STABILITY ANALYSIS OF VARIETIES AND HYBRIDS IN CASTOR (*Ricinus communis* L.)

MANJESH CHANDRA S.

DEPARTMENT OF GENETICS AND PLANT BREEDING
COLLEGE OF AGRICULTURE, DHARWAD
UNIVERSITY OF AGRICULTURAL SCIENCES,
DHARWAD – 580 005

AUGUST, 2016

STABILITY ANALYSIS OF VARIETIES AND HYBRIDS IN CASTOR (*Ricinus communis* L.)

Thesis submitted to the
University of Agricultural Sciences, Dharwad
in partial fulfillment of the requirements for the
Degree of

MASTER OF SCIENCE (AGRICULTURE)

IN

GENETICS AND PLANT BREEDING

BY

MANJESH CHANDRA S.

DEPARTMENT OF GENETICS AND PLANT BREEDING
COLLEGE OF AGRICULTURE, DHARWAD
UNIVERSITY OF AGRICULTURAL SCIENCES,
DHARWAD – 580 005

AUGUST, 2016

DEPARTMENT OF GENETICS AND PLANT BREEDING
COLLEGE OF AGRICULTURE, DHARWAD
UNIVERSITY OF AGRICULTURAL SCIENCES, DHARWAD

CERTIFICATE

This is to certify that the thesis entitled “STABILITY ANALYSIS OF VARIETIES AND HYBRIDS IN CASTOR (*Ricinus communis* L.)” submitted by Mr. MANJESH CHANDRA S. for the degree of MASTER OF SCIENCE (AGRICULTURE) in GENETICS AND PLANT BREEDING to the University of Agricultural Sciences, Dharwad is a record of bonafide research work done by him during the period of his study in this University under my guidance and supervision and the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar titles.

DHARWAD

AUGUST, 2016

(P. V. KENCHANAGOUDAR)
CHAIRMAN

Approved by:

Chairman: ______________________________

(P. V. KENCHANAGOUDAR)

Members: **1.**______________________________
(S. K. DESHPANDE)

2.______________________________
(BASAVARAJ YENAGI)

Acknowledgement

In every one's life, the day arises when one has to shape the feelings in words. Sometimes, the words become unable to express the feelings of the mind, because, the feelings of heart are beyond the reach of the words. When, I came to complete this manuscript, so many memories have rushed through my mind, which are full of gratitude to those who encouraged and helped me at various stages of this research. It gives me immense pleasure to record my feelings at this place.

I express my deep gratitude to Dr. P. V. KENCHANAGOUDAR, Principal Scientist (GPB), AICRP on Chickpea, MULLaRP, University of Agricultural Sciences, Dharwad. He has been the source of inspiration and prime driving force throughout my study. I wish my profound sense of reverence to him for giving opportunity to work under his chairmanship. His level of guidance, encouragement, constructive criticism, generous, assistance at every stage of my research work is behind measure, in fact it was his ideas of smooth dealing with the things which motivated me to work under his guidance and all credits go to him.

It has been very good fortune to have an admirable advisory committee of Dr. S. K. DESHPANDE, Professor and Head, Department of Genetics and Plant Breeding, College of Agriculture, Dharwad, his keen interest to teach me and his observation in detecting errors and correcting the manuscript, which consuming his valuable time, and beyond this, his kind and understanding nature has been overwhelming. I would like to thank him for including me in his Staff Research Project. I also thank Dr. BASAVARAJ YENAGI, Agronomist, AICRP on Groundnut, University of Agricultural Sciences, Dharwad, who gave unflinching cooperation and timely suggestions throughout my course of investigation.

I remain ever thankful to all the Professors Dr. S. S. Patil, Dr. S. A. Desai, Dr. B. R. Patil and Dr. B. D Biradar of the Genetics and Plant Breeding, for their constant help and encouragement through out my study period.

There are no words to express my feelings of adoration, love, respect and obligation to my beloved parents, who moulded me to what I am now. They taught me to lead an obedient, trustworthy and well-planned life, which constantly guided me as a lighted lamp towards my destination. Without their mental support and encouragement, I would not have been able to overcome my hardships. My beloved father Shri. Shivappa T. K., mother Smt. Bhagyamma K., brothers Kishore and Prashanth, who always backed me throughout my life.

I extend my deep sense of gratitude to my friend Lalitha M. and my seniors Veeresh B., Deepa P., Guruprasad, Satish T. N., Supriya, for their valuable suggestions, moral support and needful help during my research work.

Friends are our biggest assets who make life colourful and cheerful. I fail in my duty if I do not express my warm thanks to my memorable friends. Their lively companionship and spontaneous help enabled me to complete this mammoth task. My stay in Dharwad recasts a pleasant memory and happy feeling only because of my affectionate and caring friends, Kiran, Anjangouda,, Hanamanth, Sunilkumar, Manjunath P, Kiran, Utpal, Vijaykumar, Freeman, Ismail, Shivaputra, Vishwanthareddy, Vinayak, Ravindra, Ashutosh, Aman, Lasya, Bhumika Priya, Shalini, Leelavati, Bhumika, Arpita, Akkamahadevi and Shweta, my junior Shivayya .

I am very thankful to non-teaching faculty Mr. F. Lobo, Mr. Mallikarjun, Department of Genetics and Plant Breeding, for their kind co-operation and help during the period of my research work.

I convey my whole hearted thanks to Mr. Arjun and Mr. Kalmesh (Arjun Computers), for their meticulous typing of the manuscript neatly, timely and more vitally their co-operation and affection towards me.

…Any omission in this brief acknowledgement does not mean lack of gratitude.

DHARWAD
AUGUST, 2016 **(MANJESH CHANDRA S.)**

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

1. INTRODUCTION

Castor is a member of the *Euphorbiaceae* family that is found across all the tropical and semi-tropical regions of the world (Weiss, 2000). It is one of the most important non-edible oilseed crops having chromosome number 2n=20 with cross pollination up to the extent of 50 per cent. Throughout the world Castor is grown in an area of 16.34 lakh hectares with the production and productivity of 15.20 lakh tonnes and 830 kg ha^{-1} of seed yield respectively (Anon., 2016a).

India ranks first both in area and production with 68 and 76 per cent, respectively in the world. In our country, castor is grown only in an area of 10.27 lakh ha with the production and productivity of 12.32 lakh tons and 1229 kg ha^{-1} of seeds respectively. Gujarat accounts for nearly 62.55 per cent of area (6.89 lakh ha) and 73.92 per cent of production (10.07 lakh tonnes) with an average yield of 1454 kg ha^{-1} in the country (Anon., 2016b). Gujarat, Rajasthan and Andhra Pradesh are the major castor growing states in the country. It is also grown in Chhattisgarh, Karnataka, Orissa, Tamil Nadu, Maharashtra, Assam, Bihar, Haryana, Madhya Pradesh and Jharkhand. In Karnataka, the crop is grown in an area of 20,000 hectares with the production of 18,000 tonnes and average yield of about 900 kg ha^{-1}.

It is one of the oldest cultivated crops but currently it represents only 0.15 % of the vegetable oil produced in the world. Castor oil is of continuing importance to the global specialty chemical industry, because it is the only commercial source of a hydroxylated fatty acid. Castor has tremendous future potential as an industrial oilseed crop because of its high seed oil content (more than 480 g kg^{-1}), unique fatty acid composition (900 g kg^{-1} of ricinoleic acid), potentially high oil yields (1,250–2,500 litre ha^{-1}), and ability to be grown under drought and saline conditions. The castor oil has pivotal usage in petrochemicals, pharmaceuticals, cosmetics, textile, soap, leather, paint, varnish, ink, nylon, and plastic industries. This oil is traditionally associated with medical and veterinary uses, for example in obstetrics and dermatology and also as purgative and laxative. Its current use as bio-fuel production has magnified its importance. Moreover, castor oil does not freeze at high altitude, because this particular property, it can be used in aeroplanes, helicopters and other vehicles operating at high altitudes or in low temperature zones. Further, it is the best lubricant for jet engines. The shell of castor bean is used in termite control in soil, and its seed cake can be used as manure (Maiti *et al.*, 1988 and Moshkin, 1986).

In recent years, a number of short to medium duration, input responsive, high yielding varieties, have been released in India. Of these, few are recommended for specific regions, like Aruna, Bhagya, Sowbhagya in Andhra Pradesh, RC 8 in Karnataka and TMV 5 in Tamil Nadu are important varieties. Unlike the traditional long duration castor varieties of about 8 months duration, the newly developed varieties produce as much as 80 per cent of their potential yields within 130-150 days.

In India, it was Gujarat, which concentrated on the development of hybrid castor in mid-sixties. To start with, TSP 10 R (Texas S - pistillate 10) released in 1962 in USA, formed the pistillate base. India is the first country in the world to exploit commercial cultivation of hybrid castor. The development of indigenous pistillate line VP-1 paved the way for producing commercial hybrids. Gujarat has released four hybrids for cultivation, of which GCH-4 was recommended for most parts of the country including Karnataka. Further, more number of hybrids and varieties suitable for specific environments are needed for cultivation in India especially for Karnataka in order to enhance the productivity level on par with the world average.

Although castor is a low input requiring crop and can be grown on marginal land, yet farmers are not inclined to grow it in many parts of the country due to lack of suitable and stable high yielding genotypes/varieties that may fit in country's cropping system. In India, this crop is largely grown under drought stress conditions with limited inputs, thereby causing agronomic problems in arid and semi arid regions. The growing condition under dry lands prevents it from reaching the genetically determined theoretical maximum yield.

The productivity of a population is the function of its adaptability and stability. Stability of a genotype depends on the ability to retain certain morphological and physiological characters steadily and allowing others to vary resulting in predictable G x E interactions for yield. A population that can adjust its genotypic and phenotypic state in response to environmental fluctuations in such a way to give high and stable yield is termed as 'Well buffered". The study of individual yield components can lead to simplification in genetic explanation and determination of environmental affects (Joshi *et al*., 2002b).

Successful castor (*Ricinus communis* L.) cropping in a location depends on the yielding ability and yield stability of the cultivars (hybrids or varieties) as well as the reliability of production systems (Koutroubas *et al*., 1999). Selection based on yield components is advantageous if different yield-related traits are well documented with respect to genetic behaviour (Johnson *et al*., 1955). Seed yield is a complex and multifaceted trait and represents the ultimate expression of different yield factors. Path coefficients can be used to assess the contribution of component traits towards seed yield, allowing the traits to be focused upon to be chosen.

