation was observed between plant diameter and number of nodes on main stem (0.37), number of bolls per plant (0.36), number of bolls per sq.m. (0.29), boll weight (0.31), ginning outturn (0.40), seed index (0.33) and total biomass (0.38). Fibre upper half mean length (-0.33) had negative significant correlation, fibre strength (-0.21) was negatively but non-significantly correlated and micronaire value (0.17) had positive non-significant correlation with plant diameter.

Number of nodes on main stem had positive significant correlation with number of bolls per plant (0.95), number of bolls per sq.m. (0.73), boll weight (0.91), ginning outturn (0.96), seed index (0.97) and total biomass (0.95). Fibre traits, upper half mean length (-0.17) and fibre strength (-0.10) were negatively but non-significantly correlated and micronaire value (0.18) had non-significant correlation with number of bolls per plant.

Positive significant correlation was noticed between number of bolls per plant and number of bolls per sq.m. (0.78), boll weight (0.94), ginning outturn (0.98), seed index (0.97) and total biomass (0.97). Fibre traits, upper half mean length (-0.01) was negatively but non-significantly correlated. Micronaire value (0.18) and fibre strength (0.04) were non-significantly correlated with number of bolls per plant.

Number of bolls per sq.m. had positive significant correlation with boll weight (0.73), ginning outturn (0.78), seed index (0.75) and total biomass (0.74). Fibre traits, upper half mean length (-0.14) and fibre strength (-0.08) were negatively and non-significantly correlated. Micronaire value (0.19) was positively and non-significantly correlated with the number of bolls per sq.m.

Boll weight had positive significant correlation with ginning outturn (0.90), seed index (0.94), and total biomass (0.95). Fibre traits, upper half mean length (0.02), fibre strength (0.12) and micronaire value (0.10) were positively but non-significantly correlated with it.

The trait, ginning outturn had positive significant association with seed index (0.96) and total biomass (0.97). Fibre traits, upper half mean length (-0.06) and fibre strength (-0.01) were negatively and non-significantly associated with ginning outturn. Micronaire value (0.12) had no significant correlation with it.

Seed index was positively and significantly correlated with the total biomass (0.97). Fibre traits, upper half mean length (-0.07) and fibre strength (-0.02) were negatively and non-significantly correlated with seed index. Micronaire value (0.18) had no correlation with it.

No correlation was observed between total biomass and upper half mean length (-0.01), fibre strength (0.05) and micronaire value (0.10).

The fibre trait, upper half mean length had positive significant association with fibre strength (0.80) and negative significant correlation with micronaire value (-0.35). Non-significant correlation was observed between fibre strength and micronaire value (-0.08).

4.4 Path coefficient analysis

The path coefficient analysis was done to partition the correlation coefficient into direct and indirect effects. The phenotypic correlation coefficients of various characters which showed significance with seed yield per plant were subjected to path coefficient analysis to estimate the direct and indirect effects of component traits on seed yield, considered as the dependent variable in the analysis. The direct and indirect effects of various traits on yield are presented in Table 6.

4.4.1 Direct effects

Eight out of fourteen characters had positive direct effect and six had negative direct effect on seed cotton yield per plant at phenotypic level. The highest positive direct effect on seed cotton yield was observed in sympodial length at 50 per cent plant height (0.6764) followed by number of sympodia per plant (0.3903), seed index (0.3284), total biomass (0.2230), plant height (0.1051), boll weight (0.0941) and number of bolls per sq.m. (0.0550). The highest negative direct effect on seed cotton yield was observed in case of number of bolls per plant (-0.4776) followed by number of nodes on main stem (-0.3985), plant diameter (-0.0345), fibre strength (0.0181), upper half mean length (-0.0146) and micronaire value (-0.0059).

4.4.2 Indirect effects

The indirect effect of each trait on seed cotton yield is described below.

4.4.2.1 Plant height

Plant height exhibited significant positive correlation with seed cotton yield and showed positive direct effect on it. It had positive indirect effect through all the characters,

Table 6: Direct and indirect effects of different characters on seed cotton yield at phenotypic level in *G. hirsutum* genotypes in the recommended planting density (60 cm × 30 cm) evaluated at ARS, Dharwad during *kharif* 2016-17

Characters	P H	NSP	SL 50	PD	NMS	NBP	NBSM	BW	GOT	SI	TB	UHML	FS	Mic	Correlation with SCY
P H	**0.1051**	0.0965	0.0916	0.0480	0.0953	0.0905	0.0643	0.0828	0.0951	0.0936	0.0943	-0.0112	-0.0013	0.0187	0.89**
NSP	0.3583	**0.3903**	0.3785	0.1567	0.3853	0.3746	0.2888	0.3514	0.3789	0.3805	0.3755	-0.0512	-0.0342	0.0748	0.97**
SL50	0.5891	0.6559	**0.6764**	0.2659	0.6524	0.6513	0.5031	0.6336	0.6487	0.6561	0.6598	-0.0408	-0.0024	0.1135	0.98**
PD	-0.0158	-0.0139	-0.0136	**-0.0345**	-0.0130	-0.0125	-0.0103	-0.0107	-0.0140	-0.0115	-0.0132	0.0115	0.0075	-0.0661	0.37**
NMS	-0.3612	-0.3934	-0.3844	-0.1495	**-0.3985**	-0.3825	-0.2919	-0.3636	-0.3830	-0.3893	-0.3818	0.0696	0.0399	-0.0742	0.95**
NBP	-0.4112	-0.4584	-0.4598	-0.1728	-0.4584	**-0.4776**	-0.3741	-0.4524	-0.4699	-0.4645	-0.4672	0.0094	-0.0210	-0.0624	0.94**
NBSM	0.0337	0.0407	0.0409	0.1664	0.0403	0.0431	**0.0550**	0.0406	0.0434	0.0418	0.0412	-0.0078	-0.0049	0.0105	0.75**
BW	0.0741	0.0847	0.0881	0.0292	0.0858	0.0891	0.0694	**0.0941**	0.0847	0.0887	0.0897	0.0024	0.0114	0.0996	0.92**
GOT	0.0307	0.0329	0.0325	0.0137	0.0326	0.0334	0.0267	0.0305	**0.0339**	0.0328	0.0331	-0.0021	-0.0005	0.0042	0.95**
SI	0.2924	0.3202	0.3185	0.1091	0.3208	0.3194	0.2495	0.3097	0.3176	**0.3284**	0.3207	-0.0249	-0.0088	0.0613	0.97**
TB	0.1999	0.2146	0.2175	0.0852	0.2137	0.2181	0.1669	0.2126	0.2180	0.2178	**0.2230**	-0.0332	0.0113	0.0236	0.97**
UHML	0.0016	0.0019	0.0009	0.0049	0.0026	0.0003	0.0021	-0.0004	0.0009	0.0011	-0.0002	**-0.0146**	-0.0118	0.0052	-0.07
FS	0.0002	0.0016	0.0001	0.0039	0.0018	0.0008	0.0016	-0.0022	0.0003	0.0005	-0.0009	-0.0146	**-0.0181**	0.0016	-0.03
Mic	-0.0010	-0.0011	-0.0010	-0.0010	-0.0011	-0.0008	-0.0011	-0.0006	-0.0007	-0.0011	-0.0006	0.0021	0.0005	**-0.0059**	0.17

* Significance at 0.05 probability ** Significance at 0.01 probability Residual effect: 0.087

PH – Plant height, **NSP** – Number of sympodia per plant, **SL.50** – Sympodial length at 50 per cent plant height, **D** – Diameter, **NMS** – Number of nodes on main stem, **NBP** – Number of bolls per plant, **NBSM**– Number of bolls per sq.m. **BW** – Boll weight, **GOT** – Ginning outturn **S.I** – Seed index, **T.B** – Total biomass, **UHML** – Upper half mean length, **FS** – Fibre strength, **Mic** – Micronaire value.

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number of sympodia per plant (0.0965), sympodial length at 50 per cent plant height (0.0916), plant diameter (0.0480), number of nodes on main stem (0.0953), number of bolls per plant (0.0905) number of bolls per sq.mt (0.0643), boll weight (0.0828), ginning outturn (0.0951), seed index (0.0936), total biomass (0.0943) and micronaire value (0.0187). It had the negative indirect effect through upper half mean length (-0.0112) and fibre strength (-0.0013).

4.4.2.2 Number of sympodia per plant

Number of sympodia per plant had positive significant correlation with seed cotton yield and also exhibited positive direct effect (0.3903) on seed cotton yield. It had indirect positive effect through plant height (0.3583), sympodial length at 50 per cent plant height (0.3785), plant diameter (0.1567), number of nodes on main stem (0.3853), number of bolls per plant (0.3746) number of bolls per sq.m. (0.2888), boll weight (0.3514), ginning outturn (0.3789), seed index (0.3805), total biomass (0.3755) and micronaire value (0.0748). It had the negative indirect effect through upper half mean length (-0.0512) and fibre strength (-0.0342).

4.4.2.3 Sympodial length at 50 per cent plant height

Sympodial length at 50 per cent plant height showed the significant positive correlation with seed cotton yield and also exhibited positive direct effect (0.6764) on seed cotton yield. It had indirect positive effect through plant height (0.5891), number of sympodia per plant (0.6559), plant diameter (0.2659), number of nodes on main stem (0.6524), number of bolls per plant (0.6513), number of bolls per sq.m. (0.5031), boll weight (0.6336), ginning outturn (0.6487), seed index (0.6561), total biomass (0.6598) and micronaire value (0.1135) and also exhibited the negative indirect effect through upper half mean length (-0.0408) and fibre strength (-0.0024).

4.4.2.4 Plant diameter

Plant diameter exhibited significant positive correlation with seed cotton yield and showed negative direct effect on it. It had the positive indirect effect through upper half mean length (0.0115) and fibre strength (0.0075). It had negative indirect effect through all the characters, plant height (-0.0158), number of sympodia per plant (-0.0139), sympodial length at 50 per cent plant height (-0.0136), number of nodes on main stem (-0.0130), number of bolls per plant (-0.0125), number of bolls per sq.m. (-0.0103), boll weight (-0.0107), ginning outturn (-0.0140), seed index (-0.0115), total biomass (-0.0132) and micronaire value (-0.0661).

4.4.2.5 Number of nodes on main stem

Number of nodes on main stem had positive correlation with seed cotton yield and negative direct effect on it. It had positive indirect effect through upper half mean length (0.0696) and fibre strength (0.0399). It had negative indirect effect through plant height (-0.3612), number of sympodia per plant (-0.3934), sympodial length at 50 per cent plant height (-0.3844), plant diameter (-0.1495), number of bolls per plant (-0.3825), number of bolls per sq.m. (-0.2919), boll weight (-0.3636), ginning outturn (-0.3830), seed index (-0.3893), total biomass (-0.3818) and micronaire value (-0.0742).

4.4.2.6 Number of bolls per plant

Number of bolls per plant exhibited positive correlation with seed cotton yield and had negative direct effect on it. It had positive indirect effect through upper half mean length (0.0094). It had negative indirect effect through plant height (-0.4112), number of sympodia per plant (-0.4584), sympodial length at 50 per cent plant height (-0.4598), plant diameter (-0.1728), number of nodes on main stem (-0.4584), number of bolls per sq.m. (-0.3741), boll weight (-0.4524), ginning outturn (-0.4699), seed index (-0.4645), total biomass (-0.4672), fibre strength (-0.0210) and micronaire value (-0.0624).

4.4.2.7 Number of bolls per sq.m.

Number of bolls per sq.m. had positive significant association with seed cotton yield and positive direct effect on it. It had positive indirect effect through plant height (0.0337), number of sympodia per plant (0.0407), sympodial length at 50 per cent plant height (0.0409), plant diameter (0.1664), number of nodes on main stem (0.0403), number of bolls per plant (0.0431), boll weight (0.0406), ginning outturn (0.0434), seed index (0.0418), total biomass (0.0412) and micronaire value (0.0105). It had negative indirect effect through upper half mean length (-0.0078) and fibre strength (-0.0049).

4.4.2.8 Boll weight

Boll weight showed positive significant association with seed cotton yield and had positive direct effect on it. It had positive indirect effect through plant height (0.0741), number of sympodia per plant (0.0847), sympodial length at 50 per cent plant height (0.0881), plant diameter (0.0292), number of nodes on main stem (0.0858), number of bolls per plant (0.0891), number of bolls per sq.m. (0.0694), ginning outturn (0.0847), seed index (0.0887), total biomass (0.0897), upper half mean length (0.0024) and micronaire value (0.0996). It had negative indirect effect through fibre strength (-0.0114).

4.4.2.9 Ginning outturn

Ginning outturn had positive significant association with seed cotton yield and positive direct effect on it. It had positive indirect effect through plant height (0.0307), number of sympodia per plant (0.0329), sympodial length at 50 per cent plant height (0.0325), plant diameter (0.0137), number of nodes on main stem (0.0326), number of bolls per plant (0.0334), number of bolls per sq.m. (0.0267), boll weight (0.0305), seed index (0.0328), total biomass (0.0331) and micronaire value (0.0042). It had negative indirect effect through upper half mean length (-0.0021) and fibre strength (-0.0005).

4.4.2.10 Seed index

Seed index exhibited positive significant association with seed cotton yield and had positive direct effect on it. It had positive indirect effect through plant height (0.2924), number of sympodia per plant (0.3202), sympodial length at 50 per cent plant height (0.3185), plant diameter (0.1091), number of nodes on main stem (0.3208), number of bolls per plant (0.3194), number of bolls per sq.m. (0.2495), boll weight (0.3097), ginning outturn (0.3176), total biomass (0.3207) and micronaire value (0.0613). It had negative indirect effect through upper half mean length (-0.0249) and fibre strength (-0.0088).

4.4.2.11 Total biomass

Total biomass showed positive significant association with seed cotton yield and had positive direct effect on it. It had positive indirect effect through plant height (0.1999), number of sympodia per plant (0.2146), sympodial length at 50 per cent plant height (0.2175), plant diameter (0.0852), number of nodes on main stem (0.2137), number of bolls per plant (0.2181), number of bolls per sq.m. (0.1669), boll weight (0.2126), ginning outturn (0.2180), seed index (0.2178), fibre strength (0.0113) and micronaire value (0.0236). It had negative indirect effect through upper half mean length (-0.0332).

4.4.2.12 Upper half mean length

Fibre upper half mean length had negative non-significant association with seed cotton yield and negative direct effect on it. It had positive indirect effect through plant height

(0.0016), number of sympodia per plant (0.0019), sympodial length at 50 per cent plant height (0.0009), plant diameter (0.0049), number of nodes on main stem (0.0026), number of bolls per plant (0.0003), number of bolls per sq.m. (0.0021), ginning outturn (0.0009), seed index (0.0011) and micronaire value (0.0052). It had negative indirect effect through fibre strength, boll weight (-0.0004) and total biomass (-0.0002).

4.4.2.13 Fibre strength

Fibre strength had negative non-significant association with seed cotton yield and negative direct effect on it. It had positive indirect effect through plant height (0.0002), number of sympodia per plant (0.0016), sympodial length at 50 per cent plant height (0.0001), plant diameter (0.0039), number of nodes on main stem (0.0018), number of bolls per plant (0.0008), number of bolls per sq.m. (0.0016), ginning outturn (0.0003), seed index (0.0005) and micronaire value (0.0016).