Castor plays an important role in the national economy by earning foreign exchange of Rs. 3911 crores through export of castor oil (Anon., 2016a). The development and deployment of hybrids and varieties, adaptable to different agro-climatic situation is expected to increase productivity in India. Castor crop is more sensitive to environmental variations, particularly differences for fertility status of soil, temperature, photoperiod and relative humidity during growth period and moisture availability (Thakkar *et al*., 2010). The sensitivity of castor genotypes to environmental variations suggested the need of using array of environments instead of single environment to study the nature response and inheritance of components of adaption (Solanki and Joshi, 2000; Patel *et al*., 2010a). Limited attempts were made to identify genotypes that perform well under rainfed conditions, since it is considered as a drought tolerant crop (Radhamani *et al*., 2014)

Considering the drought resistant nature of this crop, there is every need to identify promising castor varieties and hybrids with early maturity and high yield potential suited to the northern transition zone conditions of Karnataka, not only to stabilize agricultural production of the region, but also to support the oil seed processing industry which is facing a crisis due to lack of adequate raw material.

In view of this 8 hybrids and 6 varieties were chosen to study their response for seed yield and other component characters over three environments of northern transition zone for two seasons with the following objectives:

1. To identify stable genotypes over environments for growth parameters, yield and yield parameters.
2. To study the association pattern between seed yield and its component traits under different locations.
3. To assess the variations in morpho-physiological structures and their relationship with productivity in castor genotypes.

2. REVIEW OF LITERATURE

Description of the nature and amount of variation and the contribution of the different yield and quality attributing characters of the breeding material to the final economic product is a road map for any successful crop improvement programme. Improvement of both quantitative and qualitative characters is the main interest of any plant breeder for which an adequate knowledge on genetics of yield and its component characters is very much essential and also crop varieties show wide fluctuations in their yielding ability when grown over varied environments or agro-climatic zones. This causes difficulty in demonstrating the superiority of particular variety. Besides yield potential, yield stability over a range of environment is of major concern to the plant breeders and this has direct bearing on the spread of the variety, productivity and total production of the crop. Each genotype has a specific environment for its maximum performance and similarly in a specific environment, a specific genotype performs better.

Keeping in view the objectives of the present investigation, the literature on variability, character association and stability analysis of castor genotypes has been reviewed and presented under following headings:

2.1 Genetic variability parameters
2.2 Correlation and path coefficient analysis
2.3 G × E interaction and Stability analysis in castor (*Ricinus communis* L.)

2.1 Genetic variability parameters

Phenotypic variability expressed by a genotype or a group of genotypes in any species can be partitioned into genotypic and phenotypic components. The genotypic components being the heritable part of the total variability, its magnitude on yield and its component character influences the selecting strategies to be adopted by the breeder.

Fisher (1918) partitioned the total genetic variance (σ^2_g) (i) additive genetic variance (σ^2_a), which is the sum of additive genetic variances contributed by individual loci (ii) Dominance variance (σ^2_d) component which results from intra allelic interaction of genes at segregating loci (iii) Epistatic variance (σ^2_i) results from inter allelic interaction of genes at segregating loci.

Lush (1940) defined heritability in both broad sense and narrow sense. In broad sense, heritability refers to the functioning of the whole genotype as a unit and is used in contrast with the environmental effects. In the narrow sense, heritability largely includes only the average effect of genes transmitted additively from parent to off spring. Warner (1952) has suggested different technique for estimating the degree of heritability in crop plant which is based on parent offspring regression variance component from an analysis of variance and approximation of non-heritable variance from genetically uniform population to estimate the total genetic variance.

Comstock (1955) reported that phenotype associated with a given genotype varies with the environment. This leads to complete inconsistency of genotypic value, a different value of a given genotype relative to every variance of environment major or minor. Lonquist (1964) reported that phenotype of a quantitative character was mainly due to the joint action of genotype and environment.

Golakia *et al*. (2007) noted that a high estimate of phenotypic coefficient of variation (PCV) was observed for seed yield per plant, effective seed branches per plant and number of capsules on main raceme. While genotypic coefficient of variation (GCV) was higher for effective branches per plant, seed yield per plant and number of capsules on main raceme, suggestion the potential variability available for these characters. The characters *viz*., days to maturity of main raceme, number of nodes up to main raceme, days to flowering of main raceme, 100-seed weight and in the present investigation plant height showed high heritability indicating low environmental effect to subsequent generation, genetic advance as percentage of mean ranged from moderates (17.17 %) for days to maturity of main raceme to high (47.00 %) for seed yield per plant.

According to Ghulam *et al*. (2010) plant height showed high heritability (bs) (54 %) along with high genetic advance (19.87) seemed to be governed by additive genes while days to mature exhibited high heritability (45.10 %) with low genetic advance (6.61) governed by non-additive type of genes (dominant, epistasis or their interaction).

Patel *et al*. (2010b) conducted experiment to evaluate 41 castor genotypes for assessment of genetic variability of 9 characters. The GCV and PCV were of high magnitude for the character number of capsules on primary raceme followed by plant height, seed yield per plant and number of effective branches per plant. The magnitude of PCV was higher than GCV for all the characters, suggesting the role of environmental variance. High genetic variability coupled with high heritability and high genetic advance was recorded for plant height, number of capsules on primary raceme, number of effective branches per plant and seed yield per plant indicating that direct selection for these traits could be effective.

Shaik and Jabeen (2011) concluded that analysis of variance revealed significant differences among the genotypes for all the characters studied indicating that the data generated from the above diverse material representing wide variability. The genotypic coefficients of variation for all the characters studied were lesser than the phenotypic coefficients of variation indicating the modifying effect of the environment in association with the characters at genotypic level. High PCV coupled with high GCV observed for plant height, number of spikes per plant, effective spike length, number of capsules per plant. Seed yield per plant indicate the presence of wider variability for these traits in the population studied. High heritability coupled with high genetic advance as per cent of mean was observed for all the traits except for days to maturity indicates preponderance of additive gene action in the inheritance of these traits and improvement in these characters is possible through simple selection.

The result of variance analysis by Abimiku *et al*. (2012) revealed that large phenotypic variation and phenotypic coefficient variation estimates in the two locations were observed in 9 characters *viz*., plant height, leaf area, panicle length per plant, days to 50 per cent flowering, days to 50 per cent maturity, capsule per plant, 100 seed weight, seed yield per plant and seed yield/hectare. The estimate of broad sense heritability ranged from 48-92 per cent for seed yield. The number of capsule per plant, 100 seed weight, seed yield/plant and seed yield/hectare had high genetic component as shown by GCV of 73.08, 78.25, 82.59 and 58.78, respectively, while seed yield/hectare had highest heritability valve of 92.0 per cent. These characters also had high values of genetic advance (GA).

Hafiz *et al.* (2012) studied nineteen mutant lines in M_4 and M_5 generations for their variability and both M_4 and M5 mutant lines exhibited higher variances both phenotypic and genotypic with respect to all the morphological traits. Number of capsules of main spike, main spike length and number of spikes per plant showed high heritability coupled with high genetic advance which revealed the preponderance of additive genes and seed yield could be improved via these traits.

Goodarzi *et al.* (2012) found that accessions showed high coefficient of variation for hollow seed number on primary raceme, secondary and tertiary branch fresh weight, secondary and tertiary branch dry weight, lamina leaf length and leaf length traits. Principal component analysis (PCA) revealed that the principal components (PC) accounted for 93 per cent of the total variation.

Thirty castor accessions were evaluated by Halilu *et al.* (2013) and Aanalysis of the data showed that the GCV was low for all the yield components but moderate for yield. The PCV was also low for peduncle length, number of nodes to the first raceme and height, while it was moderate for number of capsules in the first raceme, number of secondary branching, number of spikes/plant and yield. Amongst the yield components height at harvest had the highest difference between GCV and PCV (RD=71.4 %) while all the others were also high except number of spikes/plant (RD=36 %).These indicate that the observed variations for the traits were mostly due to environment factors. Moderate broad sense heritability coupled with moderate Genetic gain (GA) observed for number of secondary branching, number of spikes/plant and yield indicating that these traits are mainly controlled by additive type of genes and that direct selection for these traits could be effective. However, moderate heritability coupled with low GA was observed for peduncle length. Thus this character is controlled by non-additive genes (dominance and epistasis). Low heritability with low GA observed in height and number of nodes to the first raceme indicates environmental control on the expression of these traits.

Nalini Tewari and Yadavendrakumar (2013) observed that the analysis of variance revealed highly significant differences among the genotypes for all the characters studied. The highest genotypic coefficient of variation (GCV) and phenotypic coefficient variation (PCV) were observed for seed yield plant^{-1}, plant height and number of effective spikes plant^{-1}. High heritability with high genetic advance was recorded in number of capsules in primary raceme, plant height and seed yield plant^{-1} indicating the predominance of additive gene action.

Udaya *et al.* (2013) reported that all the characters exhibited significant variability. Phenotypic Coefficient of Variation (PCV) was higher than Genotypic Coefficient of Variation (GCV) for all the characters studied indicating the role of environmental variance in the total variance. Heritability estimates were found to be high for all the characters. High heritability coupled with high genetic advance as per cent mean was observed for all traits except oil content and L/B ratio of seed indicating that most likely the heritability is due to additive gene effects and direct selection of these traits were effective.

According to Lakshmamma *et al.* (2014) the coefficient of variation (CV), both genotypic and phenotypic indicated that there were significant differences among the genotypes for all the characters studied while the phenotypic coefficient of variation (PCV) is higher than genotypic coefficient of variation (GCV) for all the characters indicating the influence of environment. The CV is especially high for the characters like plant height, root volume, root fresh weight, root dry weight, TDM and LAI. Heritability was maximum for root volume and minimum for root length. Majority of the traits *viz.,* plant height and node number up to primary spike, fresh and dry weight of root and shoot, TDM and LAI recorded high heritability (>80).The genetic advance expected in the next generation was higher in root volume and LAI suggesting the role of dominance variance and Low genetic advance in the next generation for the traits like stem girth and root length indicate the role of additive variance.

Destaw (2014) identified that analysis of variance revealed the existence of highly significant difference among the forty eight accessions for most of the characters studied. For all traits, phenotypic coefficient of variation was higher than genotypic coefficient of variation this indicating that there was environmental influence on these traits. High heritability with moderate genetic advance was estimated for days to 50 per cent second maturity. Moderate heritability values with relatively higher genetic advance as per cent of mean were observed for days to 50 per cent first flowering, days to 50 per cent second flowering and hundred seed weight.

Combined analysis of variance carried out by Getinet *et al*. (2014) over locations revealed the existence of significant variation among accession in all the traits considered in study. The interaction between accessions and environment was significant for eight of the 12 traits studied. Estimates of genetic variance ranged from 0.2 for number of branches/plant to 2394.9 for number of seeds/plant. The range of phenotypic variance was 0.4 for number of branches/plant and 4891.5 for number seeds/plant. Compared with environmental variance, genetic variance was larger for days to first flowering, days to second flowering, days to first maturity, days to second maturity, number of nodes/plant, plant height and 100 seed weight. Therefore, the higher proportion of phenotypic variance observed on these traits was due to the larger proportion of genotypic variance. Overall highest value of heritability, genetic coefficient of variability and genetic advance as per cent of the mean was recorded for number of nodes/plant, number of capsules/plant and 100 seed weight.

Radhamani *et al*. (2014) opined that phenotypic and genotypic variances were observed for plant height up to primary spike and single plant yield (g), while minimum variances were shown by number of capsules in primary. Number of capsules in primary spike, plant height up to primary spike and single plant yield exhibited high PCV and GCV estimates, while oil content, chlorophyll stability index and relative water content had lower PCV and GCV estimates. Little difference between PCV and GCV for all the traits indicated that the least role played by environment on these characters.

Forty-two castor accessions were evaluated by Gila and Manga (2015) and identified that variations existed from the primary to the tertiary panicles in yield components per panicle types of the germplasm. There were sequential percentage decreases in number of capsules, 100-seed weight and seed yield per panicle types from primary to penterinary panicles. Over 85 per cent of the seed yield components each were captured from primary to quarternary panicles.

Goodarzi *et al*. (2015) found that the analysis of variances revealed significant differences among 12 castor bean accessions for majority of studied traits. Results pertaining to mean comparison showed that there was a great and significant variability in female flower length, main stem fresh weight, main stem dry weight, secondary and tertiary racemes weight, 10 seed weight on primary raceme, seed number on primary raceme, lamina leaf dry weight and oil content of seed.

Sowmya *et al.* (2015) determined that the variability for genotypes was significant for seed yield and yield components such as effective spike length, number of spikes, capsule number, capsule weight and total seed number.

Torres *et al.* (2015) revealed the experimental coefficient of variation (CVE) ranged between 7.7 (oil content) and 25.0 (number of fruits) and the genotypic coefficient of variation (CV_g) varied between 0.4 (oil content) and 35.4 (mass of hundred seeds), which indicates that among the descriptors evaluated mass of hundred seeds and number of fruits are the ones who show greater variability. The descriptors plant height, stem diameter, number of bunches, number of fruits and mass of hundred seeds showed heritability (h^2) greater than 60 %, indicating that it less influenced by the environment and the low h^2 of mass of fruits descriptor indicating that these descriptors are highly influenced by the environment.

2.2 Correlation and path coefficient analysis

The inter relationship of quantitative characters with yield determine the efficiency of detection in breeding programs. It merely indicates the intensity of association. Phenotypic correlation reflects the observed relationship, while genotypic correlation underline the true relationship among characters. Selection procedures could be varied depending on the relative contribution of each. The following paragraphs give review of literature on correlation and path analysis in castor.

Assuming yield is a contribution of several characters which are correlated among themselves and to the yield, path coefficient analysis was developed (Wright, 1921; Dewey and Lu, 1959). Unlike the correlation coefficient which measures the extent of relationship, path coefficient measures, the magnitude of direct and indirect contribution of a component character to a complex character and it has been defined as a standardized regression coefficient which splits the correlation coefficient into direct and indirect effects.

Kulmi and Soni (1995) reported that bean yield of castor was positively correlated with branches/plant (r= 0.8794), spikes per plant (r =0.8022), capsules/plant (r = 0.6609), yield index (r=0.9999) and harvest index (r = 0.8270) but negatively correlated with plant height (r = -0.8693) and days to maturity (r =-0.8424). Days to maturity was positively correlated with days to 50 % flowering and plant height, but negatively correlated with harvest index.

Correlation and path coefficients were studied by Thatikunta *et al.* (2001) for eight characters in 64 F_1 s of castor and the character association studies indicated that plant height up to primary spike and effective length of primary spike were strongly associated with seed yield. Path coefficient analysis revealed that plant height up to primary spike had high direct effect on yield.

Golakia *et al.* (2007) found that the genotypic correlations were higher than phenotypic correlations. The total length on main raceme, effective length on main raceme and number of capsule on main raceme were significantly and positively associated with seed yield per plant and also among each other at both phenotypic and genotypic levels, indicating that selection for these characters would definitely lead to yield improvement. Effective length of main raceme and effective branches per plant had significant but negative correlation at genotype level with days to flowering and maturity of main raceme. The path coefficient analysis revealed that total length of main raceme had the highest positive direct effect followed by days to flowering of main raceme. Whereas, highest negative direct effect was expressed by effective length of main raceme followed by days to maturity of main raceme.

Adeyanju *et al*. (2010) studied the relationship between castor oil yield and seven agronomic characters in 28 selected castor genotypes. Results indicated that the genotypic correlations generally showed more significant differences between the pairs of characters than the phenotypic correlations. 100 - Seed weight showed significant positive genotypic and phenotypic correlations with oil yield per plant. The path analysis also revealed that 100 - seed weight had a positive highly significant correlation with as well as a high direct effect on oil yield per plant. Apart from this, 100 - seed weight also influenced the effects of other characters indirectly on their effects on oil yield per plant thus suggesting that 100 - seed weight is undoubtedly the most reliable character to select for in castor oil yield improvement to improve oil yield of castor populations.

Dhedhi *et al*. (2010) evaluated twenty nine genotypes to study the correlation and path co-efficient analysis for ten quantitative characters in castor (*Ricinus communis* L.) under irrigated conditions during *Kharif* seasons of 2007-08 and 2008-09 and correlation studies revealed that seed yield was positive and significantly genotypic as well as phenotypic associated with leaf length, capsule length, length of primary spike and 100-seed weight. Path co-efficient analysis showed that leaf length, length of primary spike, number of nodes and days to 50 per cent flowering were the most important characters manifesting large direct effects on seed yield per plant. It is, therefore, suggested that simultaneous selection for length of primary spike and leaf length would result in improvement of seed yield by phenotypic selection in castor.

Ghulam *et al*. (2010) estimated the different genetic parameters along with correlation coefficient. Path and cluster analysis were done in castor bean mutants on quantitative traits and results showed positive and significant genotypic correlation of main spike length, capsules of main spike, capsules of secondary spike and spikes per plant with seed yield. These traits along with branches per plant also showed positive but non-significant phenotypic correlation with seed yield. Days to mature, number of branches and capsules of main spike showed positive direct effects coupled with positive genotypic correlation with seed yield.

Patel *et al*. (2010b) conducted experiment to evaluate 41 castor genotypes for assessment of correlation in respect of 9 characters. Seed yield per plant showed highly significant and positive correlation with plant height, length of primary raceme, number of capsules on primary raceme and number of effective branches per plant.

Correlation studies conducted by Shaik and Jabeen (2011) indicated that number of spikes per plant, effective spike length, number of capsules per plant, 100 seed weight and oil content had significant positive association with seed yield per plant hence simultaneous improvement of these characters along with seed yield is possible. The path analysis indicated that capsules per plant had direct positive effect on seed yield. Direct selection through this trait for improvement of seed yield is highly effective. In case of number of spikes per plant and 100 seed weight though the associations are positive and significant, direct effects are low indirect effects through effective spike length, number of capsules per plant and plant height are to be considered to bring about improvement in seed yield.

The results of correlation analysis by Abimiku *et al.* (2012) revealed that Panicle/plant, Capsule/plant, Panicle length and Branches had negative and significant correlation with seed yield. Plant height had significant positive correlation value of 0.52 having branches per plant more at the main stem shown by a highly significant correlation value “r” = 0.88 of nodes to primary panicle (NPP) on the main stem.

Hafiz *et al.* (2012) conducted experiment on nineteen mutant lines in M_4 and M_5 generations to study the interdependence of morphological traits. During M_4 generation, capsule yield and number of spikes per plant showed significant and positive correlation with seed yield (0.4555). While during 2007, capsule yield exhibited positive and highly significant correlation with seed yield (0.8131) and number of spikes per plant also showed significant and positive correlation with seed yield (0.486).

Goodarzi *et al.* (2012) found that among the studied traits, seed number on primary raceme as a yield component in castor bean showed positive correlation with the first component (PC1). Hollow seed number on primary raceme showed positive correlation with the second component (PC2). Oil per cent presented negative correlation with PC2.

Nalini Tewari and Yadavendrakumar (2013) observed that the phenotypic and genotypic correlations were on par with each other suggesting the negligible role of environment on the genotypic expression. It was observed that number of capsules in primary raceme (0.74) and number of effective spikes plant^{-1} (0.56) showed highly significant and positive genotypic association with seed yield plant^{-1}. Seed yield plant^{-1} had significant and negative association with oil content (-2.18), volume weight (-2.06), days to maturity (-1.14), number of nodes to primary raceme (-0.79), days to 50 % flowering (-0.64) and 100 seed weight (-0.42).

Destaw (2014) identified that seed yield had positive and significant phenotypic and genotypic association with number of capsules per plant (CP), number of seeds per plant (SP), number of primary branches per plant (PB), number of secondary branches per plant (SB), length of inter node (LIN) and number of inflorescence per plant (IP). Oil content (OC) had positive and significant genotypic correlation with seed yield. Phenotypic and genotypic path analysis showed that number of capsules per plant, number of secondary branches per plant, length of inter node, days to 50 per cent second flowering and seed yield exhibited positive direct effect on oil content.

Msaakpa and Obasi (2014) conducted experiment in two cropping seasons and revealed that number of leaves, length of internodes, leaf area index, absolute growth rate and plant height were correlated positively and significantly with yield characters. Net assimilation rate was positively correlated with yield characters except capsules per panicle, dry weight of harvestable material, harvest index and 100 seed weight. Each growth character that correlated positively and significantly with a yield character indicates that it is an important determiner of that yield character.