4.4.2.14 Micronaire value

Micronaire value exhibited positive significant correlation with seed cotton yield and had positive direct effect on it. It had positive indirect effect through upper half mean length (0.0021) and fibre strength (0.0005). It had negative indirect effect through plant height (-0.0010), number of sympodia per plant (-0.0011), sympodial length at 50 per cent plant height (-0.0010), plant diameter (-0.0010), number of nodes on main stem (-0.0011), number of bolls per plant (-0.0008), number of bolls per sq.m. (-0.0011), boll weight (-0.0006), ginning outturn (-0.0007) and seed index (-0.0011).

4.5 Plant type characterization

The twenty eight genotypes were characterized in to six different plant type categories in the three different environments separately, based on plant height and plant diameter as outlined in the material and methods chapter. The classification was based on the index score method. Accordingly, there were three plant diameter classes and two plant height classes which in conjunction gave six plant type categories *viz.*, super compact, compact, compact spreading, tall compact, robust and highly robust.

4.5.1 Plant type characterization in E1

The genotypes N-57, A-2, A-11, A-16 and A-31 fell in the super compact category and N-45, N-30, U-21 and F-21 were categorised as compact type. Genotypes F-31, U-16, U-

31, S-32, BRCC-1601, BRCC-1602, ARBH-813 and ARBC-64 were categorized as compact spreading type. Under the tall compact type, genotypes U-20, S-34 and ARBC-19 were seen, whereas, F-25 and Sahana fell in the robust category. The genotypes that were categorized as the highly robust type were N-59, F-17, F-22, SCS-1206, RAH-100 and Suraj (Table 7).

4.5.2 Plant type characterization in E2

In the second environment, the genotypes N-45, F-17, F-31, U-16, U-21, S-32, A-2 and A-16 were categorized as the super compact type. The genotypes N-30, F-25, BRCC-1601, SCS-1206, Suraj and ARBC-64 were of compact type. No genotypes were found in the compact spreading category. In the tall compact category, genotypes N-57, N-59 and F-22 were found. The genotypes, F-21, U-20, U-31, BRCC-1602, Sahana, S-32, ARBC-19, A-11 and A-31 were of the robust type. Genotypes ARBH-813 and RAH-100 were highly robust (Table 8).

4.5.3 Plant type characterization in E3

In the third environment, genotypes N-59, F-22, F-31, U-16, U-20, A-11 and A-31 were of the super compact type. Genotypes F-17, U-31, A-16, BRCC-1601, SCS-1206, Sahana, RAH-100, Suraj, ARBC-19 and ARBC-64 were categorized as compact spreading type. The genotypes F-21, F-25, U-21, S-32, A-2 and BRCC-1602 were categorized under compact type. No genotypes were found in the tall compact category. Genotypes N-45, N-30 and N-57 fell in the robust plant type category. In the highly robust type, S-34 and ARBH-813 were found (Table 9).

4.5.4 Genotypes with similar plant type common to environments

Across all the three environments, no genotype had the same plant type. Therefore, genotypes which fell in the same plant type category at least in two environments have been listed. Genotypes F-31, U-16, A-11, A-16 and A-31 were categorized in the super compact type. Genotypes N-30, U-21, F-25 and F-21 were of the compact type. The genotypes U-31, BRCC-1601 and ARBC-64 were of the compact spreading type, Sahana was of robust type and genotypes ARBH 813 and RAH-100 were highly robust. No genotype was found in the tall compact plant type in at least two environments (Table 10).

4.5.5 Per cent change in plant type traits between environments

The ANOVA for the four plant type traits *viz.*, plant height, sympodial length at 50 per cent plant height, sympodial angle and plant diameter was carried out on transformed values

Table 7: Plant type characterization of the *G. hirsutum* genotypes under high planting density (E1) at ARS Dharwad during *kharif*, 2016-17

Plant height (cm)	Plant diameter (cm)		
	21.50 - 26.48 (Low)	26.49 - 31.47 (Medium)	31.48 - 36.45 (High)
48.00 - 62.95 (Dwarf)	**Super compact** N-57, A-2, A-11, A-16, A-31	**Compact** N-45, N-30, U-21, F-21	**Compact spreading** F-31, U-16, U-31, S-32, BRCC-1601, BRCC-1602, ARBH-813, ARBC-64
62.96 - 77.90 (Tall)	**Tall compact** U-20, S-34, ARBC-19	**Robust** F-25, Sahana	**Highly robust** N-59, F-17, F-22, SCS-1206, RAH-100, Suraj

E1: Spacing of 60 cm × 15 cm–1,11,111 plants/ha

Table 8: Plant type characterization of the *G. hirsutum* genotypes under regular planting density (E2) at ARS Dharwad during *kharif*, 2016-17

Plant height (cm)	Plant diameter (cm)		
	25.27 - 34.15 (Low)	34.16 - 43.05 (Medium)	43.06 - 51.95 (High)
49.90 - 63.10 (Dwarf)	**Super compact** N-45, F-17, F-31, U-16,U-21, S-32, A-2, A-16	**Compact** N-30, F-25, BRCC-1601, SCS-1206, Suraj, ARBC-64	**Compact spreading** (no genotypes found)
63.20 - 76.50 (Tall)	**Tall compact** N-57, N-59, F-22	**Robust** F-21, U-20, U-31, BRCC-1602, Sahana, S-34, ARBC-19, A-11, A-31	**Highly robust** ARBH-813, RAH-100

E2: Spacing of 60 cm × 30 cm – 55,555 plants/ha

Table 9: Plant type characterization of the *G. hirsutum* genotypes under low planting density (E3) at ARS Dharwad during *kharif*, 2016-17

	Plant Diameter (cm)		
Plant height (cm)	31.77 - 38.99 (Low)	39.00 - 46.22 (Medium)	46.23 - 53.45 (High)
57.50 - 81.25 (Dwarf)	**Super compact** N-59, F-22, F-31, U-16, U-20, A-11, A-31	**Compact** F-21, F-25, U-21, S-32, A-2, BRCC-1602	**Compact spreading** F-17, U-31, A-16, BRCC-1601, SCS-1206, Sahana, RAH-100,Suraj, ARBC-19, ARBC-64
81.26 - 105.00 (Tall)	**Tall compact** (no genotypes found)	**Robust** N-45, N-30. N-57	**Highly robust** S-34, ARBH-813

E3: Spacing of 60 cm × 60 cm – 27,777 plants/ha

Table 10: Genotypes of same plant type common to different planting densities

Plant type	Genotypes common to at least 2 planting densities
Super compact	F-31, U-16, A-2, A-11, A-16, A-31
Compact	N-30, U-21, F-25, F-21
Compact spreading	U-31, BRCC-1601, ARBC-64
Tall compact	No genotype was found
Robust	Sahana
Highly robust	ARBH 813, RAH-100

of the per cent change values between any two environments. There were significant differences among the genotypes in all the three comparisons between E1 and E2, E2 and E3 and between E1 and E3 for all four plant type traits (Table 11).

The per cent change in plant type traits between any two environments was assessed and the results are presented in Table 10. As the planting density decreased, there was an increase in all the plant type trait values of plant height, sympodial length at 50 per cent plant height, sympodial angle and plant diameter.

Between E1 and E2, the minimum per cent increase was shown by RAH-100 for plant height (17.60) and maximum (36.10) increase was seen in U-21with a mean increase for plant height of 31.93 per cent. For sympodial length at 50 per cent plant height, the mean change in genotypes was 54.69 per cent. The minimum increase was 42.75 per cent and the maximum was 74.6 per cent observed in RAH-100 and U-21 genotypes, respectively. The genotypes F-17 and N-57 exhibited minimum (17.10) and maximum (26.70) per cent increase for sympodial angle with mean of 20.86 per cent. For plant diameter, RAH-100 and U-21 genotypes had minimum (38.04) and maximum (64.95) per cent increase with mean increase of 54.00 per cent.

Between E2 and E3, The minimum per cent increase was shown by S-34 (29.55) for plant height and maximum (46.80) increase was seen in A-31 with a mean increase for plant height of 38.69 per cent. In case of sympodial length at 50 per cent plant height, the genotypes S-34 and A-31 exhibited minimum (74.2) and maximum (83.85) per cent increase with a mean increase of 78.12 per cent. Similarly, the mean per cent increase in genotypes for sympodial angle was 30.17 per cent with the genotypes U-20 and A-31 exhibiting 23.95 and 40.60 per cent minimum and maximum per cent increase for the trait. Lastly, for plant diameter, BRCC-1601 (46.56) and A-31 (68.23) genotypes showed the minimum and maximum per cent increase, respectively. The mean increase in genotypes for plant diameter was 57 per cent with the per cent minimum increase seen in genotype BRCC-1601(46.56) and the maximum increase in A-31 (68.23).

Between E1 and E3, the genotypes ARBC-19 and ARBH 813 showed the minimum (34.70) and maximum (63.70) increase in per cent for plant height with mean change in genotypes being 42.10 per cent. For sympodial length at 50 per cent plant height, the mean per cent increase was 81.85 per cent with minimum and maximum per cent increase seen in

Table 11: Analysis of variance for percentage change in plant type traits between planting densities at ARS, Dharwad during *kharif*, 2016-17

Plant type Traits	**Mean sum of squares**								
	Between E1 and E2			**Between E2 and E3**			**Between E1 and E3**		
	Rep	**Genotype**	**Error**	**Rep**	**Genotype**	**Error**	**Rep**	**Genotype**	**Error**
Plant height (cm)	3.69	15.40*	4.61	0.01	13.82*	2.74	18.97	56.52*	3.90
Sympodial length (cm)	24.30	0.34*	2.81	0.83	7.01*	0.99	18.22	3.75*	4.85
Sympodial angle (degree)	0.66	6.29*	1.44	0.04	21.93*	1.77	3.84	11.38*	1.98
Plant diameter (cm)	38.18	5.85*	2.06	2.42	19.72*	3.35	1.64	23.07*	2.61

Note: E1: 60 cm × 15 cm - 1,11,111 plants/ha
E2: 60 cm × 30 cm - 55,555 plants/ha
E3: 60 cm × 60 cm - 27,777 plants/ha

Table 12: Per cent change in four traits related to plant type between environments at ARS Dharwad during *kharif* 2016-17

Between E1 and E2				
Per cent change	**Plant height**	**Sympodial length at 50%plant height**	**Sympodial angle**	**Plant diameter**
Minimum change	17.60 (RAH-100)	42.75 (RAH-100)	17.10 (F-17)	38.04 (RAH-100)
Maximum change	36.10 (U-21)	74.60 (U-21)	26.70 (N-57)	64.95 (U-21)
Mean change	31.93	54.69	20.86	54.00
Between E2 and E3				
Minimum change	29.55 (S-34)	74.2 (S-34)	23.95 (U-20)	46.56 (BRCC-1601)
Maximum change	46.80 (A-31)	83.85 (A-31)	40.60 (A-31)	68.23 (A-31)
Mean change	38.69	78.12	30.17	57.00
Between E1and E3				
Minimum change	34.70 (A-19)	77.60 (A-16)	27.25 (F-21)	66.85 (A-16)
Maximum change	63.70 (ARBH-813)	92.26 (U-16)	44.20 (ARBC-64)	75.01 (U-16)
Mean change	42.10	81.85	36.94	62.19

Note: Genotype name is given in parentheses genotypes A-16 (77.60) and U-16 (92.26). The genotypes F-21 and ARBC-64 showed minimum (27.25) and maximum (44.20) per cent increase in sympodial angle with mean percent increase in genotypes being 36.94 per cent. Similarly, in case of plant diameter, the genotypes A-16 and U-16 had 66.85 and 75.01 per cent as minimum and maximum increase with the mean increase in genotypes being 62.19 per cent.

4.6 Stability analysis

4.6.1 Pooled analysis of variance

The data were subjected to pooled analysis after the variances were found to be homogenous. Pooled analysis of variance for all the five traits *viz*., plant height, plant diameter, bolls per sq.m., seed cotton yield per plant and harvest index across the three environments are presented in Table 13. The results revealed that there were significant differences among the genotypes tested for plant height, plant diameter and bolls per sq.m. The environments in which the observations were made differed significantly to influence significant variations among the genotypes.

4.6.2 AMMI ANOVA for stability

The stability analysis was carried out for plant type traits *viz*., plant height and plant diameter along with bolls per sq.m., seed cotton yield and harvest index by using AMMI model. AMMI analysis of variance indicated significant mean squares due to PCA 1 for plant diameter, number of bolls per sq.m. and harvest index (Table 14). First principal component analysis axis explains 62.19 per cent, 59.55 per cent, 58.62 per cent, 75.07 per cent and 56.05 per cent of genotype × environment interaction for plant height, plant diameter, number of bolls per sq.m., seed cotton yield per plant and harvest index, respectively.

The mean performance of all the traits is presented in Appendix I.

4.6.3 Stability parameters

Stability parameters were estimated for plant height, plant diameter, bolls per sq.m., seed cotton yield per plant and harvest index as these five traits are important plant type traits.

4.6.3.1 Plant height

For plant height, U-21, N-30, U-31 and A-11 were considered as stable genotypes with lower mean values (58.20, 62.60, 63.43 and 64.54 cm, respectively) for plant height and

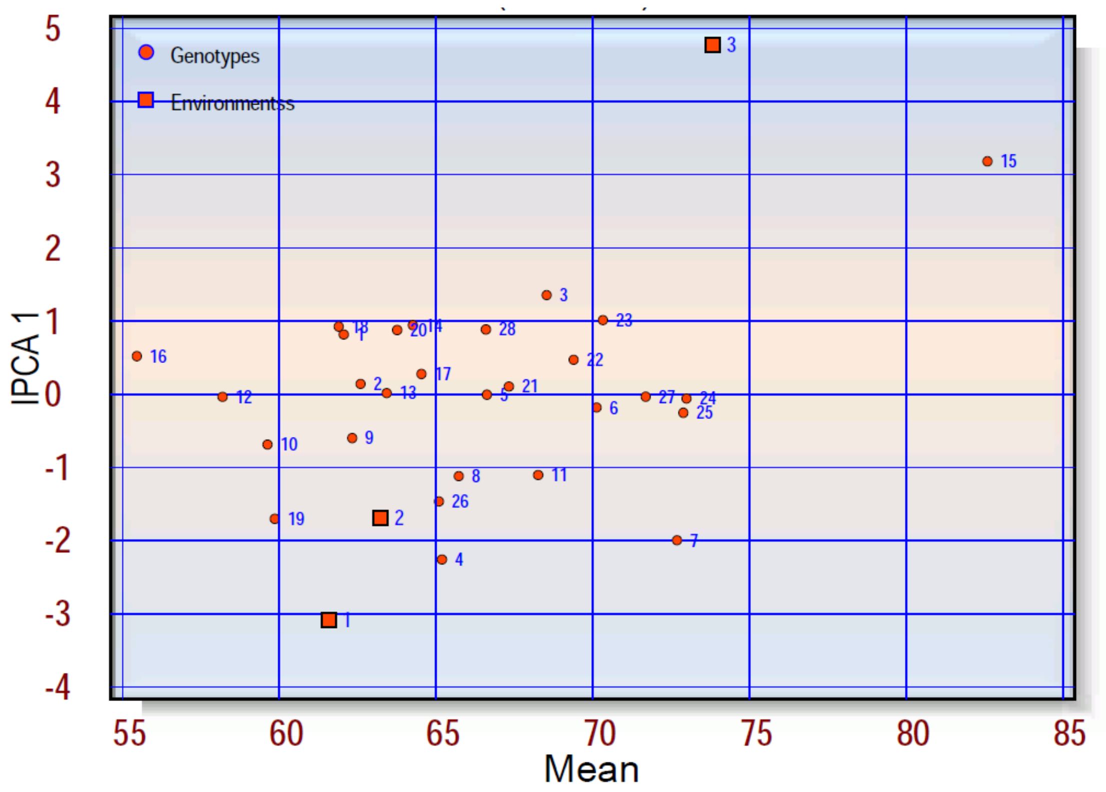

Fig. 3. Biplot (AMMI) for plant height (cm)

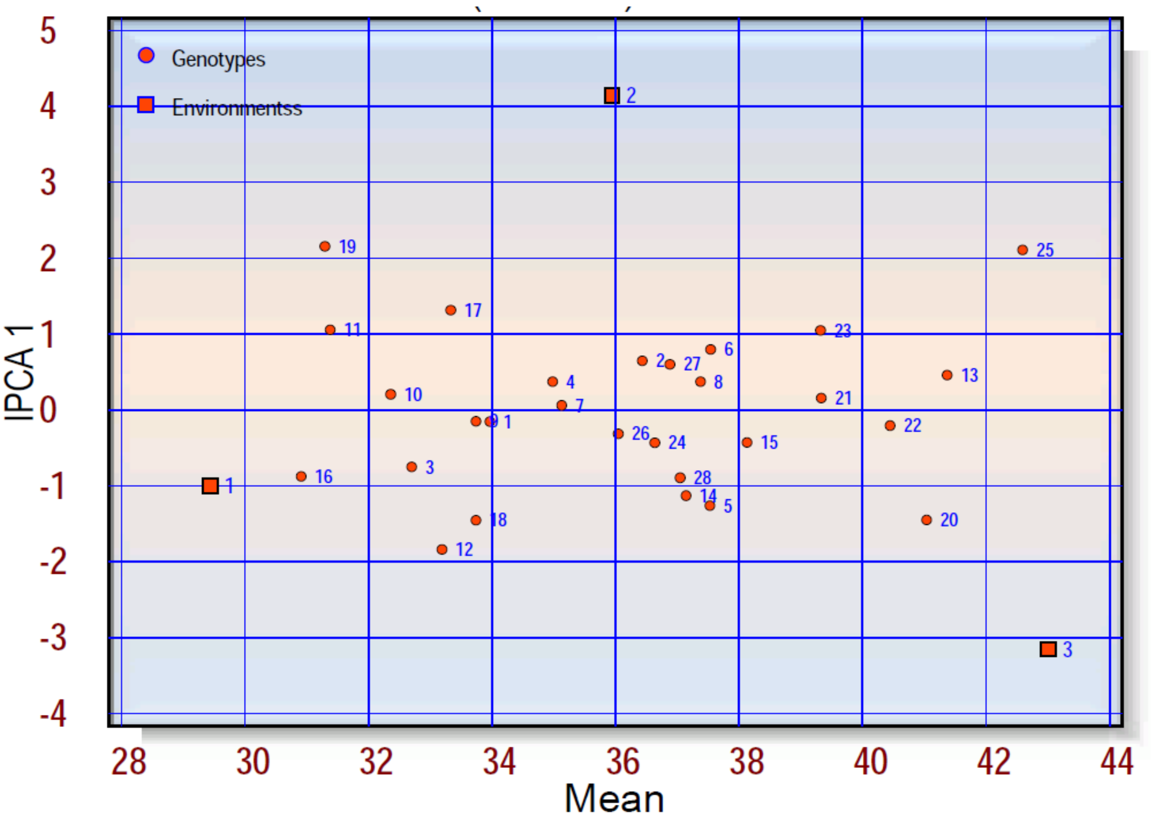

Fig. 4. Biplot (AMMI) for plant diameter (cm)

Table 13: Pooled analysis of variance for stability for five quantitative characters of *G. hirsutum* across three environments at ARS Dharwad during *kharif*, 2016-17

Sources	**d.f.**	**Plant height**	**Plant diameter**	**Bolls/ sq.m.**	**Seed cotton yield/plant**	**Harvest index**
Varieties	27	92.79**	30.94*	83.24*	776151.30	80.77
Environment	2	1239.10**	1288.40**	3471.90**	137142**	9227.77**
Variety × environment	54	36.68	24.65	48.54	582971.60	69.26
Environment (linear)	1	2478.20**	2576.80**	6943.90**	2742845**	18455.50**
Variety × environment (linear)	27	45.60	20.85	56.56	521514.10**	76752
Pooled deviation	28	26.77	27.43**	39.08	621413.70**	59.56**
Pooled error	81	24.52	3.48	25.72	157772.20	24.36

* Significance at 0.05 probability

** Significance at 0.01 probability

Table 14: AMMI ANOVA of *G. hirsutum* genotypes for five quantitative characters at ARS Dharwad during *kharif*, 2016-17

Source of variation	Mean sum of squares					
	d.f.	Plant height	Plant diameter	Bolls/sq.m.	Seed cotton yield/plant	Harvest index
Genotypes	27	92.79**	30.94	83.24*	776155.0	80.77
Environments	2	1239.10**	1288.40**	3471.90**	137142230*	9227.77**
G × E Interaction	54	36.68	24.65	48.54	582972.29	69.26**
PCA 1	28	43.99	28.31**	54.88**	844032.8	74.8728**
Pooled residual	26	28.80	20.71	41.71	301830.16	63.21
%contribution of PCA 1		62.19	59.55	58.62	75.07	56.07
Residual (%)		37.81	40.45	41.38	24.93	43.95

*Significance at 0.05 probability ** Significance at 0.01 probability having PCA score zero. The genotypes F-17, BRCC-1602, SCS-1206, F-21, Sahana and RAH-100 also showed stable performance for this trait and indicated PCA score zero with higher mean values (66.63, 67.33, 69.40, 70.13, 73.0 and 72.90 cm, respectively). The genotypes N-45, A-16 and BRCC-1601 with lower mean values (62.07, 61.90 and 63.77 cm, respectively) and all had positive PCA score equal to unity. The genotypes ARBC-64, N-57, ARBH-813 and S-34 had higher mean values (66.60, 68.53, 70.33 and 82.60 cm, respectively) for plant height and showed positive PCA score equal to unity. The genotypes U-16, F-31 ARBC-19, and A-31 had lower mean values (59.63, 62.33, 59.87 and 59.87, respectively) and exhibited negative PCA score equal to unity. The genotypes N-59, Suraj, F-25 and U-20 had higher mean values (65.20, 65.10, 65.73 and 68.27 cm, respectively) for plant height and had negative PCA score equal to unity. AMMI analysis indicated that two environments (E1 and E2) showed negative PCA, whereas E3 exhibited positive PCA score.

4.6.2.2 Plant diameter

The genotypes U-16, N-45, F-22, N-59, F-25, F-31, BRCC-1602, Sahana and SCS-1206 exhibited stable performance with PCA score zero and had lower mean values (32.37, 33.97, 35.13, 34.98, 37.38, 33.75, 39.33, 36.64 and 34.45 cm, respectively) for plant diameter. The genotypes Suraj, S-34 and U-31 showed stable performance for this trait and indicated PCA score zero with higher mean values (39.05, 38.13, and 41.37 cm, respectively).

The genotypes U-20, A-11 and A-31 with lower mean values (31.39, 33.34 and 31.30 cm, respectively) and had positive PCA score. The genotypes N-30, ARBC-19, F-21, ARBH-813 and RAH-100 had higher mean values for plant diameter (36.44, 36.88, 37.54, 39.32 and 42.59 cm, respectively) and showed positive PCA score. The genotypes A-2, N-57 and U-21 had lower mean values (30.92, 32.71 and 33.20 cm, respectively) and exhibited negative PCA score. The genotypes ARBC-64, S-32, F-17 and BRCC-1601 had higher mean values (37.05, 39.32, 37.53 and 41.04 cm, respectively) for plant diameter and exhibited negative PCA score.

The results of AMMI analysis showed positive PCA for E2 and negative PCA for both E1 and E3 environments.

4.6.2.3 Number of bolls per sq.m.

The genotypes U-16, Suraj, ARBC-19, N-45, A-11, F-22, F-25, U-20 and F-21 exhibited stable performance with PCA score zero and had lower mean values (40.95, 37.97,

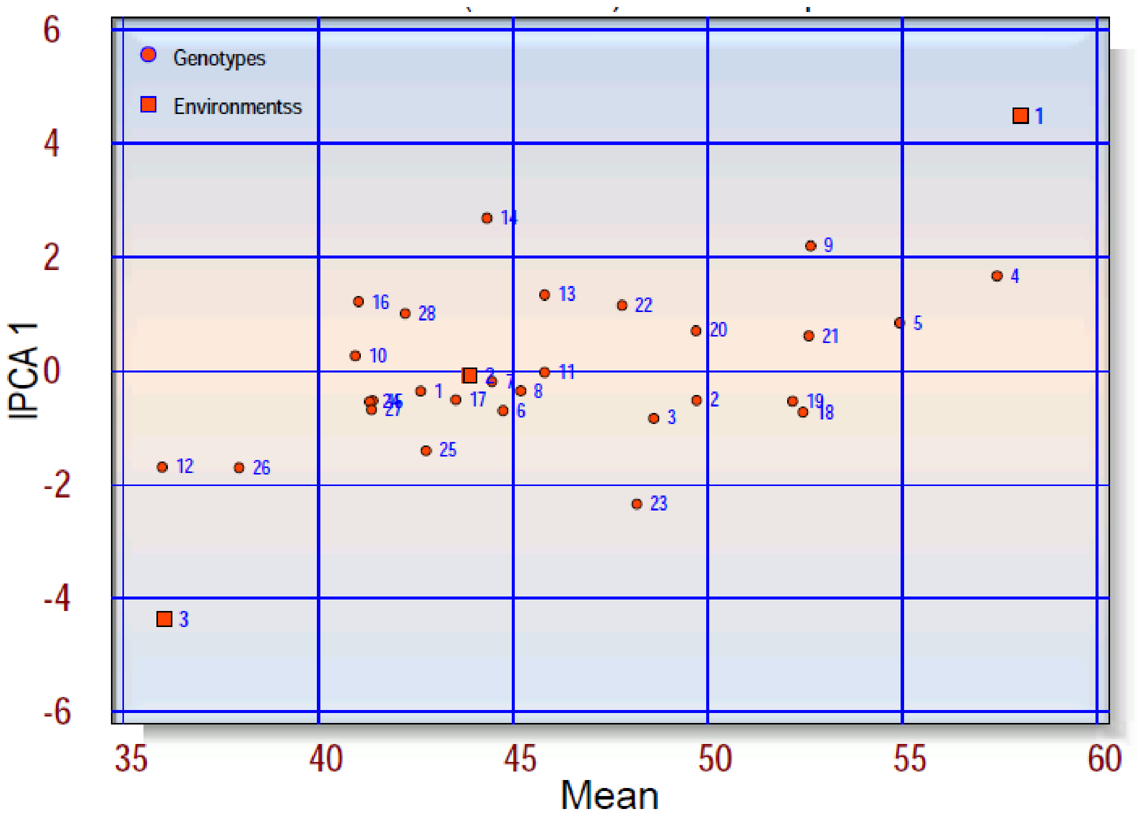

Fig. 5. Biplot (AMMI) for number of bolls per sq.m.

41.37, 42.63, 43.53, 44.47, 45.20, 45.82 and 44.75, respectively) for number of bolls per sq.m. Whereas, the genotypes BRCC-1601, BRCC-1602, F-17, N-30, N-57, A-31 and A-16 can be considered as stable and had higher mean values (49.70, 52.60, 54.93, 52.18, 49.72, 48.29, 52.18 and 52.45, respectively) and showed zero PCA score.

The genotypes A-2, ARBC-64, S-32 and U-31 had lower mean values (41.03, 42.23, 44.33 and 45.82, respectively) and exhibited positive PCA score. The genotypes SCS-1206, F-31 and N-59 had higher mean values (47.80, 52.65 and 57.43) and showed positive PCA score. The genotypes U-21, Suraj and RAH-100 had lower mean values (36.0, 37.97 and 42.77, respectively) and showed negative PCA score. The genotype ARBH-813 had higher mean value (48.18) and exhibited negative PCA score.

The AMMI analysis showed positive PCA for E1 and E2 and negative PCA for E3 environment.

4.6.2.4 Seed cotton yield per plant

For seed cotton yield per plant, the genotypes A-11, RAH-100, F-25, BRCC-1601, BRCC-1602, SCS-1206 and A-16 showed stable performance with PCA score zero and had higher mean values (45.57, 47.60, 46.19, 50.99, 52.32, 51.94 and 48.27 g, respectively) for seed cotton yield. The genotypes F-21, A-31, ARBC-64 and U-31 can be considered as stable genotypes and had lower mean values (39.84, 44.18, 41.84 and 39.24 g, respectively) with PCA score of zero. Genotypes F-22 and Suraj had lower mean values (41.80 and 43.86 g, respectively) and showed positive PCA score equal to unity. The genotypes N-30, S-34, Sahana, ARBH-813 and A-2 had higher mean values (47.48, 51.38, 49.05, 50.70 and 51.50 g, respectively) with positive PCA score equal to unity. The genotypes F-17 and SCS-1206 had higher mean values (48.02 and 51.94 g, respectively) and exhibited negative PCA score equal to unity. The genotypes N-45, N-57, U-31, ARBC-19, U-16, N-59 and F-31 had lower mean values (40.33, 33.86, 39.24, 38.61, 56.72, 38.77 and 43.88 g, respectively) for seed cotton yield and exhibited negative PCA score equal to unity.

The AMMI analysis showed positive PCA for E2 and negative PCA for both E1 and E3 environments.