Gila and Manga (2015) reported from stepwise regression analysis that secondary panicle alone fitted into the yield equation contributed 57.6 per cent of the total seed yield. While primary to quarternary panicles yielded 88.4 per cent of the total seed yield. This implies that research, in this indeterminate crop, could be terminated after the harvest of the quarternary panicles without distorting the yield trends of the crop.

Goodarzi *et al.* (2015) revealed that total seed primary raceme weight had an intermediate positive correlation with majority of studied traits. This trait was positively and significantly correlated with seed number on primary raceme (r=88). Also, this trait exhibited significant positive correlation with female flower length, primary raceme length and main stem diameter. There was non-significant negative correlation between total seed primary raceme weight trait with male flower length and oil content. Path coefficient analysis, showed the positive direct effect of predictable variables including main stem fresh weight (0.2), 10 seed weight on primary raceme (0.36), seed number on primary raceme (0.82) and hollow seed number on primary raceme (0.15) on total seed weight on primary raceme as responsible variable.

Shah *et al.* (2015) studied thirteen inbred lines and identified that one hundred seed weight showed a positive correlation with per cent of kernel (r=0.472), kernel oil content is significantly positively correlated with seed oil content (r=0.803) and the seed coat had highly significant negative correlation with kernel per cent (r=-1.000).

Sowmya *et al.* (2015) studied that seed yield was positively and significantly correlated with number of spikes per plant (0.622,), ESL (0.609), capsule number (0.899) and capsule weight (0.965) and seed number (0.914) in castor. Hence, all these traits may be directly attributed for the improvement of seed yield and important in the selection of better genotypes in castor.

Torres *et al.* (2015) found significant phenotypic correlations (r_p) ($p<0.05$) between descriptors plant height x stem diameter, plant height x oil content, plant height x mass of hundred seeds, stem diameter x oil content, stem diameter x mass of hundred seeds, oil content x mass of hundred seeds and number of fruits x mass of hundred seeds. Analyzing only the direct effects, there was a positive influence of descriptors plant height, stem diameter, number of bunches and mass of hundred seeds on the variable oil content. By analyzing the indirect effects, an association of the very same descriptors was found, in other words, their selection can influence directly or indirectly the increase in OC.

Dapke *et al.* (2016) revealed that seed yield was positive and significantly genotypic as well as phenotypic associated with plant height up to primary spike, total length of primary spike, length of capsule bearing region of primary spike, number of effective branches per plant, number of capsules on primary spike and oil content. Path coefficient analysis showed that number of capsules on primary spike, number of effective branches per plant and oil content were the most important characters manifesting large direct effects on seed yield per plant.

2.3 Studies on stability analysis in castor

A genotype is known to be stable if it performs well under a wide range of environments. The genetic effects are dependent on environmental effects. The deviation of a genotype from expressing the same phenotypic performance when grown under different environments is reflected by genotype x environment interaction. Castor is well known for its hardiness and thrives well under rain fed conditions. Fluctuation in rainfall affects yield. Therefore yield stability becomes a factor of prime importance. A precise knowledge of the nature and magnitude of genotype x environment interaction is very important in understanding the stability in yield of a particular variety before it is recommended for general cultivation. Genotype x environment interaction is of major importance to plant breeders in developing improved varieties. In the past, few experimental results have been reported in castor on the performance of a number of genotypes at different locations or in different years or at a range of locations over a period of years. Such of these studies in castor are briefly reviewed herein.

2.3.1 Genotype x Environment interaction and Stability of genotypes

A phenotype is the result of interplay of a genotype and its environment. A specified genotype doesn't exhibit the same phenotypic characteristics under all environments and different genotypes respond differently to a specified environment. This variation arising from the lack of correspondence between the genetic and non-genetic effects is known as the genotype x environment interactions.

Based on the study conducted under different conditions Gopani *et al.* (1972) stated that variety x locality interactions were significant for 100 seed weight, bean number on the main spike, weight of one litre of seeds and number of plants having 100 % pistillate flowers. Moshkin and Sachli (1972) classified 16 characters into four groups, and reported that fluctuation in the magnitude of co-efficient of variation from year to year were non-significant.

In a 4 x 4 diallel analysis, Ramaswamy and Madhav (1973) reported that out of the six traits considered, capsule number was found to be highly influenced by environment. Annappan (1981) evaluated the performance of the parents and the hybrids, obtained in a Line x Tester cross in four environment and reported that the effect of environment was reflected on characters like flowering duration, number of racemes per plant. Further he has observed that the differences between the parents, which were significant in one environment, were not significant in another environment.

Hirasingh and Yadava (1982) evaluated six hybrids of castor at 6 locations representing various agro climate conditions. They observed that the hybrids performed differently in different environments indicating genotype x environment interaction.

Evaluation of some varieties and hybrids of castor by Prasad and Francisco (1984) indicated that the early maturing varieties NPH 1, VI-9, RC-11, R-53 and JI44 were superior in yield to the long duration check varieties such as Campinas, Amarela and Sipeal-1. The variety NPH 1 was found to be superior in yield to the best hybrid of F-B x R-53, while the rest four were comparable to the productive hybrids.

A significant genotype x environment interaction indicated the differential response of genotypes was reported by Henry and Daulbey (1985). A major portion of the interaction was accounted for by the presence of linear component, although non-linear component was also significant.

Lauret (1988) studied the genotype-environment interaction for four genotypes at nine locations and observed significant differences between cultivars as well as between location for seed yields, 1000 seed weight, raceme number per plant and plant height.

Forty diverse genotypes were assessed by Patel and Jaimini (1988) for various quantitative characters under irrigated and rain fed conditions. They reported wide phenotypic variability and significant varietal differences for all the traits, indicating considerable variability under irrigated as well as rainfed conditions.

Phenotypic stability was studied by Mandal and Dana (1994) in 15 genotypes. The yield data indicated that the genotypes recorded best performance during 1989-90 seasons. Aruna and HC-8 showed high stability across the environments and produced average yields of 979 and 924 kg per ha, respectively.

Lauret (1995) reported genotype and genotype x environment interaction in 23 genotypes. Among the cultivars significant differences were observed for yield, 1000 seed weight, number of racemes per plant, plant height and flowering. Genotypes x environment interactions were always significant indicating that each trait was very variable across environments. However, genotype variance for each trait was consistently higher than those for genotype x year or genotype x irrigation interaction.

An experiment was conducted by Raghuram Reddy *et al.* (1999) during rainy season with 9 genotypes of castor *(Ricinus communis* L.) and found that reduction under rainfed conditions was higher for stem height, diameter and internode length than under irrigated conditions in early genotypes. The reduction was much higher for medium and late duration genotypes. Node number remained unchanged under both the situations. Under late-seeded conditions increase in stem height but decrease in diameter was observed. The study indicated that different varieties gave high yield through different yield components; though capsule number, capsule weight and seed number were the major components under both irrigated and rainfed situations. A total yield reduction of 49 per cent was observed while oil content was least influenced by the stress conditions.

Koutroubas *et al*. (1999) conducted an experiment to study adaptation and yield stability of the cultivars which includes 19 modern castor oil genotypes and in which genotypes combining high seed and oil yield and desirable morphological characteristics were tested for 2 or 3 years, whereas the rest were tested for 1 year only and found that the plant height was dependent mainly on the genotypes but also was affected by the site and the year of the experimentation and seed yield was highest in the site where plants produced more secondary racemes. The seed oil content was dependent mainly on the genotype and variation in seed yield between years was low and in most genotypes less than 20 per cent. Results indicate that the castor oil crop was satisfactorily adapted in the area.

Solanki and Joshi (2001) analysed the variance and revealed significant mean sum of squares due to genotypes and its subdivisions (parents. hybrids and parents vs hybrids) for oil content. It indicated the presence of sufficient variability in material under experimentation. Highly significant variance due to environment for this trait indicated differences in the environments created for study. Significant genotype x environment interaction revealed that expression of different genotypes was influenced by the environments. Further partitioning of G x E interaction into parents x environments; hybrids x environments showed higher magnitude of hybrid x environments interaction.

A set of 112 crosses of castor were studied by Joshi *et al*. (2002a) under four artificially created environments to characterize stability for yield and its contributing components. Both linear and non-linear components of G x E interaction were found to be significant for all the traits (except days to flowering and days to maturity) revealing difficulty in prediction of performance of the characters studied in varied environments. The crosses SKP 25 x T 4, SKP 25 x EC 97700, SKP 93 x JI 77, VP 1 x Aruna and SKP 25 x RC 8 showed high seed yield/plant with unit regression coefficients and non-significant deviation from regression indicating stable performance of these crosses in varying environments. Number of effective branches/plant, number of capsules/plant and 100-seed weight were the major components of seed yield varied in compensatory fashion to impart homeostasis to seed yield/plant.

According to Sarada *et al*. (2012) the results of the study to explore the effect of genotype (G) and Genotype x Environment (G x E) on seed yield of nine castor genotypes tested in four locations utilizing GGE Bi-plot method indicated that Environment (E) explained 65.41 per cent variation and Genotypes (G) explained 11.23 per cent and GE interaction captured 20.34 per cent of the total (G + E + GE) variation. The polygon view of the bi-plot indicates the interaction pattern between genotypes and environment and it indicated that the performance of PCH-111 was similar in all the locations except Yethapur. High correlation has been observed among HCH-6, ANDCI-8 and local check indicating that the response is similar in an environment. The experimental results for the year 2011 - 12 shows that PCH-111 is promising stable genotype followed by HCH-6 and ANDCI-8.

Five castor genotypes were tested for agronomic performance in 12 diverse environments by Travis and Dick (2014). The results indicated that castor was well adapted to several diverse environments and appears to be adapted to areas with shorter growing season where it produced good seed and oil yields. Analysis of variance and F-tests of genotypes, environments, and the genotype by environment showed that they were highly significant ($p = 0.001$) between all three factors for all indices except for seed yield and oil yield. Most of the genotype by environment interaction seems to be due to the superior performance of castor in the five test environments of latitudes north of 40°. The southern environments (< 40° N) produced seeds with higher oil content and had higher harvest indices than the more northern environments. However the northern environments produced almost double the seed yield of the southern environments resulting in more kilograms of oil per hectare.

Onkarappa *et al*. (2014) evaluated 15 castor hybrids and revealed that analysis of variance for stability indicated highly significant differences among the hybrids for all the characters. Significant mean squares due to genotypes × environment for plant height and seed yield suggested differential behaviour of the hybrids across the locations for these two characters. It was observed that none of the test hybrids were found to be stable for all the characters. Nevertheless the hybrid TH-2 was identified as highly stable for days to 50 per cent flowering, number of spikes, effective spike length, number of capsules and seed yield and the hybrid TH-7 was also found stable for plant height, effective spike length, seed yield, 100 seed weight and oil content.