4.6.2.5 Harvest index

The genotypes A-31, U-31, F-22, and N-57 exhibited stable performance with PCA score zero and had lower harvest index (50%, 47%, 48% and 43%, respectively). Whereas, the genotypes RAH-100, SCS-1206, F-21, U-16, F-25, BRCC-1601, ARBH-813 and N-59

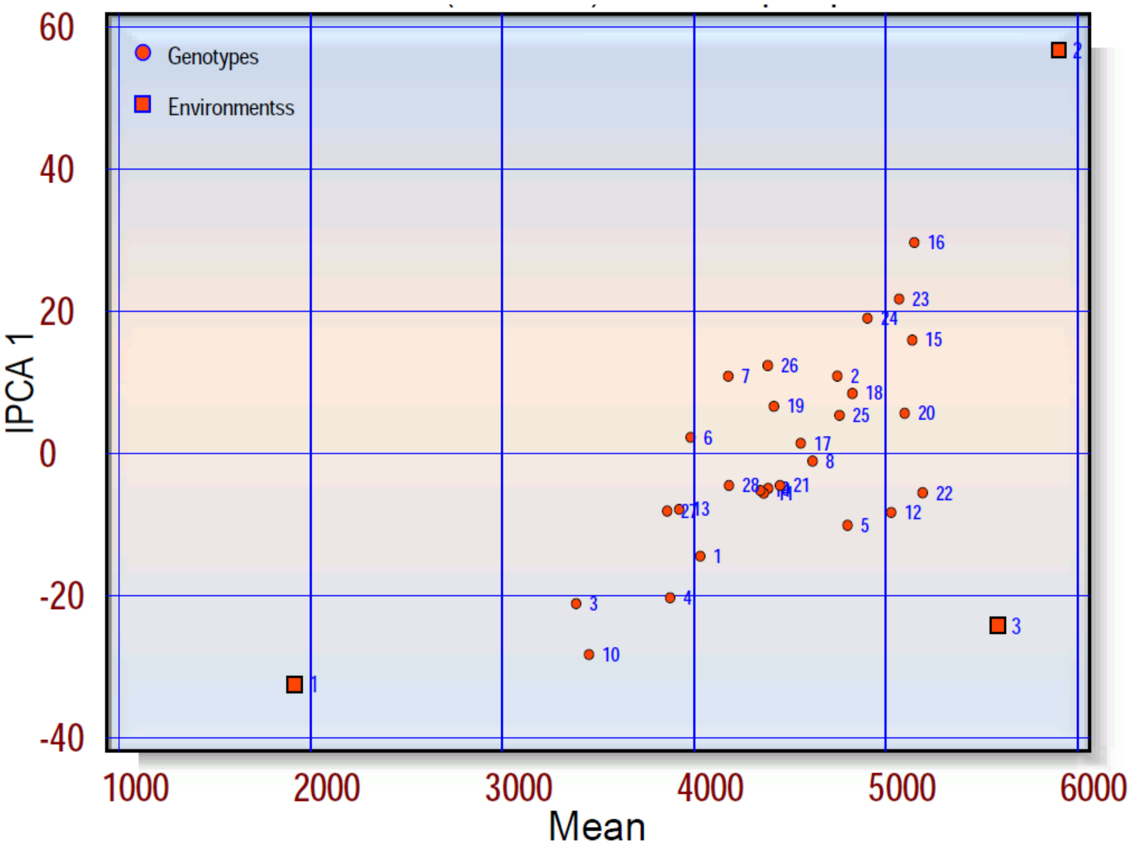

Fig. 6. Biplot (AMMI) for seed cotton yield (g/plant)

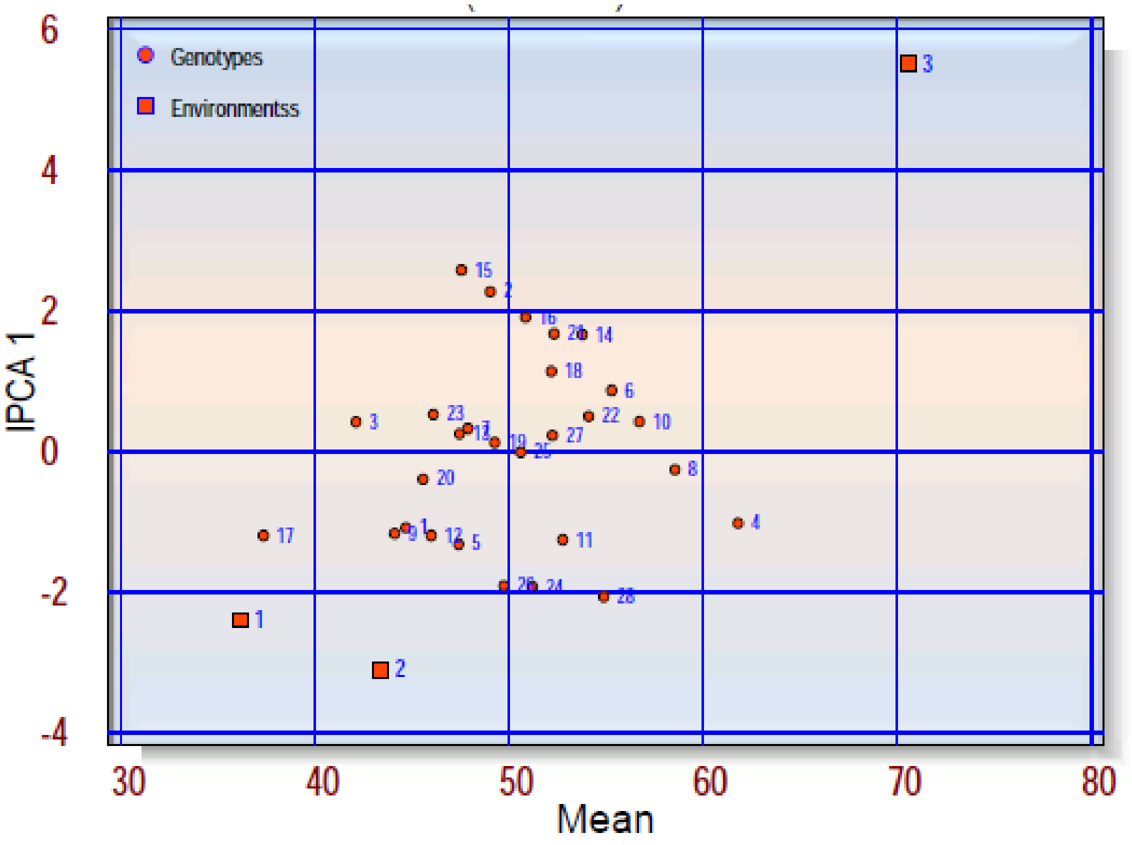

Fig. 7. Biplot (AMMI) for harvest index (%)

can be considered as stable and had high per cent of harvest index (55%, 54%, 55%, 58%, 57.5%, 56%, 53% and 62%, respectively) with zero PCA score.

The genotypes N-30 and S-34 had lower harvest index (49% and 48%, respectively). Whereas, the genotypes A-2, BRCC-1602, S-32 and A-16 had high harvest index (51%, 53%, 55% and 53.3%, respectively) and the genotypes showed positive PCA score. The genotypes A-11, F-31, N-45, U-21, F-17 and Suraj had lower harvest index (38%, 44%, 44.5%, 46%, 48% and 45%, respectively) and the genotypes Sahana, U-20, ARBC-19 and ARBC-64 had high harvest index (51%, 53%, 52% and 51%, respectively) and the genotypes showed negative PCA score.

The AMMI analysis showed negative PCA for E1 and E2 and positive PCA for E3 environment.

Discussion

5. DISCUSSION

Cotton is an important fibre yielding crop of global importance, grown in tropical and subtropical regions. The primary goal of cotton breeding is increasing the seed cotton yield. New genotypes are being identified using conventional plant breeding methods and are being tested for their stability across different growing situations. Cotton cultivation has relied on this principle even now. However, to address the yield plateauing, innovative methods are being explored. The increase in yield can be achieved in two ways. The first is increasing the plant yield *per se* and the second, increasing production per unit area. The second option entails increasing the planting density. The available genotypes in cotton are mostly robust and high density planting will invite a host of problems, including building a hostile pest and disease environment apart from competition for resources. An ideal plant type to suit such high density planting is a compact plant type which seems to be the solution. The compact plant type is short in height, usually less than a meter, and has a smaller plant diameter enabling closer planting leading to increased planting density. Breeding for genetically compact genotypes is now progressing what with some already being released for cultivation. The need for such compact genotypes is increasingly being felt in rainfed areas. With compact genotypes, mechanical harvesting becomes easy and cotton cultivation can become lucrative again. The present study aims to understand the morphological bases of the plant type in cotton and also identify productive compact genotypes, especially for high density planting.

The knowledge on the nature and the degree of genetic variability, heritability, correlation among various traits that contribute towards seed yield would help the breeder in identifying a promising genotype from a set of genotypes. If the genotype is also widely adaptable across the environments, it is an added advantage.

Path analysis has been used by plant breeders to assist in identifying useful traits that help during plant selection. Path analysis partitions the correlation coefficient into its components, one component being the path coefficient that measures the direct effect of a predictor variable on the response variable and the other component that measures the indirect effect through another predictor variable, making it easier to identify important traits that influence each other and ultimately, yield.

Cotton is grown over varied environmental conditions where significant environmental influence exists. The G × E interaction is an important component of the final phenotype and has to be accounted for. The different environments may refer to different planting densities, different locations, seasons and years. Fluctuating yields in different crop growing situations necessitates the use of stably performing genotypes with higher yields.

In the present investigation, studies on assessment of genetic variability, broad sense heritability, genotypic and phenotypic variances, predicted genetic advance, GCV and PCV with respect to important yield determining traits were carried out. The dynamics of these traits, directly and indirectly affecting the yield were also studied. The above studies were in addition to the primary objective of plant type characterization and stability analysis of the plant type traits leading to identification of genotypes suited to high density planting. The results of the present investigation are discussed under the following heads:

5.1 Analysis of variance
5.2 Analysis of genetic variability parameters
5.3 Association analysis
5.4 Path co-efficient analysis
5.5 Plant type characterization
5.6 Pooled analysis of variance
5.7 Stability analysis

5.1 Analysis of variance

Analysis of variance is a statistical tool for detection of variability. It was performed for all the three different planting densities to test the significance of difference among the genotypes for the characters studied. Highly significant treatment mean sum of squares were noticed in all the three environments for most characters *viz.*, plant height, number of sympodia, internode distance, number of bolls per plant, sympodial angle, plant diameter, number of bolls per sq.m., boll weight, boll capsule weight, seed index, lint index, total biomass and harvest index except for interboll distance and seed cotton yield per plant. Significant differences existed among genotypes in only E2 for sympodial length at 50 per cent plant height. These traits can be relied up on in crop improvement.

5.2 Analysis of genetic variability parameters

The genetic variability parameters were assessed in the recommended planting density environment (E2) only, and have been discussed here under.

5.2.1 Plant height

Plant height is one of the important traits, which influences final yield of the crop. Its range was variable accounting from 49.90 to 76.50 cm with a mean value of 63.30 cm. The trait showed high heritability with moderate genetic advance as per cent of mean which indicated the predominance of additive and non additive genetic variance. Such high heritability and moderate genetic advance indicates a moderate response of the character to selection. Similar reports have been made by Lavanya Kumar (2004), Kale and Annapurve (2007), Do Thi *et al*. (2008), Ravi Kumar Patnaik and Parshuram Sial (2010), Vinodhana Kumari *et al*. (2013), Dahiphale *et al*. (2015), Latif *et al*. (2015), Liaqat *et al*. (2015) and Baloch *et al*. (2016).

5.2.2 Internode distance

Internode distance will make the plant compact *i.e*., shorter the internode distance more sympodia can be accommodated resulting in increased yields. The range observed for this trait was from 3.16 to 4.47 cm. The trait exhibited high heritability coupled with moderate GAM. The results are in confirmation with the findings of Ranganatha *et al*. (2013) and Alkuddsi *et al*. (2013).

5.2.2 Plant diameter

Plant diameter is an important trait for plant type to characterize the genotypes as super compact and compact for high density planting system. The observed range for this character was from 25.27 to 51.95 cm. The trait showed high heritability with high GAM. High heritability together with high GAM indicates additive genetic variance and selection will be of use. Present results are in line with Gururaj (2006) and Bharat Kumar *et al*. (2014).

5.2.3 Number of bolls per sq.m.

The number of bolls per sq.m. varies according to the planting densities followed as the number of plants vary per environment. In case of high density planting, bolls obtained are higher than the regular and low density planting systems. The trait exhibited moderate heritability with moderate GAM. No previous reviews were found for this trait.

5.2.4 Boll weight

Boll weight is crucial in deciding seed cotton yield. The range for this trait was from 1.60 to 5.62 g with mean boll weight of 3.54 g. The observed values of GCV and PCV were high. Similar results were obtained by Srinivas *et al.* (2014) and Mohan Kumar and Katageri (2017). The heritability was high coupled with high GAM, indicating the presence of additive genetic variance, hence this trait will show a high response to selection. These results on heritability and GAM are in agreement with those of Basbag and Gencer (2004), Kale and Annapurve (2007), Bayyapu Reddy and Chenga Reddy (2016) and Manjunath Paloti (2016).

5.2.5 Boll capsule weight

The boll capsule weight showed a considerable variation among the genotypes with moderate GCV and PCV. High GAM and high heritability were noticed for the trait. The partitioning of resources between the capsule and the seed cotton within can influence the seed cotton yield. However, no previous studies were found dealing with this trait.

5.2.6 Seed index

The trait had a range of 7.41 to 10.74 g with mean values of 8.96 g. The GCV and PCV observed were low with narrow difference between them indicating lesser role of environment. Low values of observed PCV and GCV are in agreement with those made by Rao *et al*. (2001), Vinodhana Kumari *et al*. (2013), Ahsan *et al*. (2015) and Nishanth *et al.* (2015). The heritability for this trait was high coupled with moderate GAM indicating the prevalence of additive genetic variance. Simple selection can be practiced to develop good genotypes though the progress may be slow. These results on variability, heritability and GAM are in agreement with studies of Reddy and Pradeep (2001), Neelima and Potdhuke (2002), Ratna Kumari and Subbaramamma (2006), Do Thi *et al.* (2008), Kulkarni *et al*. (2011), Liaqat *et al*. (2015), Ahsan *et al.* (2015), Nishanth *et al*. (2015) and Manjunath Paloti (2016).

5.2.7 Lint index

The range for lint index was ranging from 6.43 to 34.01 g with mean value of 12.95 g. The difference between GCV and PCV for this trait was high indicating the role of environment. Moderate values of observed PCV and GCV are in agreement with the studies of Do Thi *et al.* (2008) and Mohankumar and Katageri (2017).

The heritability for this trait was high coupled with high GAM indicating the prevalence of additive genetic variance. Simple selection can be practiced so that good genotypes can be developed. These results on variability, heritability and GAM are in agreement with those made by Reddy and Pradeep (2001), Neelima and Potdukhe (2002), Nataraj (2005), Ratna Kumari and Subbaramamma (2006), Do Thi *et al*. (2008), Kulkarni *et al*. (2011), Liaqat *et al*. (2015), Dahiphale *et al*. (2015), Ahsan *et al*. (2015), Nishanth *et al*. (2015) and Manjunath Paloti (2016).

5.2.8 Total biomass

It was measured by uprooting the plants with intact roots by iron jack after harvest and drying in the field. The range for this trait was 116.25 to 218.75 g with mean value of 213.12 g. The observed heritability and genetic advance for this trait were high indicating good response to selection. The results are in partial agreement with those made by Percival and Sheriff (2002), Parre Suman (2012) and Manjunath Paloti (2016).

5.2.9 Seed cotton yield per plant

Significant variability was observed for seed cotton yield per plant among the genotypes. High variability for seed cotton yield was reported earlier by Reddy and Pradeep (2001), Gururaj (2006), Gitte *et al*. (2007), Do Thi *et al*. (2008), Khan *et al*. (2009), Singh *et al*. (2009), Vinodhana Kumari *et al*. (2013), Farooq *et al*. (2014), Pujer *et al*. (2014), Dahiphale *et al*. (2015), Nishanth *et al*. (2015) and Baloch *et al*. (2016).

Moderate GCV coupled with high PCV were observed for this trait. The differences were narrow between PCV and GCV indicating that most of the variability observed was due to the predominance of genotype in the ultimate expression of the phenotype. Similar reports of higher levels of PCV and GCV in cotton were made by earlier workers *viz.*, Kowsalya and Raveendran (1996), Ahuja and Tuteja (2000), Reddy and Pradeep (2001), Gururaj (2006), Gitte *et al*. (2007), Do Thi *et al*. (2008), Khan *et al*. (2009), Singh *et al*. (2009), Ravi Kumar Patnaik and Parshuram Sial (2010), Pujer *et al*. (2014), Dahiphale *et al*. (2015), Nishanth *et al*. (2015) and Manjunath Paloti (2016).

Seed cotton yield had high heritability estimates. The genetic advance was found to be moderate whereas GAM was found to be high for this trait. GAM, together with high heritability indicates the predominance of additive genetic variance and hence selection will be of use. Similar reports of high heritability and high GAM were made by many workers *viz*., Ahuja and Tuteja (2000), Reddy and Pradeep (2001), Neelima and Potdukhe (2002), Kaushik *et al*. (2003), Do Thi *et al*. (2008), Khan *et al*. (2009), Singh *et al*. (2009), Pujer *et al*.

(2014), Farooq *et al*. (2015), Dahiphale *et al*. (2015), Ahsan *et al*. (2015), Nishanth *et al*. (2015) and Manjunath Paloti (2016).

5.2.10 Harvest index

Harvest index is an important trait in plant breeding, which describes plant capacity to allocate biomass (assimilates) into the formed reproductive parts. The observed variability and heritability were high coupled with high GAM indicating that effective selection can be based on this trait. However, no previous studies were found for this trait.

5.3 Association analysis

Genetic variability and association among seed yield and its attributes help in identifying a suitable genotype with desired characteristics. The success of selection depends on the choice of selection criteria for improvement of seed yield and correlation coefficient analysis can establish significant relationships among the evaluated traits.

In the present study, association analysis was done for seed cotton yield with thirteen other yield attributing traits and also among themselves in the recommended planting density environment, E2. Discussion on this analysis follows.

Seed cotton yield had highly significant and positive correlation with its component characters *viz*., plant height, number of sympodia per plant, sympodial length, plant diameter, number of nodes on main stem, number of bolls per plant, number of bolls per sq.m., boll weight, ginning outturn, seed index and total biomass.

Plant height exhibited significant positive correlation (0.89) with seed cotton yield. Yield improvement can be achieved if selection is practiced for higher plant height. Similar reports on positive correlation between seed cotton yield per plant and plant height were made by Neelima and Potdukhe (2002), Muthuswamy and Vivekanandan (2004), Alkuddsi *et al*. (2013), Baloch *et al*. (2014), Farooq *et al*. (2014), Pujer *et al*. (2014) and Manjunath Paloti (2016).

Number of sympodia per plant revealed strong positive correlation (0.97) with seed cotton yield. This was in concurrence with the findings of Ladole and Meshram (2000), Rao *et al*. (2001), Neelima and Potdukhe (2002), Kaushik *et al*. (2003), Gururaj (2006), Annapurve *et al*. (2007), Leelapratap *et al*. (2007), Dahiphale *et al*. (2015), Latif *et al*. (2015), Farooq *et al*. (2015), Baloch *et al*. (2016) and Manjunath Paloti (2016).

Sympodial length at 50 per cent plant height revealed positive correlation (0.98) with seed cotton yield. Greater sympodial length at 50 per cent plant height is desirable which helps to accommodate more number of fruiting points in turn contributing to higher yield. Similar result was observed by Parre Suman (2012), Bharat Kumar *et al.* (2014) and Manjunath Paloti (2016).

Plant diameter showed positive correlation (0.37) with seed cotton yield. Robust plant has a greater plant diameter and can thus give higher yield. Similar results were found by Gururaj (2006) and Bharat Kumar *et al.* (2014).

Number of nodes on main stem exhibited significant positive correlation (0.95) with the seed cotton yield. More number of nodes on main stem results in more branches per plant leading to increased seed cotton yield. Similar results were found by Gururaj (2006) and Manjunath Paloti (2016).

Number of bolls per plant showed significant positive correlation (0.94) with seed cotton yield. Yield improvement can be achieved if selection is practiced for more number of bolls. Similar reports were made by Rao *et al.* (2001), Neelima and Potdukhe (2002), Kaushik *et al.* (2003), Muthuswamy and Vivekanandan (2004), Gururaj (2006) Leelapratap *et al.* (2007), Arega Gashaw (2013), Vinodhana Kumari *et al.* (2013), Baloch *et al.* (2014), Farooq *et al.*(2014), Pujer *et al.* (2014), Latif *et al.* (2015), Bayyapu Reddy *et al.* (2015), Baloch *et al.* (2016) and Manjunath Paloti (2016).

Number of bolls per sq.m. revealed positive correlation (0.75) with seed cotton yield. By following the closer planting geometry, more number of plants gets accommodated with increase in the number of bolls per sq.m. Thus, seed cotton yield increases per unit area. No published previous studies were found for this association.

Boll weight revealed positive significant correlation (0.92) with seed cotton yield. Similar results of association of boll weight with seed cotton yield were observed by Ladole and Meshram (2000), Kaushik *et al.* (2003), Muthuswamy and Vivekanandan (2004), Leelapratap *et al.* (2007), Vinodhana Kumari *et al.* (2013), Farooq *et al.* (2014), Latif *et al.* (2015), Bayyapu Reddy *et al.* (2015), Baloch *et al.* (2016) and Manjunath Paloti (2016).

Ginning outturn expressed positive significant correlation (0.95) with seed cotton yield. Similar observation was made by Rao *et al.* (2001), Neelima and Potdukhe (2002), Kaushik *et al*. (2003), Annapurve *et al*. (2007), Kale and Annapurve (2007), Leelapratap *et al*. (2007), Ashokkumar and Ravikesavan (2010), Naqib *et al*. (2010), Farooq *et al*. (2014), Pujer *et al*. (2014), Dahiphale *et al*. (2015), Latif *et al*. (2015) and Manjunath Paloti (2016).

Seed index had positive correlation (0.97) with seed cotton yield. Similar results were reported by Krishnarao and Mary (1990), Sambamurthy *et al*. (1995), Sambamurthy (1997), Yadav *et al*. (1998), Neelima and Potdukhe (2002), Gururaj (2006), Ashokkumar and Ravikesavan (2010), Baloch *et al*. (2014), Pujer *et al*. (2014) and Manjunath Paloti (2016).

Total biomass showed positive correlation (0.97) with seed cotton yield. Similar results of correlation of total biomass with seed cotton yield were made by Sambamurthy *et al*. (1997), Yadav *et al*. (1998), Parre Saman (2012) and Manjunath Paloti (2016).

Upper half mean length and fibre strength exhibited negative association (-0.07 and -0.03, respectively) with seed cotton yield. Similar observation of negative significant correlation of seed cotton yield with both traits was made by Valarmathi (1996), Ahuja and Tuteja (2000), Rao *et al*. (2001), Ashokkumar and Ravikesavan (2010), Bayyapu Reddy *et al*. (2015) and Manjunath Paloti (2016).

Micronaire value had positive significant association with seed cotton yield. This result was in concurrence with the findings of Ahuja and Tuteja (2000), Ashokkumar and Ravikesavan (2010), Pujer *et al*. (2014), Bayyapu Reddy *et al*. (2015) and Manjunath Paloti (2016).

Apart from correlations with seed cotton yield all the traits also showed significant correlations among themselves except with fibre properties. Some important correlations have been mentioned.

Plant height had positive significant correlation with number of sympodia. Similar results were found by Kowsalya and Raveendran (1996), Sambamurthy (1999), Muthuswamy and Vivekanandan (2004), Leelapratap *et al.* (2007), Karademir *et al*. (2009), Vinodhana Kumari *et al*. (2013), Alkuddsi *et al*. (2013), Baloch *et al*. (2014), Liaqat *et al*. (2015) and Manjunath Paloti (2016).

Plant height had positive significant correlation with number of bolls per plant. Similar results were found by Krishnarao and Mary (1990), Kowsalya and Raveendran (1996), Sambamurthy (1999), Muthuswamy and Vivekanandan (2004), Annapurve *et al*.

(2007), Leelapratap *et al*. (2007), Karademir *et al*. (2009), Vinodhana Kumari *et al*. (2013), Alkuddsi *et al*. (2013), Baloch *et al*. (2014), Dahiphale *et al*. (2015), Baloch *et al*. (2016) and Manjunath Paloti (2016).

Plant height had positive significant correlation with boll weight. Similar results were found by Krishnarao and Mary (1990), Muthuswamy and Vivekanandan (2004), Annapurve *et al*. (2007), Leelapratap *et al*. (2007) and Manjunath Paloti (2016).

Number of sympodia per plant had positive significant correlation with number of bolls per plant. Similar results were found by Singh *et al*. (1979), Kowsalya and Raveendran (1996), Sangeetha (1998), Sambamurthy (1999), Ladole and Meshram (2000), Rao *et al*. (2001), Neelima and Potdukhe (2002), Kaushik *et al*. (2003), Muthuswamy and Vivekanandan (2004), Annapurve *et al*. (2007), Leelapratap *et al*. (2007), Yashavantha Kumar (2008), Karademir *et al*. (2009), Hanamaraddi (2010), Baloch *et al*. (2014), Farooq *et al*. (2015) and Manjunath Paloti (2016).

Number of sympodia per plant had positive significant correlation with boll weight. The same was reported earlier by Sambamurthy (1999), Ladole and Meshram (2000), Neelima and Potdukhe (2002), Kaushik *et al*. (2003), Leelapratap *et al*. (2007), Farooq *et al*. (2015) and Manjunath Paloti (2016).

Number of bolls per plant had positive significant correlation with boll weight. Similar result was reported by Singh *et al*. (1979), Rao *et al*. (2001), Neelima and Potdukhe (2002), Karademir *et al*. (2009), Bayyapu Reddy *et al*. (2015) and Manjunath Paloti (2016).

Number of bolls per plant had positive significant correlation with seed index. Similar result was found by Neelima and Potdukhe (2002) and Manjunath Paloti (2016).

Number of bolls per plant had positive significant correlation with ginning outturn. Similar results were found by Ladole and Meshram (2000), Rao *et al*. (2001), Neelima and Potdukhe (2002), Muthuswamy and Vivekanandan (2004), Annapurve *et al*. (2007), Leelapratap *et al*. (2007), Naqib *et al*. (2010) and Manjunath Paloti (2016).

Boll weight had positive significant correlation with seed index. Similar results were found by Krishnarao and Mary (1990), Rajarathinam *et al*. (1993), Ramalingam *et al*. (1994), Sumathi and Nadarajan (1995), Sambamurthy (1999), Ladole and Meshram (2000), Rao *et al*. (2001), Neelima and Potdukhe (2002), Annapurve *et al*. (2007), Vinodhana Kumari *et al*. (2013) and Manjunath Paloti (2016).

Boll weight had positive significant correlation with lint index. The same was reported by Krishnarao and Mary (1990), Rajarathinam *et al*. (1993), Ramalingam *et al*. (1994), Sumathi and Nadarajan (1995), Sambamurthy (1999), Ladole and Meshram (2000), Rao *et al*. (2001), Neelima and Potdukhe (2002), Muthuswamy and Vivekanandan (2004), Vinodhana Kumari *et al*. (2013) and Manjunath Paloti (2016).

Boll weight had positive significant correlation with ginning outturn. Similar results were found by Krishnarao and Mary (1990), Kowsalya and Raveendran (1996), Neelima and Potdukhe (2002), Muthuswamy and Vivekanandan (2004), Annapurve *et al*. (2007), Naqib *et al*. (2010), Alkuddsi *et al*. (2013) and Manjunath Paloti (2016).

Seed index had positive significant correlation with lint index. Similar results were found by Govila and Sharma (1981), Krishnarao and Mary (1990), Rajarathinam *et al*. (1993), Ramalingam *et al*. (1994), Sumathi and Nadarajan (1995), Sambamurthy (1999),Jain and Yadav (2001), Rao *et al*. (2001), Neelima and Potdukhe (2002), Leelapratap *et al*. (2007), Liaqat *et al*. (2015), Bayyapu Reddy *et al*. (2015) and Manjunath Paloti (2016).

Upper half mean length had positive significant correlation with fibre strength. Similar results were reported by Ashokkumar and Ravikesavan (2010), Magadum *et al*. (2012), Vinodhana Kumari *et al*. (2013), Patil Malagouda *et al*. (2014) and Amjid *et al*. (2016).

Upper half mean length had negative significant correlation with micronaire value. Similar results were found by Basang and Gencer (2007), Ashokkumar and Ravikesavan (2010) and Amjid *et al*. (2016).

5.4 Path co-efficient analysis

Yield is a function of various component traits and comprehensive path coefficient analysis shows how various component traits affect the yield (Wright, 1921). The characters contribute directly and also indirectly through other characters to the final yield. The analysis of such interplay is done through path coefficient analysis, an account of which is given below.

Plant height had positive direct effect on seed cotton yield. Leelapratap *et al*. (2007), Talawar (2008), Karademir *et al*. (2009), Farooq *et al*. (2014), Dahiphale *et al*. (2015) and Farooq *et al*. (2015) reported positive direct effect of plant height. It also exhibited high positive indirect effect through boll number. Selection for this trait will improve yield.

There was positive direct effect of number of sympodia per plant on yield. Similar findings were reported by Gulamov *et al*. (1974), Nazir and Khan (1974), Bhatade (1982), Manivasakam (1985), Muthu *et al*. (2004), Verma *et al*. (2006), Remzi *et al*. (2010), Alkuddsi *et al*. (2013) and Bharat Kumar *et al*. (2014). It showed indirect effect which was positive and high through plant height, boll number and ginning outturn.

Sympodial length at 50 per cent plant height had high positive direct effect and positive association with yield. This result was in concurrence with the findings of Alkuddsi *et al*. (2013), Bharat Kumar *et al*. (2014) and Manjunath Paloti (2016).

Number of nodes on main stem and number of bolls per plant exhibited negative direct effect on seed cotton yield. These traits also showed negative indirect effect through most of the traits, except through upper half mean length and fibre strength. Similar results were found by Ashokkumar and Ravikesavan (2010), Bharat Kumar *et al*. (2014), Farooq *et al*. (2015), Zhang *et al*. (2015) and Manjunath Paloti (2016).

Number of bolls per sq.m. showed positive direct effect on seed cotton yield. Similar results were obtained by Linghe Zeng and William Meredith (2014). The trait also exhibited positive indirect effect through plant diameter and sympodial length at 50 per cent plant height. The selection based on this trait, indirectly increases seed cotton yield by accommodating more number of plants per unit area with lesser plant diameter.

Traits, boll weight and ginning outturn revealed positive direct effect on seed cotton yield. Lavanya Kumar (2004), Mahantesh Shastri (2004), Gururaj (2006), Hanamaraddi (2010), Pujer *et al*. (2014) and Manjunath Paloti (2016) reported the same findings earlier. These traits showed positive indirect effect through number of bolls per plant and number of bolls per sq.m. Selection for higher boll weight and ginning outturn often results in an increase in the production per plant and thus, per unit area.

Seed index and total biomass had positive direct effect on seed cotton yield. Similar findings were reported by Alkuddsi *et al*. (2013), Ashraf *et al*. (2016) and Manjunath Paloti (2016). Seed index and total biomass, also exhibited positive indirect effect through boll weight, number of bolls per plant, ginning outturn and number of bolls per sq.m. The seed cotton yield per plant was greatly influenced by seed index and total biomass. This provides evidence that selection based on these traits can be useful.

There was negative direct effect of upper half mean length and fibre strength on seed cotton yield. Wright (1921), Sambamurthy (1999), Leela *et al*. (2007), Muhammad *et al*. (2014) and Chandrashekar *et al*. (2016) reported the same. Practising selection for increasing yield based on these traits may prove counterproductive. The undesirable negative linkage between fibre properties and yield in cotton is a constant reminder.