An experiment conducted by Anastasi *et al*. (2015) with the aim of assessing plant surviving, seed yield and oil quality of four castor genotypes originating from different geographical areas and revealed that favourable climatic conditions allowed the plant to survive during the fall-winter period. Seed yield reached an average 3.45 t ha^{-1} for two years and seed oil content ranged from 45 per cent to 48 per cent.

A study was conducted by Patel and Patel (2015a) to assess the existence of genotype x environmental (G X E) interactions and stability for sex related traits in castor in three environments over three locations. Pooled Analysis of variance over three environments revealed the genotypic variances were highly significant for all the sex related characters which indicated considerable genetic variability in the population. Stability parameters for sex expression revealed that for per cent pistillate whorls on primary raceme the genotypes VP 1, JP 65, SKP 84 and JI 35 were found better under poor environments. The female parents VP 1, JP 65 and SKP 84 showed stable and consistent performance in all order of spikes, whereas, the male parent 48-1 had above average response and high stability in better environments for per cent pistillate whorls on secondary raceme only. Stability parameters analysis for seed yield per plant revealed that thirteen genotypes (GAUCH 1, GCH 2, GCH 4, GCH 6, GCH 7, VP 1, Geeta, JI 65, SKP 84, JI 35, 48-1, SH 72 and JI 96) showed non-significant deviation from regression. For regression coefficient, ten genotypes showed non-significant unity for regression.

According to Patel and Patel (2015b) the mean squares due to G x E interactions were significant for days to maturity, total length of primary raceme, number of nodes up to primary raceme, number of capsules on primary raceme and seed yield per plant which indicate differential response of genotypes in varying environments for these traits. The mean sum of square due to environment and environment (linear) was found highly significant for all the characters. Among castor promising genotypes that identified superior performance, genotypes GCH 4, GCH 6, GCH 7 and parental lines *viz.*, Geeta, 48-1 and VP 1 were stable for two or more stability parameters and combination with high seed yield potential.

3. MATERIAL AND METHODS

In any crop to assess or to evaluate genotypes a systematic approach is must. As our main aim is to assess the stability of genotypes over the locations certain procedure is necessary. Therefore, the details of materials used and methods followed in carrying out the present investigation are presented in this chapter.

3.1 Experimental details

3.1.1 Material

The material for present investigation included promising and high yielding castor genotypes comprising 8 hybrids and 6 varieties which were collected from different parts of the country like, Junagadh Agricultural University, Junagadh, Gujarath; Sardar Krishinagar Agricultural University, Sardarkrishinagar, Gujarath; Indian Institute of Oil Seed Research, Rajendranagar, A.P; Agricultural Research Station, Mandor, Rajasthan and Regional Agriculural Research Station, Palem, A.P. The hybrids *viz.,* GCH-5, GCH- 6, GCH-7, DCH-177, DCH-519, RHC-1 & PCH-111 and varieties *viz.,* DCS-107, PCS-4, PCS-136, PCS-262 & GC-3 were utilized for stability analysis with respect to various characters in selected locations and over the seasons using checks GCH-4 and 48-1 respectively. The salient features of castor hybrids and varieties have been presented in the Table 1.

3.1.2 Geographical location and weather conditions

The experiment was conducted for two seasons during *kharif*-2014 and *kharif*-2015 at 3 locations *viz.,*

1. NSP/BSP, Seed Unit, MARS, University of Agricultural Science, Dharwad, Karnataka. Geographically Dharwad comes under Northern Transition Zone-8 of Karnataka and situated at 15° 25' N latitude and 70° 25'E longitude at a altitude of 678 m above mean sea level.
2. Agricultural Research Station, Hanumanamatti, Ranebennur Taluk, Haveri District, Karnataka which are located at Latitude 14^0 40' 06.12'' N and Longitude 75^0 34' 22.00'' E, which falls under the Northern Transition Zone-8 of Karnataka.
3. Horticultural Research and Extension Station, Devihosur, Haveri District, Karnataka state. Experimental plots were situated in Northern Transitional Region (Zone-8) of Karnataka between 14 ^{0}47' N latitude, 75 ^{0}21' E longitude and 563.0 m altitude.

3.1.3 Experimental layout

The experiment was laid out using RCBD in replicated trial with row length of 6 m with inter and intra row spacing of 90 cm and 60 cm respectively. Experiment consists of 3 replications and each replication includes 14 plots with 6 rows in each plot.

3.1.4 Crop management

Crop was sown between 2nd second fortnight July and 1st fortnight of August during both the cropping seasons. Recommended package of practices was adopted to raise a healthy crop. The field was uniformly fertilized at the rate of 40 kg N, 20 kg P_2O_5 and 20 kg K_2O per hectare. A spacing of 90 cm x 60 cm was maintained in all the experiments. The crop was completely raised under rainfed conditions and only life saving irrigations was given at requirements.

Table 1. Details of castor hybrids and varieties

a) Hybrids

Sl. No.	Hybrids	Pedigree	Year of release	Centre of release	Area recommended	Salient features
1	GHC-4	VP-1 X 48-1	1986	JAU, SK Nagar	Gujarat	Tolerant to wilt and root rot
2	GCH-5	Geetha X SH-72	1995	JAU, SK Nagar	Recommended to all India irrigated areas	Resistant to *Fusarium*wilt
3	GCH-6	JP-65 X JI-96	1999	JAU, SK Nagar	Recommended for irrigated areas of Gujarat, Rajasthan and Maharashtra	Bold seeded and high oil content
4	GCH-7	SKP-84 X SKI-215	2007	JAU, SK Nagar	Irrigated areas of Gujarat	wilt – nematodes complex resistant hybrid
5	DCH-177	DPC-9 X DCS-9	2000	IIOR, HYDERABAD	Rainfed areas of Deccan plateau and irrigated areas of Maharashtra	Resistant to *Fusarium*wilt, whitefly
6	DCH-519	M-574 X DCS-78	2006	IIOR, HYDERABAD	Irrigated and rainfed areas of Rajasthan	Resistant to *Fusarium* wilt, leaf hoppers
7	RHC-1	VP-1 X TMV 5-1	2002	Rajasthan	All India irrigated areas	-
8	PCH-111	DCPC-9 X CS-9	1999	ANGRAU, Palem	Recommended for rainfed areas of Andra Pradesh	Resistant to wilt

b) Varieties

Sl. No.	Varieties	Year of release	Centre of release	Area recommended	Salient features
1	DCS-107	2010	IIOR, Hyderabad	Identified for both rainfed and irrigated areas of the country,	Resistant to wilt
2	PCS-4	1999	ANGRAU, Palem	Released for Andra Pradesh	Tolerant to wilt
3	PCS-136	2002	ANGRAU, Palem	Released for Andra Pradesh	Tolerant to *Botrytis*
4	PCS-262	2015	ANGRAU, Palem	Released for Andra Pradesh	Resistant to wilt
5	48-1	2007	IIOR, Hyderabad	All castor growing areas under both rainfed and irrigated	Resistant to wilt and drought, Resistant to *Fusarium* wilt; tolerant to *Botrytis*, salinity
6	GC-3	2009	JAU, Junagadh	Irrigated areas of Gujarat	Resistant to wilt

Necessary prophylactic measures were taken up to safeguard the crop from pests and diseases. The seeds were treated with 3 g Thiram or captan/kg seed to control seedling blight, alternaria leaf spot and Fusarium wilt. Incidence of pests like semilooper, *spodoptera*, shoot and capsule borer were found. Collection and destruction of larvae and spraying of monocrotophos (2.0 ml/l) was taken to control the pests. Overall view of the experimental plot is shown in Plate 1.

3.1.5 Collection of data

Five plants were tagged randomly for recording observations for each entry for all the quantitative characters except for days to initiation of flowering. The procedure followed in recording observation on each trait is being described below.

3.1.5.1 Days to flower initiation of primary spike

Number of days taken from sowing to initiation of anthesis in main spike was recorded.

3.1.5.2 Number of nodes upto primary spike

Total number of nodes from cotyledonary nodes to the base of main spike was recorded.

3.1.5.3 Plant height upto primary spike

The plant height was measured in centimetres (cm) from the base to the node where main spike originated.

3.1.5.4 Total length of primary spike

The length of the main spike was measured in centimetre (cm) from base to the lip of primary spike.

3.1.5.5 Effective length of primary spike

The length of primary spike bearing capsules was measured in centimetres (cm) from base to the tip of the spike.

3.1.5.6 Total number of spikes per plant

Total number of capsules bearing spikes were counted as number of spikes per plant.

3.1.5.7 Average number of capsules per spike

Total number of capsules borne on each spike were counted and averaged to number of capsules per spike.

3.1.5.8 100 seed weight

One hundred seeds from the each entry were randomly drawn and weight was recorded in grams (g).

3.1.5.9 Oil percentage

The oil content of dry seed was estimated by using Near Infrared Reflectance Spectrometer (NIRS) (Model 6500 Foss NIR system, France) and expressed in per cent (%).

3.1.5.10 SPAD chlorophyll meter reading (SCMR)

The SPAD chlorophyll meter (Minolita SPAD-502 m, Tokyo, Japan) reading was recorded on each fully grown leaf, one from bottom and one from top of the plant and averaged to express as SPAD reading from each plant. Similarly, SPAD readings were recorded from the selected five plants in all the entries. In recording the SCMR, care was taken to ensure that the SPAD meter sensor fully covered the leaf lamina and the interference from veins and midribs was avoided.

Plate 1: General view of the experimental plot

3.1.5.11 Seed yield per plant

The weight of seeds in grams (g) from five randomly selected plants was recorded and averaged to seed yield per plant.

3.1.5.12 Net plot yield

Yield from each individual plots harvested at regular intervals excluding the border rows was recorded and expressed in kilograms (kg).

3.1.5.12 Total yield

Net plot yield of each entry is used to express total yield in terms of yield per ha. Grain yield per ha was computed using the formula given below.

$$\text{Yield (q/ha)} = \frac{\text{Net plot yield x 10000}}{\text{Plot area x 100}}$$

3.1.6 Statistical analysis

The statistical analysis of the data on the individual character was carried out on the mean value of five randomly selected plants on each genotype. The mean data was analyzed. Different statistical methods employed for analysis are as follows.