Micronaire value of fibre showed positive direct effect on seed cotton yield. Similar findings were reported by Srinivas *et al*. (2015) and Ashraf *et al*. (2016). It exhibited negative indirect effects through all other quantitative traits. Selection based on this trait may not result in increased seed cotton yield.

5.5 Plant type characterization

Plant type characterization is essential to identify genotypes that can fit into different planting geometries based on the availability of resources. Rich environments are usually created for cultivating cotton intensively where the plant type is highly robust. These days, cotton cultivation is no more remunerative and mechanization seems one good solution for partial mitigation. Mechanical harvesters are now available and cotton genotypes suited for machine picking need to be identified. It is in this scenario that the need for compact genotypes is being felt. Such genotypes can be grown in high density, especially under rainfed situations as they are dwarf in nature, occupy less three dimensional space in the field because they have less plant diameter and are also early. Thus, the concept of compact cotton is to increase productivity and overall profitability. An attempt has been made in this study to characterize the plant type under varying growing situations created by differing planting geometries where a cotton plant is subjected to differential competition from its neighbours. The way it reacts in the form of yielding ability, by either maintaining or modifying its stature across environments, has given an insight into the dynamics of the plant type in cotton.

Different planting densities *i.e.,* three environments were created by altering planting geometries. In each environment, 28 genotypes were raised in randomised block design with replications to characterize their plant type. Six different plant type categories were made based on the index score method using plant height and plant diameter *viz*., super compact, compact, compact spreading, tall compact, robust and highly robust plant type.

If a genotype shows the same plant type across all environments, it means it is genetically stable for the plant type traits. Stability analysis of plant type traits and yield was carried out. Such a genotype if found compact and is also high yielding, can be recommended for high density planting. This was one major objective of the present study.

The 28 genotypes were characterized for plant type to see if some genotypes with the same plant type were common to all the three environments. There were none. Hence, genotypes common to at least two planting densities were sought after. Five genotypes were categorized as super compact type and four as compact type. Three genotypes were of the compact spreading type. One was robust and two genotypes were highly robust. No genotype was found in the tall compact plant type in at least two environments.

Further, to assess the change in the phenotypic expression of the plant type traits in the genotypes across the environments, per cent differences were calculated for four plant type traits *viz*., plant height, sympodial length at 50 per cent plant height, sympodial angle and plant diameter between two environments taken at a time *viz*., between E1 and E2, between E2 and E3 and between E1 and E3. The minimum per cent change in the expression of the four traits between any two different planting densities would indicate that the genotype is suitable for both the planting densities. On the other hand, maximum per cent change in the expression for the above traits between any two planting densities indicates that the genotype is suited to the particular planting density where it actually performs better. The expression change will also be an indicator of the interaction between the genotype and environment, with minimum change pointing towards a truly genetic basis for the plant type traits of the genotype. This means, a genotype could be having genes for compactness if the said genotype falls in the compact plant type category. Such a genotype can be selected with confidence for high density planting for the best yield realisation. Consequently, a consistently robust genotype can fit better in a rich environment. This methodology also supports stability analysis results obtained for the plant type traits in the present study.

Considering the differences related to plant type traits between E1 and E2, the minimum and maximum per cent differences were exhibited by the genotypes RAH-100 and U-21, for plant height, sympodial length at 50 per cent plant height and plant diameter indicating that genotype RAH-100 was better suited than U-21. The genotype RAH-100 had highly robust plant type and was well suited to E2, the recommended planting density.

Considering differences between E2 and E3, the genotype A-31 had maximum per cent difference for all the four characters *viz*., plant height, sympodial length at 50 per cent plant height, sympodial angle and plant diameter. The minimum change for plant height and sympodial length at 50 per cent plant height was shown by the genotype S-34, which exhibited robust plant type and with higher yield per plant, it could be suitable for either E2 or E3.

The differences related to plant type traits between E1 and E3 were high as the planting densities are extreme. The minimum and maximum change was noticed in the genotypes A-16 and U-16 for sympodial length at 50 per cent plant height and plant diameter. The minimum change observed for plant height and sympodial angle was in the genotypes ARBC-19 and F-21, respectively. The genotypes ARBH-813 and ARBC-64 had maximum differences for plant height and sympodial angle, respectively. Hence the genotypes A-16 and ARBC-19 which also exhibited super compact and tall compact plant type with higher yield levels were found suitable for high density planting.

Across the three different planting densities, the mean per cent differences noticed for all the four plant type characters was higher between E1 and E3, followed by between E2 and E3 and finally between E1 and E2. The space, consequently, the resources available to a single plant increased from E1 through E3 thus changing the phenotypic expression of the plant type traits. That, no genotype had the same plant type across all three environments been proof enough for the environmental influence on the genotype. A similar plant type across at least two environments pointed towards the genetic basis of the plant type. Compact genotypes suited for high density planting have thus been identified in this study. As a natural corollary, a genotype having a specific plant type, can be cultivated in the ideal planting density most suited to it, instead of thwarting its growth or unnecessarily letting waste, the resources.

5.6 Stability analysis

Since the objective was to identify promising genotypes that are also stable, the experiment was conducted in three environments created by varying the planting density. The experiment also involved assessing the plant type of the genotypes and stability analysis of traits contributing to specific plant types. It was envisaged that differing environments would influence the plant type to change. A genotype with minimal change in its phenotype across the environments would be considered as stable and the one that changes its plant type according to the resources it gets would be considered unstable. Planting density specific recommendations for a genotype can then be made. In the present study, stability analysis was carried out to identify genotypes suited to each environment with an emphasis on genotypes for high density planting situation.

5.6.1 Pooled analysis of variance

The pooled analysis of variance revealed that, the environments chosen for the study were appropriate as depicted by significance of mean sum of squares (MSS) due to environment for the traits *viz*., plant height, plant diameter, number of bolls per sq.m., seed cotton yield and harvest index. Similarly, MSS due to genotype were significant only for plant height and number of bolls per sq.m., indicating the presence of variability among the genotypes for these characters.

MSS due to environment (linear) was significant for all the traits studied indicating that environment effects were additive. The pooled deviation was also significant for plant diameter and seed cotton yield, indicating that nonlinear component of G × E interaction was predominant.

The genotypes were raised in a uniform piece of land with three different planting geometries. The genotype × environment interaction was not significant for all the traits indicating no differential response between the genotypes and environments. Similar findings were reported by Arshad *et al*. (2016). The linear component of G × E interaction was only significant for seed cotton yield per plant as earlier also reported by Anandan *et al*. (2005).

The genotypes chosen for the experiment were mostly identified as belonging to the compact plant type in previous studies conducted in the research stations. This may be one reason why the interaction was non-significant. The second reason could be due to the large number of degrees of freedom for genotype × environment interaction item making the interaction mean squares non-significant in the *F*- test even when the interaction sum of squares is large. In such cases, Darbeshwar Roy (2000) advises to still continue with stability analysis. Hence, in the present study, stability of the plant type traits and yield were assessed using Additive Main Effects and Multiplicative Interactive (AMMI) model where genotype × environment interaction component is divided into different principal components.

5.6.2 AMMI analysis of variance

AMMI statistical model is a hybrid which makes use of standard ANOVA procedure to separate the additive variance from the multiplicative variance (genotype by environment interaction) and then uses a multiplicative procedure – Principal Component Analysis (PCA) to extract the pattern from the G × E portion of ANOVA analysis. The resulting statistical model is a hybrid of the two models and results in a least squares analysis which with further graphical representation of the numerical results (Biplot analysis) often allows interpretation of the underlying causes of G × E interaction (Gollob, 1968; Zobel *et al*. 1988; Gauch, 1993). When the AMMI model includes more than one IPCA axes, assessment and presentation of genetic stability will become complicated. To overcome this, second and higher order IPCA axes are normally pooled into residual while presenting biplot assay.

In AMMI biplot the usual interpretation of a biplot is that the displacements along the abscissa indicate differences in main (additive) effects, whereas displacements along the ordinate indicate differences in interaction effects. In additive ANOVA model, the yield estimate for any genotype in any environment can be computed by adding the genotype mean to the environment mean and subtracting the grand mean. The AMMI estimates are then worked out by adding the ANOVA model estimates to the estimated GEI effect. Biplot assays of the AMMI results are presented with main effects (genotype and environment) shown along the abscissa (x-axis) and the ordinate (y-axis) representing the first PCA. Both main effects and interaction component are very clearly depicted in the biplots. The usual interpretation of such a biplot assay is that if a genotype or an environment has a PCA score of nearly ‘zero’, it has small interaction effects and when a genotype and an environment have the same sign on the PCA axis, their interaction is positive; if different, their interaction is negative. These biplots help in visual interpretation of the GE patterns and help identify genotypes or locations that exhibit low, medium and high levels of interaction effects. (Vijaykumar *et al*., 2001).

In GGE biplot analysis, the GEI effect is determined by the product of corresponding PCA scores, genotypes or environments with a small GEI will have small scores and be close to the centre of the axes. Genotypes occurring close together on the plot will tend to have similar yields in all the environments, while genotypes far apart may either differ in mean yield or show a different pattern of response over the environments. Thus, biplots serve as effective graphical representation of the variability in different environments which is in agreement with Adugna and Labuschagne (2002) in linseed and Adugna (2007) in sorghum.

In GGE biplot analysis, the PC1 accounted for 62.19 per cent for plant height. The genotypes U-21, N-30, U-31 and A-11 had lower plant height with higher seed cotton yield and were generally adaptable to all environments. Instead of growing these genotypes in low planting density, they can be grown in high density planting thus increasing unit productivity. The genotypes N-45, S-32, A-16 and BRCC-1601 showed lower plant height even in low planting density but they were unstable.

For plant diameter, PC 1 accounted for 59.55 per cent in GGE biplot analysis. The genotypes U-16, N-45, F-22, N-59, F-25, F-31, BRCC-1602 and SCS-1206 had lower diameter and showed stable performance for this trait across environments. The genotypes U-20, A-11 and A-31 exhibited lower plant diameter with high PCA1 score and were suitable for the regular recommended planting density.

For seed cotton yield, PC 1 accounted for 75.07 per cent in GGE biplot analysis. The genotypes A-11, RAH-100, F-25, BRCC-1601, BRCC-1602, SCS-1206 and A-16 showed stable performance for seed cotton yield and also had higher seed cotton yield. The genotypes F-22, S-34, Suraj, N-30, Sahana, ARBH-813 and A-2 were identified as specifically adapted to the regular recommended planting density.

In GGE biplot analysis, the PC1 accounted for 58.62 per cent for bolls per sq.m. The genotypes BRCC-1601, BRCC-1602, F-17, N-30, N-57, A-31 and A-16 had higher bolls per sq.m. with higher seed cotton yield and were generally adaptable to all environments.
The genotypes F-31 and N-59 had higher bolls per sq. m. but they were unstable.

For harvest index, PC 1 accounted for 56.07 per cent in GGE biplot analysis. The genotypes RAH-100, A-19, SCS-1206, F-21, U-16, F-25, BRCC-1601 and N-59 showed stable performance for harvest index across all environments.

Overall, the genotypes SCS-1206, A-2, BRCC-1601, A-16 and N-30 were found desirable. The genotype SCS-1206 had lower plant diameter, lesser plant height, more number of bolls per sq.m. and high harvest index with higher seed cotton yield. It showed minimal per cent differences for plant type traits across environments. It was also stable across environments for plant type traits and seed cotton yield per plant but not for bolls per sq.m. The genotypes A-2, BRCC-1601, A-16 and N-30 were high yielding with BRCC-1601 and A-16 also being stable for seed cotton yield per plant. Though, these four genotypes were not stable for all the plant type traits, they did show minimal per cent differences for them across environments. Among all the genotypes, Suraj and N-57 had very good fibre properties.

The genotypes SCS-1206, A-2, BRCC-1601, A-16 and N-30 have been identified as promising for high density planting based on their plant type and yielding ability.

Future line of work

1. The characters *viz.*, plant height, plant diameter, boll weight, lint index, total biomass and seed cotton yield had high genetic variability and can be used in selection exercises to develop improved varieties.
2. The promising genotypes have to be extensively tested in high density planting situations across locations.
3. Identified super compact and highly robust parents can be used to develop segregating populations to unravel the genetics of plant type traits.

Summary and Conclusions

6. SUMMARY AND CONCLUSIONS

The present investigation was undertaken during the *kharif* season of 2016-17 in the fields of the Agricultural Research Station, Dharwad Farm to identify promising *Gossypium hirsutum* L. genotypes by evaluating them in three different planting densities for yield and its component traits. The genetic material consisted of twenty five new potential genotypes and three checks evaluated in randomized block design. Genetic variability present in the 28 genotypes was assessed to identify suitable genotypes with desirable traits. Future breeding programs rest on such genotypes. The relationship among the traits was also studied through correlation and path analysis.

An attempt was made to categorize these 28 genotypes based on their plant height and plant diameter in to six plant type classes, *viz*., super compact, compact, compact spreading, tall compact, robust and highly robust in all the three planting density environments, separately. The presence of genotype × environment interaction was investigated primarily to study the behaviour of plant type across different environments. Seed cotton yield and its component traits of these genotypes were also evaluated in this process with an objective to utilize promising genotypes in future breeding programs aimed at high density planting.

The observations were recorded on eighteen traits including seed cotton yield and its component characters *viz.,* plant height, number of sympodia per plant, sympodial length at 50 per cent plant height, internodes distance, interboll distance, number of bolls per plant, number of bolls per sq.m., boll weight, seed cotton yield per plant, total biomass, harvest index, seed index, ginning out turn, fibre length, fibre strength and micronaire value.

Analysis of variance revealed significant differences among the genotypes in all the three different planting densities for most of the traits indicating a high degree of variability among the genotypes tested. Variability was assessed for yield and its component characters among all the genotypes in the recommended planting density environment. The PCV and GCV in the genotypes was observed to be high for plant height, plant diameter, boll weight, lint index, seed cotton yield, total biomass and harvest index. These characters also recorded moderate to high heritability estimates and high GAM proving their reliability in further breeding programs.

Association analysis revealed significant positive correlation for seed cotton yield per plant with all the traits except with fibre upper half mean length and fibre strength.

Path co-efficient analysis revealed positive direct effect of plant height, number of sympodia, sympodial length at 50 per cent plant height, number of bolls per sq.m., boll weight, ginning outturn, seed index and total biomass on seed cotton yield. Selection based on these traits can improve the seed cotton yield.

Plant type characterization revealed that no genotype had the same plant type across all three environments. The plant type did change with differing environmental pressures. But, there were genotypes common to at least two environments with less change in the plant type traits pointing towards the genetic basis of plant type. The genotypes U-16 and A-16 were of the super compact type. Genotypes N-30 and F-21 were compact in nature.

The genotype SCS-1206 was stable across environments for plant type traits and also showed high stable seed cotton yield. The genotypes A-2, BRCC-1601, A-16 and N-30 were high yielding with BRCC-1601 and A-16 also being stable for seed cotton yield per plant. Though, these four genotypes were not stable for all the plant type traits, they did show minimal per cent differences for the traits across environments. Following extensive testing the genotypes can be considered for release in specific growing situations, with an eye on their plant type.

Diverse plant type genotypes identified can be used to generate segregating populations for studying the genetics of plant type traits to fuel further breeding programs especially geared towards high density planting genotype requirements.

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Appendices

Appendix I: Mean performance of *G. hirsutum* genotypes for seed cotton yield and its component traits across the three environments at ARS Dharwad during *kharif,* 2016-17

Genotypes	Plant height (cm)				Number of sympodia			
	E1	E2	E3	Mean	E1	E2	E3	Mean
N-45	56.4	55.9	73.9	62.07	15.08	16.5	20.2	17.26
N-30	54.8	62.7	70.3	62.60	14.15	19.75	21.5	18.47
N-57	56.9	66.7	82	68.53	13.31	15.5	21.75	16.85
N-59	66.4	67.4	61.8	65.20	17.85	17.3	19.15	18.10
F-17	64.7	60.4	74.8	66.63	17.88	15.9	23.55	19.11
F-21	62.9	71.3	76.2	70.13	14.26	20.9	22.1	19.09
F-22	77.9	68.6	71.6	72.70	17.93	15.1	19	17.34
F-25	65.9	63	68.3	65.73	15.70	19.75	21.8	19.08
F-31	62.8	56.4	67.8	62.33	16.40	15.95	19.2	17.18
U-16	59.1	55.4	64.4	59.63	17.00	15.9	17.15	16.68
U-20	67.9	66.1	70.8	68.27	13.23	17.6	17.2	16.01
U-21	58.1	49.9	66.6	58.20	14.60	12.95	23	16.85
U-31	56.3	63.4	70.6	63.43	17.60	21.65	23.8	21.02
S-32	61.4	54	77.4	64.27	17.30	15.7	23.15	18.72
S-34	66.3	76.5	105	82.60	12.80	19.4	25.8	19.33
A-2	48	53.1	65.3	55.47	10.90	14.3	21.85	15.68
A-11	56.5	64.2	72.93	64.54	12.10	19.85	19.1	17.02
A-16	56.6	54.7	74.4	61.90	12.00	14.95	24.8	17.25
A-31	51.9	70.2	57.5	59.87	11.35	20.15	16.15	15.88
BRCC-1601	58.9	56.3	76.1	63.77	17.60	18.1	27.15	20.95
BRCC-1602	58.4	69	74.6	67.33	18.90	19.8	23.1	20.60
SCS-1206	66.7	61.5	80	69.40	17.80	20.2	24.05	20.68
ARBH-813	59.4	69.5	82.1	70.33	13.70	22.75	23.45	19.97
Sahana	71.6	66.4	81	73.00	15.90	17.8	22.75	18.82
RAH-100	65.3	74.9	78.5	72.90	16.00	26.3	22.55	21.62
Suraj	67.6	61.4	66.3	65.10	15.95	17.7	22.6	18.75
ARBC-19	63.7	73	78.4	71.70	13.30	20.35	22.55	18.73
ARBC-64	61.8	59	79	66.60	14.05	17.65	25.05	18.92
Mean	61.58	63.25	73.84	66.22	15.17	18.21	21.91	18.43

E1 (High density planting): Spacing of 60 cm x 15 cm – 1,11,111 plants/ha

E2 (Regular density planting): Spacing of 60 cm x 30 cm – 55,555 plants/ha

E3 (Low density planting): Spacing of 60 cm x 60 cm – 27,777 plants/ha

Appendix I. Contd...

Genotypes	Sympodial length at 50 per cent plant height (cm)				Internode distance (cm)			
	E1	E2	E3	Mean	E1	E2	E3	Mean
N-45	10.3	12.2	15	12.50	1.50	1.35	1.35	1.40
N-30	11	12.5	14.3	12.60	1.32	1.58	1.50	1.47
N-57	12.1	11.7	14.5	12.77	1.10	1.33	1.50	1.31
N-59	11.8	13.6	13.7	13.03	1.48	1.27	1.40	1.39
F-17	11.2	10.9	13.6	11.90	1.58	1.48	1.74	1.60
F-21	12.6	13.7	14.1	13.47	1.11	1.53	1.56	1.40
F-22	13.3	12.5	12.2	12.67	1.35	1.21	1.55	1.37
F-25	10.6	12.1	12.8	11.83	1.48	1.63	1.72	1.61
F-31	10.7	11.1	12.7	11.50	1.53	1.44	1.51	1.49
U-16	11.1	10.1	13.5	11.57	1.52	1.58	1.27	1.46
U-20	9.7	11.9	12.3	11.30	1.37	1.51	1.40	1.43
U-21	10.6	10.7	12.4	11.23	1.38	1.21	1.84	1.47
U-31	10.8	12	13.7	12.17	1.60	1.80	1.74	1.71
S-32	13.5	13.6	16	14.37	1.27	1.15	1.44	1.29
S-34	10.6	13.1	16.4	13.37	1.22	1.47	1.57	1.42
A-2	9.9	13	12.8	11.90	1.10	1.10	1.71	1.30
A-11	9.8	11.9	12	11.23	1.24	1.75	1.59	1.53
A-16	9.9	10	12.6	10.83	1.21	1.50	1.98	1.57
A-31	9.8	14.3	13.1	12.40	1.16	1.40	1.23	1.26
BRCC-1601	10.9	11.6	14.2	12.23	1.61	1.56	1.92	1.70
BRCC-1602	11.95	13.5	15.2	13.55	1.58	1.48	1.52	1.53
SCS-1206	11.5	11.5	14.5	12.50	1.55	1.76	1.66	1.65
ARBH-813	10.8	14.3	14.5	13.20	1.27	1.60	1.62	1.49
Sahana	10.8	12.5	14.8	12.70	1.48	1.47	1.54	1.50
RAH-100	10.7	12.6	14.6	12.63	1.50	2.18	1.55	1.74
Suraj	12.8	12.3	13.5	12.87	1.24	1.44	1.67	1.45
ARBC-19	11.6	12.8	13.3	12.57	1.15	1.58	1.70	1.48
ARBC-64	13.4	14.5	16.2	14.70	1.05	1.23	1.55	1.27
Mean	11.21	12.38	13.88	12.49	1.36	1.49	1.58	1.47

E1 (High density planting): Spacing of 60 cm x 15 cm – 1,11,111 plants/ha
E2 (Regular density planting): Spacing of 60 cm x 30 cm – 55,555 plants/ha
E3 (Low density planting): Spacing of 60 cm x 60 cm – 27,777 plants/ha

Appendix I. Contd…..

Genotypes	Interboll distance (cm)				Plant diameter (cm)			
	E1	E2	E3	Mean	E1	E2	E3	Mean
N-45	3.75	3.32	4.04	3.70	29.74	32.46	39.70	33.97
N-30	3.51	3.80	3.69	3.67	27.59	38.88	42.34	36.27
N-57	3.49	3.61	4.21	3.77	25.75	29.70	42.66	32.70
N-59	4.74	4.05	3.47	4.08	33.79	33.63	37.52	34.98
F-17	4.32	4.05	4.12	4.16	34.65	31.52	46.44	37.53
F-21	3.95	3.93	4.28	4.05	27.90	41.29	43.43	37.54
F-22	4.46	3.77	4.35	4.19	34.61	29.87	37.41	33.96
F-25	4.35	3.82	4.10	4.09	30.25	38.76	42.92	37.31
F-31	3.72	3.24	3.73	3.56	31.79	31.59	37.85	33.75
U-16	3.64	3.81	3.75	3.73	32.47	30.98	33.64	32.36
U-20	4.29	4.47	4.71	4.49	26.09	34.87	33.19	31.38
U-21	3.77	3.42	4.16	3.78	28.70	25.27	45.61	33.20
U-31	3.49	3.76	3.76	3.67	34.59	42.49	46.54	41.21
S-32	3.42	3.16	4.36	3.65	33.86	30.96	45.61	36.81
S-34	4.20	4.35	5.63	4.73	25.28	38.08	51.02	38.13
A-2	3.44	3.43	3.93	3.60	21.50	28.14	43.10	30.92
A-11	3.67	4.04	4.24	3.98	23.50	39.14	37.37	33.34
A-16	3.77	4.01	4.42	4.07	23.68	28.94	48.62	33.74
A-31	3.48	4.25	3.32	3.68	21.90	39.72	31.78	31.13
BRCC-1601	3.57	3.51	4.25	3.77	34.44	35.23	53.44	41.04
BRCC-1602	3.50	3.84	4.17	3.83	36.49	38.63	42.92	39.35
SCS-1206	3.89	4.07	4.48	4.14	34.93	38.89	47.56	40.46
ARBH-813	3.98	3.86	4.40	4.08	26.78	44.88	46.29	39.32
Sahana	4.89	4.03	4.73	4.55	30.74	34.55	44.63	36.64
RAH-100	4.22	4.38	4.36	4.32	31.09	51.95	44.75	42.60
Suraj	4.06	3.81	4.17	4.01	29.50	34.61	44.04	36.05
ARBC-19	3.98	4.20	4.25	4.14	25.84	40.29	44.53	36.88
ARBC-64	3.55	3.19	4.36	3.70	26.99	34.39	49.77	37.05
Mean	3.90	3.83	4.19	3.97	29.44	35.71	43.02	36.06

E1 (High density planting): Spacing of 60 cm x 15 cm – 1,11,111 plants/ha
E2 (Regular density planting): Spacing of 60 cm x 30 cm – 55,555 plants/ha
E3 (Low density planting): Spacing of 60 cm x 60 cm – 27,777 plants/ha

Appendix I. Contd...

Genotypes	Number of bolls per plant				Number of bolls per sq. m.			
	E1	E2	E3	Mean	E1	E2	E3	Mean
N-45	4.91	7.40	12.33	8.21	54.54	37.50	35.82	42.62
N-30	5.41	8.33	14.58	9.44	60.10	46.29	42.77	49.72
N-57	5.13	8.33	14.75	9.40	57.07	46.29	42.50	48.62
N-59	6.91	10.00	13.92	10.27	76.77	55.55	39.99	57.44
F-17	5.86	11.58	12.25	9.90	65.15	64.35	35.27	54.92
F-21	4.77	7.92	14.92	9.20	53.03	43.98	37.25	44.75
F-22	5.00	7.67	13.25	8.64	55.56	42.59	35.25	44.46
F-25	5.27	6.67	15.33	9.09	58.59	37.03	39.99	45.20
F-31	6.59	8.47	13.83	9.63	77.78	43.51	36.66	52.65
U-16	4.95	6.67	11.00	7.54	55.05	37.03	30.82	40.97
U-20	5.18	7.92	13.67	8.92	57.58	43.98	35.82	45.79
U-21	4.35	5.32	14.75	8.14	43.94	26.85	37.21	36.00
U-31	6.09	6.42	11.92	8.14	67.68	35.64	34.16	45.83
S-32	5.91	8.58	7.33	7.27	65.66	47.68	19.72	44.35
S-34	4.27	8.42	10.75	7.81	47.47	46.75	29.99	41.41
A-2	5.36	6.58	10.92	7.62	59.60	36.57	26.94	41.03
A-11	4.91	7.00	13.33	8.41	54.54	38.89	37.21	43.55
A-16	5.59	8.75	16.42	10.25	62.12	48.61	46.65	52.46
A-31	5.41	9.67	16.33	10.47	60.10	53.70	42.77	52.19
BRCC-1601	5.95	8.08	13.25	9.09	66.16	44.90	38.04	49.70
BRCC-1602	6.18	8.58	15.42	10.06	68.69	47.68	41.38	52.58
SCS-1206	5.82	8.33	12.17	8.77	64.65	46.29	32.49	47.81
ARBH-813	3.91	9.75	16.08	9.91	45.96	54.16	44.43	48.18
Sahana	4.64	6.83	12.83	8.10	51.51	37.96	34.43	41.30
RAH-100	4.59	6.42	14.92	8.64	51.01	35.64	41.66	42.77
Suraj	3.91	6.08	12.83	7.61	43.43	33.79	36.66	37.96
ARBC-19	4.09	8.92	10.92	7.97	45.45	49.53	29.16	41.38
ARBC-64	5.00	8.42	8.92	7.44	55.56	46.75	24.44	42.25
Mean	5.21	7.97	13.18	8.78	58.03	43.91	36.05	46.00

E1 (High density planting): Spacing of 60 cm x 15 cm – 1,11,111 plants/ha
E2 (Regular density planting): Spacing of 60 cm x 30 cm – 55,555 plants/ha
E3 (Low density planting): Spacing of 60 cm x 60 cm – 27,777 plants/ha

Appendix I. Contd…..

Genotypes	Boll weight (g)				Ginning outturn (%)			
	E1	E2	E3	Mean	E1	E2	E3	Mean
N-45	3.02	4.15	3.50	3.55	44.45	30.70	58.90	44.68
N-30	2.75	3.16	2.71	2.87	29.10	35.90	82.10	49.03
N-57	3.42	2.68	2.16	2.75	37.50	24.20	64.65	42.12
N-59	3.08	2.93	2.56	2.86	42.20	101.25	76.95	73.47
F-17	2.37	1.60	3.92	2.63	40.20	41.45	60.55	47.40
F-21	3.37	3.86	1.99	3.07	42.15	43.20	93.85	59.73
F-22	2.96	3.55	2.69	3.06	35.30	38.20	70.15	47.88
F-25	2.85	3.60	2.66	3.03	44.75	53.25	77.65	58.55
F-31	2.58	3.46	3.12	3.05	45.85	28.65	57.80	44.10
U-16	3.04	3.33	4.07	3.48	42.50	48.10	92.75	61.12
U-20	3.69	5.02	2.59	3.76	40.60	51.30	66.40	52.77
U-21	5.96	5.62	3.74	5.11	36.75	41.35	74.85	50.98
U-31	2.93	4.94	3.07	3.64	31.10	41.85	69.40	47.45
S-32	3.22	2.33	4.94	3.50	32.60	45.15	110.15	62.63
S-34	2.91	3.87	4.10	3.63	32.50	27.99	88.15	49.55
A-2	3.49	4.64	3.47	3.87	32.35	38.15	81.90	50.80
A-11	2.90	4.52	3.35	3.59	25.50	35.25	51.30	37.35
A-16	3.11	2.56	2.73	2.80	36.95	40.65	78.95	52.18
A-31	2.91	2.82	1.93	2.55	24.25	52.75	70.80	49.27
BRCC-1601	2.67	3.46	3.85	3.32	27.85	44.80	64.05	45.57
BRCC-1602	2.45	3.10	2.69	2.75	26.75	47.90	82.30	52.32
SCS-1206	3.51	4.40	3.84	3.92	36.10	48.75	85.00	56.62
ARBH-813	3.27	2.98	2.78	3.01	31.65	37.15	79.50	49.43
Sahana	2.49	2.30	3.25	2.68	40.95	51.50	61.15	51.20
RAH-100	4.15	4.39	2.78	3.77	37.10	43.65	71.05	50.60
Suraj	3.54	4.30	2.32	3.38	44.55	45.05	59.60	49.73
ARBC-19	2.96	2.90	3.64	3.16	33.15	49.80	88.15	57.03
ARBC-64	2.00	2.59	4.88	3.16	37.65	62.75	64.25	54.88
Mean	3.13	3.54	3.19	3.28	36.16	44.67	74.37	51.73

E1 (High density planting): Spacing of 60 cm x 15 cm – 1,11,111 plants/ha
E2 (Regular density planting): Spacing of 60 cm x 30 cm – 55,555 plants/ha
E3 (Low density planting): Spacing of 60 cm x 60 cm – 27,777 plants/ha

Appendix I. Contd…..