3.1.6.1 Mean

On the basis of individual plant observations, the population mean for each character was computed as follows.

$$\overline{X} = \frac{1}{n} X_i \sum_{i=1}^{n}$$

Where,

$\overline{X}$ = population mean

X_i = individual value

n = number of observations

3.1.6.2 Range

The minimum and maximum values on the basis of individual plant observations were used to indicate the range of given character.

3.1.6.3 Estimation of genetic parameters

Genetic parameters were estimated for different traits on castor genotypes.

3.1.6.3.1 Genotypic and phenotypic coefficient of variation

The genotypic and phenotypic coefficient of variation was computed according to Burton and Devane (1953) and expressed as percentage.

$$\text{Genotypic coefficient of variation (GCV)} = \frac{\sigma_g}{\overline{X}} \times 100$$

$$\text{Phenotypic coefficient of variation (GCV)} = \frac{\sigma_p}{\overline{X}} \times 100$$

Where,

σ_g = Genotypic standard deviation

σ_p = Phenotypic standard deviation

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

PCV and GCV values were categorized as low, moderate and high values as indicated by Sivasubramanian and Menon (1973) as follows.

0 -10 per cent	: Low
10 - 20per cent	: Moderate
> 20	: High

3.1.6.3.2 Heritability (h^2_{bs})

Heritability in broad sense was estimated as the ratio of genotypic variance to the phenotypic variance and expressed in percentage (Robinson *et al.* 1949).

$$\text{Heritability } (h^2_{bs}) = \frac{V_g}{V_p} \times 100$$

Where,

V_g = Genotypic variance

V_p = Phenotypic variance

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

0 – 30 per cent	: Low
30 – 60 per cent	: Moderate
> 60 per cent	: High

3.1.6.3.3 Genetic advance

The extent of genetic advance to be expected by selecting five per cent of the superior progeny was calculated by using the following formula given by Robinson *et al.* (1949).

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

Where,

i = efficacy of selection which is 2.06 at 5 per cent selection intensity

σ_p = phenotypic standard deviation.

h^2_{bs} = heritability in broad sense.

3.1.6.3.4 Genetic advance as per cent of mean

$$\text{Heritability } (h^2_{bs}) = \frac{GA}{\overline{X}} \times 100$$

Where,

GA = genetic advance

$\overline{X}$ = general mean of character

The GA as per cent of mean was categorized as low, moderate and high as following by Robinson *et al.* (1949) as follows.

0 - 10 per cent	: Low
0 – 20per cent	: Moderate
20 and above	: High

3.1.6.4 Association analysis

The correlation coefficients were calculated to determine the degree of association of characters with yield and also among the yield components themselves.The analysis of covariance was conducted by following the method designed by Singh and Chaudhary (1979).

$$\text{Genotypic correlation} = V_{xy}\ (g) = \frac{COV_{xy}\ (g)}{\sqrt{V_x\ (g) \text{ x } V_y\ (g)}}$$

$$\text{Genotypic correlation} = V_{xy}\ (p) = \frac{COV_{xy}\ (p)}{\sqrt{V_x\ (p) \text{ x } V_y\ (p)}}$$

Where,

COV_{xy} (p) = Phenotypic covariance between characters x and y

Vx (p) = Phenotypic variance of character x

Vy (p) = Phenotypic variance of character y

COV_{xy} (g) = Genotypic covariance between characters x and y

Vx (g) = Genotypic variance of character x

Vy (g) = Genotypic variance of character y

3.1.6.5 Path coefficient analysis

Path analysis was carried out using the genotypic correlation coefficients to know the direct and indirect effects of the components on yield as suggested by Wright (1921) and illustrated by Dewey and Lu (1959).

The following set of simultaneous equations were formed and solved for estimating the direct and indirect effects.

$r_1y = a + r_{12}b + r_{13}c + ... + r_{11i}$

$r_2y = r_{21}ab + r_{23}c + ... + r_{21i}$

$r_3y = r_{31}ab + r_{32}c + ... + r_{31i}$

$r_ny = r_{n1}ab + r_{n2}c + ... + i$

Where,

r_{1y} to r_{ny} = coefficients of correlation between causal factors 1 to n and dependent character y.

r_{12}, r_{21}, r_{31}.... rn_1 = coefficients of correlation among the causal factors 1 to n.

a, b, c... i = direct effects of characters a toi on the dependent character y

$$\text{Residual effect (R)} = \sqrt{1 - (a^2 + b^2 + c^2......... + i^2 + 2abr_{12} + 2acr_{13} + ...)}$$

The direct and indirect effects were suggested by Lenka and Misra (1973) as mentioned below.

> 1	Very high
0.3 - 0.9	High
0.2 – 0.29	Moderate
0.1 – 0.19	Low
< 0.1	Negligible

3.2 Stability analysis of genotypes over seasons and locations

To assess the stability across locations, the experiment was conducted at three locations *viz.,* Seed Unit, MARS, University of Agricultural Science, Dharwad; Agricultural Research Station, Hanumanamatti, Haveri District and Horticultural Research and Extension Station, Devihosur, Haveri District. All the locations are coming under Northern Transitional Zone-8 of Karnataka state.

3.2.7 Statistical analysis

3.2.7.1 Analysis of variance (ANOVA)

The data obtained for all quantitative characters from 14 genotypes over three locations (Dharwad, Devihosur and Hanumanamatti), were subjected to two way analysis of variance as per Panse and Sukhatme (1964). The analysis of variance for different characters was carried out for each environment to partition the total variance (mean sum of squares) due to known and unknown causes. The structure of ANOVA is given below.

Sources of variation	Degrees of freedom	Sum of squares	Mean sum of squares	Calculated F value
Replication	(r-1)	M_1	--	
Genotypes	(g-1)	M_2	$\sigma^2E + r\,\sigma^2_g$	M_2/M_3
Error	(r-1) (g-1)	M_3	σ^2E	
Total	(rg-1)			

3.2.7.2 Tests of homogeneity of error variance

The data obtained from each of the three environments for all the characters was subjected to Bartlett’s test to examine the homogeneity of error variance.

3.2.7.3 Pooled analysis of variance

The replication wise data obtained for all the characters on 14 genotypes over three locations was subjected to pooled analysis of variance using the method outlined by Sunderaraj *et al.* (1972). This was done for each character in order to find out the variation due to genotypes and environments to reveal the existence of genotype x environment interaction, if any. Only after ascertaining the genotypic x environment interaction was significant in the two way analysis of variance, the data was further subjected to stability analysis.

The structure of pooled analysis of variance

Source of variation	d. f.	SS	MSS	F-value
Genotypes	(g-1)		-	-
Environments	(e-1)	M_1	$\sigma^2E + \sigma^2_gE + e\sigma^2_g$	-
Genotypes x Environments	(g-1) (e-1)	M_2	$\sigma^2E + \sigma^2_gE$	-
Pooled error	M*	M_3	σ^2E	-

* Degrees of freedom pooled over environments

3.2.7.4 Stability analysis

The stability model proposed by Eberhart and Russell (1966) was adapted to analyze the data over three environments by using WINDOW STAT SOFTWARE. The model involves the estimation of three stability parameters; mean (X), regression coefficient (b_i) and deviation from regression (S^2d_i), which are defined by the following mathematical formula.

$$Y_{ij} = \mu_i + \beta_i I_j + \delta_{ij}$$

Where,

Y_{ij} : Mean of the i^{th} genotype at the j^{th} environment (i = 1, 2, 3, 4… n, j = 1, 2, 3…m)

μ_i : The mean of i^{th} genotype over all the environments

β_i : The regression coefficient of i^{th} genotype on the environment index which measures the response of genotype to varying environment

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

I_j : The environmental index which is defined as the deviation of mean of all the genotype at a given environment from the overall grand mean from the mean of all genotypes at j^{th} environment.

3.2.7.5 Stability parameters

The regression coefficient (b_i) and mean square deviation from linear regression (S^2d_i) are the two stability parameters proposed by Eberhart and Russell (1966) in their stability model. These parameters were computed by using the following formula.

$$b_i \text{ (regression coefficient)} = \frac{\Sigma_j Y_{ij} I_j}{\Sigma_j I^2_j}$$

$$S^2d_i \text{ (deviation from the regression coefficient)} = \frac{\Sigma_j \delta^2_{ij}}{n-2} - \frac{\delta^2_e}{r}$$

Where,

$\frac{\delta_e^2}{r}$: Mean square for (estimate of) pooled error

N : Number of environments

Y_{ij} : Performance of i^{th} genotype in j^{th} environment

$\Sigma_j \delta^2_{ij}$: Sum of squares of deviations from the regression line

I_j : Environmental index (i.e., environmental mean – grand mean)

$$Ij = \frac{\Sigma_i Y_{ij}}{i} - \frac{\Sigma_i \Sigma_{ij} Y_{ij}}{nj}$$

Where,

$\Sigma_i Y_{ij}$ = Total of all genotypes at j^{th} environment

$\Sigma_i \Sigma_{ij} Y_{ij}$ = Grand total

N = Number of environments

I = Number of genotypes

$\Sigma_j I_j$ = 0

The total variation is partitioned into variation due genotype, environment, environment (linear), genotype × environment (linear), pooled deviation and pooled error as given below.

ANOVA for stability

Source	d.f.	M.S.S.	F test
Genotype (G)	(g-1)	MS_1	MS_1/MS_3
Environment + (G × E)	g (n-1)		
Environment (E) (linear)	1		
Genotype × environment (linear)	(g-1)	MS_2	MS_2/MS_3
Pooled deviations	g (n-2)	MS_3	
Pooled error	n (r-1) (i-1)	Me	
Total	(nv-1)		

F test

To test the significance of differences among the genotype, the 'F' test was performed as,

$F = MS_1/MS_3$

Where,

MS_1 : Mean sum of squares of genotype.

MS_3 : Mean sum of squares of pooled deviations

To test individual deviation from linear regression, the formula is as follows,

$$F = \left(\frac{\Sigma_i \delta^2_{ij}}{n - 2} \right) \times ME$$

Where,

n : Number of environments

$\Sigma_j \delta^2_{ij}$: Sum of squares of deviations from the regression

ME : Pooled error

To test the departure of regression coefficients of the genotypes on the environmental index, the appropriate test was,

$$t = \frac{|\hat{b}_i - 1|}{SE(b)}$$

Standard error of b_i is got from the component of mean square for pooled deviations corresponding to the i^{th} genotype. Thus, for genotype *i*, the mean square for deviation corresponding to this genotype should be employed to calculate standard error of $b_{i.}$ Thus,

$SE(b) = [\text{MS due to pooled deviation}/\Sigma_j I_j^2]^{1/2}$

Genotype are said to be stable, based on following criteria

1. The mean performance of the genotype over the environment $\overline{X}$
2. The regression coefficient (b_i) and
3. The deviation from linear regression (S^2d_i) is used to define stability of a genotype

The estimate of deviations from regression (S^2d_i) suggests the degree of reliance that should be put to linear regression in interpretation of the data. If these values are significantly deviating from zero, the expected phenotype cannot be predicted satisfactorily. When, deviations (S^2d_i) are not significant, the conclusion may be drawn by joint consideration of mean yield and regression coefficient (b_i) values (Finlay and Wilkinson, 1963 and Eberhart and Russell, 1966) as given below.

Regression coefficient	Stability	Mean yield	Remarks
$\hat{b}_i = 1$	Average	High	Well adapted to all environments
$\hat{b}_i = 0$	Average	Low	Poorly adapted to all environments
$\hat{b}_i \geq 1$	Below average	High	Specifically adapted to favourable environments
$\hat{b}_i \leq 1$	Above average	High	Specifically adapted to unfavourable environments

4. EXPERIMENTAL RESULTS

The present investigations were conducted during *kharif*-2014 and *kharif*-2015 at NSP/BSP, Seed Unit, MARS, University of Agricultural Science, Dharwad (E_1) ; Agricultural Research Station, Hanumanamatti (E_2) and Horticultural Research and Extension Station, Devihosur (E_3). The experiments were conducted to study the stability analysis, association analysis and nature of genetic variability of castor genotypes. The results of the present investigation entitled "Stability analysis of varieties and hybrids in castor (*Ricinus communis* L.)" are presented under following captions.

4.1 Stability analysis
    4.1.1 Analysis of variance
    4.1.2 Mean performance of hybrids and varieties of castor in individual environments
    4.1.3 Environmental index and experimental mean
    4.1.4 Pooled analysis of variance over locations
    4.1.5 Analysis of variance for performance stability
    4.1.6 Stability parameters
4.2 Character association and path coefficient analysis
    4.2.1 Correlation analysis
    4.2.2 Path analysis
4.3 Genetic variability among castor genotypes for various morpho-physiological traits and their relationship with productivity
    4.3.1 Analysis of variance for 14 genotypes of castor
    4.3.2 Genetic variability, heritability and genetic advance
    4.3.3 Relationship between various morpho-physiological traits and productivity of castor genotypes

4.1 Stability analysis

4.1.1 Analysis of variance (ANOVA)

4.1.1.1 Analysis of variance (ANOVA) of castor genotypes over the locations for two seasons

Analysis of variance among fourteen genotypes for all the characters was carried out for the two seasons *viz., kharif*-2014 and *kharif*-2015 over three locations *viz.*, Dharwad, Devihosur and Hanumamatti is presented in the Table 2 and 3. Highly significant differences have been observed among the genotypes for all the characters studied. The mean values of all the accessions for the characters are presented in Appendix II.

4.1.1.2 Analysis of variance (ANOVA) of castor genotypes for individual locations

The analysis of variance was carried out for all the characters of castor genotypes for each location to partition total variation due to genotype and other sources. The variance (mean sum of squares) due to known and unknown causes is furnished in Table 4. The analysis of variance indicated significant differences among the genotypes for all the characters considered under investigation.

Table 2. Analysis of variance for yield and other quantitative characters of castor (*Ricinus communis* L.) at three environments during *kharif*-2014

Traits	Sources of variation								
	Replications (MSS)			Genotypes (MSS)			Error (MSS)		
	DWD	DVHSR	HNMT	DWD	DVHSR	HNMT	DWD	DVHSR	HNMT
Plant height (cm)	131.381	135.107	9.494	1965.93**	403.579**	598.271**	125.690	41.698	44.588
Days to flower initiation	13.714	5.810	7.167	28.15**	16.821**	33.993**	5.509	1.886	4.756
Number of nodes upto primary spike	0.042	0.230	1.109	10.89**	2.178**	5.169**	0.806	0.841	0.907
Length of primary spike (cm)	93.619	12.219	9.560	216.90**	37.703**	49.282**	29.146	8.954	16.603
Effective length of primary spike (cm)	55.951	13.119	12.002	120.40**	31.821**	34.435*	25.359	10.518	12.129
Number of spikes per plant	0.131	0.973	0.103	5.36**	1.510**	1.434**	0.740	0.323	0.174
Average number of capsules per spike	0.796	5.454	2.021	20.15**	40.268**	52.806**	2.355	4.308	11.277
Yield per plant (g)	82.700	168.407	39.999	348.25**	1826.629**	734.166**	62.122	288.739	98.905
Net plot yield (kg)	0.096	0.134	0.010	0.40**	1.987**	0.512**	0.069	0.185	0.086
100 seed weight (g)	0.021	1.801	1.545	12.52**	5.081**	6.567**	0.952	1.770	1.255
Total yield (q/ha)	3.085	4.333	0.306	12.97**	64.038**	16.486**	2.210	5.951	2.780
Oil content (%)	0.830	1.726	0.793	2.80**	4.092**	4.532**	0.590	0.859	1.029

DWD : Dharwad, DVHSR : Devihosur, HNMT : Hanumanamatti, ,* Significant at 0.05 probability level and ** Significant at 0.01 probability level

Table 3. Analysis of variance for yield and other quantitative characters of castor (*Ricinus communis* L.) at three environments during *kharif*-2015

Traits	Sources of variation								
	Replications (MSS)			**Genotypes (MSS)**			**Error (MSS)**		
	DWD	**DVHSR**	**HNMT**	**DWD**	**DVHSR**	**HNMT**	**DWD**	**DVHSR**	**HNMT**
Plant height (cm)	166.810	31.348	4.534	1944.50**	365.759**	120.921**	120.921	38.095	45.449
Days to flower initiation	16.738	8.310	4.167	28.51**	22.718**	5.995**	5.995	4.053	5.910
Number of nodes upto primary spike	1.024	0.687	0.572	5.03**	3.153**	0.748*	0.748	0.725	0.707
Length of primary spike (cm)	3.122	27.830	1.945	180.80**	56.714**	22.231*	22.231	16.884	12.412
Effective length of primary spike (cm)	46.859	20.563	3.925	118.18**	22.644*	19.833*	19.833	9.869	11.341
Number of spikes per plant	1.443	0.722	0.084	5.58**	1.481**	0.729**	0.729	0.322	0.191
Average number of capsules per spike	3.971	2.672	8.193	18.95**	40.356**	2.167**	2.167	3.475	10.551
Yield per plant (g)	28.917	155.063	64.917	354.63**	1775.809**	61.184**	61.184	291.425	93.873
Net plot yield (kg)	0.068	0.017	0.030	0.36**	1.786**	0.061**	0.061	0.113	0.077
100 seed weight (g)	0.848	0.334	0.118	11.23**	4.997*	0.851**	0.851	1.918	1.120
Total yield (q/ha)	19.833	0.535	0.981	22.23**	57.565**	0.729**	0.729	3.654	2.497
SPAD at 75 DAS	1.66	0.15	0.40	14.71**	62.52**	14.87**	4.27	4.09	3.93
SPAD at 90 DAS	0.15	0.67	1.17	15.41**	44.81**	13.98**	1.66	4.67	2.46
SPAD at 120 DAS	11.50	11.28	21.51	54.27**	26.34**	35.56**	10.95	4.38	5.28
Oil content (%)	1.165	0.986	1.333	2.181**	4.240**	4.752**	0.569	0.923	0.949

DWD : Dharwad, DVHSR : Devihosur, HNMT : Hanumanamatti, ,* Significant at 0.05 probability level and ** Significant at 0.01 probability level

Table 4. Analysis of variance for mean data of yield and other quantitative characters of castor (*Ricinus communis* L.) over two seasons (2014-15 and 2015-16) at three environments

Traits	Sources of variation								
	Replications (MSS)			Genotypes (MSS)			Error (MSS)		
	DWD	DVHSR	HNMT	DWD	DVHSR	HNMT	DWD	DVHSR	HNMT
Plant height (cm)	177.019	12.741	121.831	1954.950**	402.521**	610.135**	125.690	35.553	1.247
Days to flower initiation	0.214	2.643	5.342	27.832**	19.269**	32.864**	5.509	2.643	5.156
Number of nodes upto primary spike	0.335	0.095	0.465	5.928**	1.193**	1.841**	0.806	0.323	0.361
Length of primary spike (cm)	68.976	10.011	28.165	211.963**	36.291**	71.667**	29.146	9.590	38.734
Effective length of primary spike (cm)	39.097	21.819	24.991	163.180**	77.527**	68.138**	25.359	15.481	30.890
Number of spikes per plant	0.615	0.249	0.728	5.422**	1.490**	1.468**	0.740	0.321	0.181
Average number of capsules per spike	0.145	1.246	2.254	19.207**	41.114**	50.305**	2.355	3.576	11.165
Yield per plant (g)	112.086	4.194	61.399	350.710**	1800.558**	685.113**	62.122	283.970	95.199
Net plot yield (kg)	0.064	0.005	0.064	0.377**	1.867**	0.481**	0.069	0.122	0.081
100 seed weight (g)	0.201	0.796	0.887	11.757**	5.540**	6.173**	0.952	1.742	1.179
Total yield (q/ha)	2.136	0.153	2.148	12.640**	62.520**	16.112**	2.210	4.093	2.714
Oil content (%)	1.029	0.070	0.558	2.646**	4.362**	4.135**	0.590	0.836	1.202

DWD : Dharwad, DVHSR : Devihosur, HNMT : Hanumanamatti, ,* Significant at 0.05 probability level and ** Significant at 0.01 probability level

4.1.2 Mean *per se* performance of hybrids and varieties of castor in individual environments

The castor genotypes grown in three locations and their mean performance recorded over three environments are presented in Table 5.

4.1.2.1 Plant height

In E_1, plant height ranged from 130.56 cm (RHC-1) to 212.37 cm (DCH-519). Hybrids GCH-5 (203.36 cm), GCH-6 (183.61 cm), GCH-7 (192.65 cm) and DCH-519 (212.37 cm) were superior than the check GCH-4 (148.25 cm). Among varieties, GC-3 (195.39 cm) was superior than the check 48-1 (171.55 cm). The population mean was 168.12 cm.