Genotypes	Seed index (g)				Lint index (g)			
	E1	E2	E3	Mean	E1	E2	E3	Mean
N-45	8.08	8.25	8.41	8.24	9.53	12.95	11.92	11.46
N-30	8.56	8.86	8.13	8.51	14.43	12.92	13.70	13.68
N-57	9.88	9.42	9.79	9.69	7.77	12.77	7.24	9.26
N-59	8.24	8.39	8.51	8.38	10.56	12.92	7.24	10.24
F-17	9.07	8.98	8.66	8.90	14.78	13.08	12.05	13.30
F-21	10.77	10.74	10.88	10.79	20.26	13.20	10.38	14.61
F-22	7.87	8.76	8.13	8.25	10.71	13.47	9.95	11.37
F-25	8.87	8.75	9.24	8.95	9.93	13.51	9.29	10.91
F-31	10.15	9.33	9.16	9.54	14.55	13.70	9.73	12.66
U-16	8.28	8.10	8.18	8.18	9.27	13.81	9.88	10.99
U-20	7.87	8.17	8.36	8.13	8.08	12.69	9.56	10.11
U-21	10.05	10.03	10.05	10.04	16.90	13.06	18.25	16.07
U-31	8.32	8.64	8.55	8.50	8.75	12.88	12.89	11.51
S-32	8.71	8.16	8.60	8.49	13.19	12.78	11.64	12.54
S-34	8.83	9.31	9.29	9.14	8.76	12.90	11.66	11.11
A-2	9.11	9.78	9.37	9.42	9.42	12.79	10.46	10.89
A-11	10.06	10.05	10.10	10.07	12.31	12.53	10.02	11.62
A-16	9.67	10.02	10.02	9.90	10.36	12.88	11.46	11.57
A-31	9.72	9.62	9.49	9.61	13.62	13.26	13.82	13.57
BRCC-1601	7.31	7.69	7.80	7.6	10.97	13.08	15.78	13.27
BRCC-1602	7.30	7.41	7.52	7.41	10.38	12.80	10.43	11.20
SCS-1206	8.34	8.65	8.85	8.61	9.54	12.90	14.67	12.37
ARBH-813	9.53	8.13	8.53	8.73	11.39	13.56	12.11	12.35
Sahana	8.78	8.77	9.14	8.89	11.03	13.77	12.73	12.51
RAH-100	8.92	8.74	8.86	8.84	10.53	13.11	9.65	11.10
Suraj	9.66	9.54	9.55	9.58	10.38	13.30	15.49	13.05
ARBC-19	9.04	9.84	10.17	9.68	11.34	13.13	13.12	12.53
ARBC-64	9.23	8.79	8.84	8.95	13.84	14.21	13.26	13.77
Mean	8.94	8.96	9.01	8.97	11.52	13.14	11.73	12.13

E1 (High density planting): Spacing of 60 cm x 15 cm – 1,11,111 plants/ha
E2 (Regular density planting): Spacing of 60 cm x 30 cm – 55,555 plants/ha
E3 (Low density planting): Spacing of 60 cm x 60 cm – 27,777 plants/ha

Appendix I. Contd…..

Genotypes	Total biomass (g)				Seed cotton yield (g/plant)			
	E1	E2	E3	Mean	E1	E2	E3	Mean
N-45	217.25	248.50	289.50	251.75	33.50	61.02	113.25	69.26
N-30	140.50	171.50	405.50	239.17	34.95	72.44	121.25	76.21
N-57	182.50	188.90	318.25	229.88	36.19	49.25	75.83	53.76
N-59	206.00	215.55	379.75	267.10	43.23	61.60	100.00	68.28
F-17	196.00	202.25	297.75	232.00	35.64	55.91	154.58	82.04
F-21	205.75	211.00	464.25	293.67	33.09	70.00	86.00	63.03
F-22	171.50	186.00	345.75	234.42	31.00	70.00	96.00	65.67
F-25	218.75	261.25	383.25	287.75	35.04	64.33	118.92	72.76
F-31	164.25	187.90	284.00	212.05	35.45	67.08	114.00	72.18
U-16	207.50	238.00	458.75	301.42	36.32	48.08	104.25	62.88
U-20	198.00	251.50	327.00	258.83	40.46	79.67	107.91	76.01
U-21	178.75	201.75	369.25	249.92	42.54	70.92	142.75	85.40
U-31	163.00	204.25	342.00	236.42	36.59	74.52	103.16	71.42
S-32	158.20	220.75	545.75	308.23	42.36	56.51	109.83	69.57
S-34	157.50	134.95	405.80	232.75	27.50	85.75	136.25	83.17
A-2	156.75	185.75	404.50	249.00	41.13	88.67	114.92	81.57
A-11	122.50	171.25	256.50	183.42	37.13	83.35	118.17	79.55
A-16	179.75	198.25	389.75	255.92	38.91	68.17	129.41	78.83
A-31	116.25	258.75	349.00	241.33	37.23	70.59	109.42	72.41
BRCC-1601	134.25	234.00	315.25	227.83	37.13	78.43	149.33	88.30
BRCC-1602	128.75	234.50	406.50	256.58	34.46	67.68	125.59	75.91
SCS-1206	175.45	238.75	420.00	278.07	41.05	82.34	144.83	89.41
ARBH-813	145.75	180.75	392.50	239.67	31.54	84.59	124.92	80.35
Sahana	199.75	255.00	300.75	251.83	32.23	60.25	127.17	73.22
RAH-100	180.50	213.25	350.25	248.00	41.54	78.41	120.42	80.12
Suraj	217.75	220.25	293.00	243.67	31.55	67.92	103.75	67.74
ARBC-19	155.75	244.00	435.75	278.50	29.09	61.83	110.50	67.14
ARBC-64	183.25	208.75	316.25	236.08	26.63	59.67	124.75	70.35
Mean	173.64	213.12	365.95	250.90	35.84	69.25	117.40	74.16

E1 (High density planting): Spacing of 60 cm x 15 cm – 1,11,111 plants/ha
E2 (Regular density planting): Spacing of 60 cm x 30 cm – 55,555 plants/ha
E3 (Low density planting): Spacing of 60 cm x 60 cm – 27,777 plants/ha

Appendix I. Contd…..

Genotypes	Harvest index (%)				Upper half mean length (mm)			
	E1	E2	E3	Mean	E1	E2	E3	Mean
N-45	52.99	62.64	57.72	57.79	26.40	26.60	26.30	26.43
N-30	62.64	65.29	62.64	63.53	26.00	24.70	25.30	25.33
N-57	43.59	48.72	42.39	44.90	29.10	28.90	28.30	28.77
N-59	55.76	52.11	45.99	51.28	26.00	27.00	25.50	26.17
F-17	61.97	53.86	58.13	57.98	25.80	26.70	25.80	26.10
F-21	65.29	39.89	48.75	51.31	26.40	28.10	27.50	27.33
F-22	57.52	58.77	55.04	57.11	24.40	24.80	24.50	24.57
F-25	52.71	52.71	49.92	51.78	26.70	27.20	27.40	27.10
F-31	56.72	55.08	51.52	54.44	27.90	27.30	26.60	27.27
U-16	52.71	80.24	54.50	62.48	26.80	27.80	27.00	27.20
U-20	50.45	43.59	53.28	49.11	27.50	28.00	28.30	27.93
U-21	62.64	61.30	64.03	62.66	27.10	27.50	26.70	27.10
U-31	51.05	62.64	60.04	57.91	24.60	25.10	27.80	25.83
S-32	59.57	57.49	57.52	58.19	25.00	27.40	25.50	25.97
S-34	49.81	60.65	55.64	55.37	24.50	24.80	27.70	25.67
A-2	50.51	60.85	52.71	54.69	24.40	27.30	25.40	25.70
A-11	55.05	44.63	49.81	49.83	24.90	26.60	26.10	25.87
A-16	51.12	46.68	53.28	50.36	27.30	25.70	26.20	26.40
A-31	58.16	60.65	57.83	58.88	24.70	25.50	24.60	24.93
BRCC-1601	60.00	66.05	65.47	63.84	23.70	26.60	24.30	24.87
BRCC-1602	58.74	61.97	57.64	59.45	24.20	27.90	24.60	25.57
SCS-1206	52.46	50.51	141.29	81.42	26.90	26.60	26.80	26.77
ARBH-813	54.46	60.65	57.72	57.61	26.50	27.30	26.30	26.70
Sahana	55.19	62.99	58.13	58.77	25.40	26.50	27.60	26.50
RAH-100	53.93	57.83	51.65	54.47	25.50	28.50	25.50	26.50
Suraj	51.12	58.74	131.97	80.61	28.10	28.50	30.60	29.07
ARBC-19	55.64	55.04	56.26	55.65	26.50	27.70	27.10	27.10
ARBC-64	60.00	61.38	60.00	60.46	27.10	27.20	24.60	26.30
Mean	55.42	57.25	61.10	57.92	26.05	26.92	26.43	26.47

E1 (High density planting): Spacing of 60 cm x 15 cm – 1,11,111 plants/ha
E2 (Regular density planting): Spacing of 60 cm x 30 cm – 55,555 plants/ha
E3 (Low density planting): Spacing of 60 cm x 60 cm – 27,777 plants/ha

Appendix I. Contd…..

Genotypes	**Fibre strength (g/tex)**				**Micronaire value (µg/inch)**			
	E1	**E2**	**E3**	**Mean**	**E1**	**E2**	**E3**	**Mean**
N-45	25.30	28.30	26.30	26.63	4.07	4.20	4.39	4.22
N-30	27.80	26.20	27.70	27.23	4.29	4.46	4.73	4.49
N-57	31.30	32.00	29.00	30.77	4.24	3.91	3.92	4.02
N-59	25.90	27.30	25.60	26.27	4.09	3.91	4.01	4.00
F-17	25.70	28.70	27.60	27.33	4.06	4.31	4.25	4.21
F-21	27.00	29.00	27.80	27.93	4.25	4.21	4.03	4.16
F-22	24.90	25.60	26.00	25.50	4.31	4.37	4.06	4.25
F-25	26.20	29.10	28.80	28.03	4.60	4.23	4.34	4.39
F-31	30.40	28.30	29.30	29.33	4.46	4.17	4.70	4.44
U-16	26.50	30.80	27.90	28.40	4.09	4.30	4.17	4.19
U-20	30.40	27.90	30.40	29.57	4.44	4.61	4.45	4.50
U-21	27.90	28.00	26.90	27.60	4.66	4.37	4.56	4.53
U-31	26.00	24.80	29.70	26.83	4.33	4.77	3.93	4.34
S-32	25.60	27.90	26.50	26.67	4.45	3.91	3.83	4.06
S-34	26.90	25.10	29.30	27.10	4.42	4.96	3.73	4.37
A-2	26.20	28.50	27.40	27.37	4.32	4.77	4.45	4.51
A-11	27.70	29.90	29.20	28.93	4.90	4.67	4.68	4.75
A-16	30.20	27.30	28.50	28.67	4.40	4.49	4.50	4.46
A-31	26.90	26.40	26.70	26.67	4.76	4.55	4.78	4.70
BRCC-1601	24.90	27.70	26.00	26.20	4.55	4.65	4.79	4.66
BRCC-1602	24.20	29.70	27.00	26.97	4.91	4.02	4.58	4.50
SCS-1206	27.20	28.00	26.70	27.30	4.16	4.26	3.91	4.11
ARBH-813	28.30	26.10	27.90	27.43	4.38	4.18	4.70	4.42
Sahana	27.20	27.80	28.80	27.93	4.21	4.24	4.33	4.26
RAH-100	26.80	31.90	27.10	28.60	4.34	3.90	4.35	4.20
Suraj	30.30	30.50	33.00	31.27	3.94	4.30	4.59	4.28
ARBC-19	27.50	28.60	28.40	28.17	4.03	4.44	4.39	4.29
ARBC-64	29.60	29.00	26.20	28.27	4.55	4.33	4.10	4.33
Mean	27.31	28.23	27.92	27.82	4.36	4.34	4.33	4.34

E1 (High density planting): Spacing of 60 cm x 15 cm – 1,11,111 plants/ha
E2 (Regular density planting): Spacing of 60 cm x 30 cm – 55,555 plants/ha
E3 (Low density planting): Spacing of 60 cm x 60 cm – 27,777 plants/ha

Appendix II: Weather parameters at ARS, Dharwad

Month	2016		Average normal of 27 years		Mean temperature (^{o} C)		Relative humidity (%)	
	Rainfall (mm)	No. of rainy days	Rainfall (mm)	No. of rainy days	Max.	Min.	Max.	Min.
January	--	--	2.1	--	31.1	13.6	79.6	19.5
February	1.0	--	2.8	1	34.4	17.8	76.7	18.5
March	0.8	--	7.0	1	37.3	21.6	71.8	14.3
April	29.0	4	45.0	3	39.3	22.7	80.7	17.1
May	68.0	5	63.0	4	37.0	22.9	83.5	26.2
June	109.0	10	123.0	9	29.7	21.6	92.3	53.8
July	151.8	16	125.0	11	27.1	21.4	93.5	65.0
August	82.2	9	100.0	11	25.9	22.2	87.5	68.7
September	45.6	5	108.0	7	29.5	22.3	86.2	32.5
October	35.3	2	124.0	7	32.1	18.2	86.6	26.8
November	14.8	1	33.0	2	32.0	14.4	78.9	20.1
December	--	--	9.0	1	31.1	13.8	78.4	21.5
Total	**537.5**	**52**	**741.9**	**57**				

CHARACTERIZATION OF PLANT TYPES AND STABILITY ANALYSIS IN PROMISING GENOTYPES OF *Gossypium hirsutum* L. UNDER RAINFED SITUATION

SOUMYA J. **2017** **Dr. RAJESH S. PATIL**
CHAIRMAN

ABSTRACT

Twenty eight new *Gossypium hirsutum* L. genotypes were evaluated in three different planting density environments *viz.,* E1 (60 cm × 15 cm), E2 (60 cm × 30 cm) and E3 (60 cm × 60 cm) at Agricultural Research Station, Dharwad Farm. The objectives included evaluation of genetic variability, association studies, path co-efficient analysis with major emphasis on the plant type characterization and stability analysis. High variability was observed for boll weight, lint index and harvest index. High heritability with high GAM was observed for plant diameter, boll weight, boll capsule weight, lint index, total plant biomass, seed cotton yield per plant and harvest index. The seed cotton yield was positively and significantly correlated with all the traits except with fibre upper half mean length and fibre strength. Path analysis revealed strong positive direct effects of plant height, number of sympodia per plant, sympodial length at 50 per cent plant height, number of bolls per square meter, boll weight, ginning outturn, seed index and total plant biomass on yield. Based on plant height and plant diameter, the plant type was characterized into six classes *viz*., super compact, compact, compact spreading, tall compact, robust and highly robust. The study revealed that no genotype had the same plant type across all three environments but thirteen new super compact to compact spreading genotypes were common to two environments. Across the three different planting densities, the mean per cent differences noticed for the plant type traits were the highest between E1 and E3 with some genotypes showing desirable minimal change. The genotypes U-16 and A-16 were super compact and N-30 and F-21 were compact in nature. The genotypes SCS-1206, A-2, BRCC-1601, A-16 and N-30 were identified as promising for high density planting based on their plant type and yielding ability across environments.