In E_2, plant height varied between 145.50 cm to184.45 cm with the population mean of 170.25 cm. All hybrids were superior than the check GCH-4 (145.50 cm) and among varieties PCS-262 (173.08 cm) recorded superior plant height and check 48-1 recorded plant height of 146.67 cm.

In E_3, all the hybrids were superior than the check GCH-4 (106.67 cm) for plant height. Plant height ranged from 106.67cm (GCH-4) to 153.85 cm (48-1) and the population mean recorded 130.91 cm. Among varieties, GC-3 recorded more plant height of 153.85 cm over the check 48-1 (184.45 cm).

The range of plant height in pooled over data varies from 133.47 cm (GCH-4) to 173.93 cm (DCH-519). Among the hybrids, GCH-5 (165.95 cm) and DCH-519 (173.93 cm) were significantly superior than their check GCH-4 (136.13 cm). Among varieties, GC-3 recorded highest plant height of 169.21 cm. The population mean was 155.69 cm.

4.1.2.2 Days to flower initiation

In E_1, days to flower initiation varied from 36.00 days (PCH-111) to 46.33 days (DCS-107) with the population mean of 40.14 days. Among varieties, GC-3 (38.33 days) took least number of days to flower initiation.

In E_2, hybrids GCH-5 (43.00), DCH-519 (41.67) and RHC-1 (40.67) have taken more days than the check GCH-4 (36.00). Among varieties, DCS-107 (40.00), PCS-136 (41.33) and GC-3 (39.33) were late in flower initiation compared to the check 48-1 (36.33). Days to flower initiation ranged from 35.00 days (PCH-111) to 43.00 days (GCH-5) and the population mean recorded was 38.50 days.

In E_3, RHC-1 (42.00) has late flower initiation compared to the check GCH-4 (37.33). Among hybrids, PCH-111 (33.00) and among varieties, PCS-4 (34.00) recorded least number of days to flower initiation. Days to flower initiation ranged from 33.00 days (PCH-111) to 43.00 days (DCS-107) and the population mean recorded was 37.62 days.

The pooled data of days to flower initiation ranged from 34.67 days (PCH-111) to 43.11 days (DCS-107) and the population mean recorded 38.61 days.

4.1.2.3 Number of nodes upto primary spike

In E_1, among the hybrids, the number of nodes upto primary spike ranged from 11.53 (RHC-1) to 16.97 (DCH-519) and the population mean recorded was 13.64, whereas, hybrid check GCH-4 recorded 12.00 nodes upto primary spike. Among varieties, PCS-262 (12.33) recorded least number of nodes upto primary spike compared to the check 48-1 (14.43).

Table 5. ***Per se*** **performance of twelve genotypes and two checks of castor (*****Ricinus communis*** **L.) at three environments over two years**

Genotypes	Plant height (cm)				Days to flower initiation				Number of nodes upto primary spike			
	E_1	E_2	E_3	Mean	E_1	E_2	E_3	Mean	E_1	E_2	E_3	Mean
GCH-5	203.36*	183.94*	110.55*	165.95*	41.33	43.00*	37.67	40.67	14.83*	13.37*	13.43	13.88*
GCH-6	183.61*	175.55*	116.67*	158.61	38.00	36.33	37.33	37.22	12.93	12.87*	12.83	12.88
GCH-7	192.65*	165.15*	120.65*	159.48	40.67	38.67	33.67	37.67	13.47*	12.70	13.33	13.17
DCH-177	162.38	176.84*	123.18*	154.13	38.67	36.33	39.00	38.00	14.90*	13.03*	13.27	13.73*
DCH-519	212.37*	183.37*	126.05*	173.93*	41.67	41.67*	39.67	41.00*	16.97*	13.53*	13.95*	14.82*
RHC-1	130.56	177.63*	130.00*	146.06	37.67	40.67*	42.00*	40.11	11.53	13.43*	12.57	12.51
PCH-111	165.35	172.68*	135.00*	157.68	36.00	35.00	33.00	34.67	13.33	11.83	13.40	12.86
DCS-107	151.81	167.97	136.88	152.22	46.33	40.00*	43.00	43.11*	14.60	13.53	12.03	13.39
PCS-4	143.63	155.87	138.33	145.95	38.67	36.33	34.00	36.33	13.37	12.73	11.50	12.53
PCS-136	143.60	163.03	141.67	149.43	39.00	41.33*	41.33*	40.56	13.00	11.90	11.93	12.28
PCS-262	149.12	173.08	144.67	155.62	38.33	38.00	35.00	37.11	12.33	12.67	11.37	12.12
GC-3	195.39*	158.40	153.85*	169.21	42.33	39.33*	39.67*	40.44	13.30	12.53	12.43	12.76
Checks												
GCH-4	148.25	145.50	106.67	133.47	37.67	36.00	37.33	37.00	12.00	11.63	12.93	12.19
48-1	171.55	184.45	148.53	168.18	45.67	36.33	34	38.67	14.43	13.13	12.17	13.24
Mean	168.12	170.25	130.91	155.69	40.14	38.5	37.62	38.61	13.64	12.78	12.65	12.96
S.Em. ±	6.37	3.44	0.64	10.29	1.33	0.94	1.31	1.35	0.39	0.33	0.35	0.46
C.D. (5 %)	18.52	10.01	1.87	29.93	3.88	2.73	3.81	3.93	1.14	0.95	1.01	1.35
C.V. (%)	6.57	3.5	0.85	11.4	5.76	4.22	6.04	6.04	5	4.45	4.75	6.17

Contd...

Genotypes	Length of primary spike (cm)				Effective length of primary spike (cm)				Number of spikes per plant			
	E_1	E_2	E_3	Mean	E_1	E_2	E_3	Mean	E_1	E_2	E_3	Mean
GCH-5	50.40	47.23	44.90	47.51	46.61	43.51	40.90	43.67	10.27	7.62	8.53	8.81
GCH-6	54.51	47.93	40.86	47.77	49.57	45.48	36.32	43.79	11.42*	8.09	8.20	9.24
GCH-7	71.12	51.03	47.83	56.66	65.06	47.24	45.52	52.61	8.83	8.38	9.20	8.81
DCH-177	57.50	52.15	52.09	53.91	51.38	48.15	47.10	48.88	7.72	8.84	8.53	8.36
DCH-519	51.04	46.13	47.98	48.38	53.98	42.50	46.13	47.54	8.37	7.70	8.67	8.25
RHC-1	46.63	46.08	46.16	46.29	44.63	41.39	38.25	41.42	6.35	6.25	8.73	7.11
PCH-111	38.66	45.83	43.88	42.79	36.99	42.37	39.87	39.74	9.62	7.86	8.47	8.65
DCS-107	57.90	42.98	42.12	47.67	55.34	38.86	38.85	44.35	8.95	7.60	8.13	8.23
PCS-4	52.73	42.00	45.08	46.60	48.69	38.57	36.83	41.36	7.39	7.50	8.93	7.94
PCS-136	52.34	47.32	51.98*	50.55	50.22	42.86	48.71*	47.26	9.88	7.05	10.33*	9.09
PCS-262	57.55	51.97	54.47*	54.66	51.59	44.44	50.08*	48.70	8.72	8.64	10.20*	9.19
GC-3	51.08	47.05	43.34	47.16	48.40	42.42	38.59	43.13	9.04	7.98	9.40*	8.81
Checks												
GCH-4	68.71	54.28	52.28	58.42	65.28	48.50	47.96	53.91	9.44	8.79	9.73	9.32
48-1	61.95	46.85	37.79	48.86	58.83	42.83	37.22	51.62	10.72	8.26	8.67	9.22
Mean	**55.15**	**47.77**	**46.48**	**49.98**	**51.9**	**44.65**	**42.31**	**46.49**	**9.05**	**7.9**	**8.98**	**8.63**
S.Em. ±	3.06	1.79	3.59	2.8	3.21	2.27	3.3	2.85	0.49	0.33	0.25	0.52
C.D. (5 %)	8.91	5.2	10.45	8.14	9.34	6.6	9.58	8.28	1.43	0.95	0.71	1.52
C.V. (%)	9.62	6.48	13.39	9.74	10.72	8.81	13.49	10.66	9.42	7.17	4.73	10.5

Contd...

Genotypes	**Average number of capsules per spike**				**Yield per plant (g)**				**Net plot yield (kg)**			
	E_1	**E_2**	**E_3**	**Mean**	**E_1**	**E_2**	**E_3**	**Mean**	**E_1**	**E_2**	**E_3**	**Mean**
GCH-5	65.08	60.45	60.45	61.99	96.69	111.39	101.30	103.13	3.09	3.34	3.00	3.15
GCH-6	64.72	60.57	58.61	61.30	98.56	124.69	126.24*	116.50	3.15	4.00	3.41*	3.52
GCH-7	72.22*	64.73	61.45	66.13	75.76	154.80*	102.08	110.88	2.42	5.38*	3.27	3.69
DCH-177	68.11	69.99	61.23	66.44	97.03	103.74	117.30*	106.02	3.07	3.40	3.63*	3.37
DCH-519	63.20	60.02	60.69	61.30	78.38	92.79	86.14	85.77	2.46	3.08	2.69	2.74
RHC-1	67.18	64.92	59.73	63.94	83.12	86.91	69.59	79.87	2.60	2.34	2.20	2.38
PCH-111	65.34	61.69	56.60	61.21	72.57	166.88*	99.60	113.01	2.28	4.62*	3.12	3.34
DCS-107	65.65	64.63	58.71	62.99	71.59	94.65	85.48	83.90	2.25	3.02	2.65	2.64
PCS-4	67.93	59.84	62.08	63.28	79.46	120.59	74.73	91.59	2.54	3.63	2.34	2.84
PCS-136	62.74	60.57	69.96*	64.42	99.42*	99.16	97.80	98.79	3.15	3.17	3.07	3.13
PCS-262	67.58	66.00	71.19*	68.26	91.61	81.31	90.81	87.91	2.86	2.65	2.91	2.81
GC-3	62.88	58.99	59.13	60.33	73.80	104.94	83.37	87.37	2.31	3.46	2.53	2.77
Checks												
GCH-4	66.28	70.07	62.62	66.32	97.84	122.31	93.62	104.59	3.13	3.89	2.90	3.31
48-1	67.18	65.98	62.61	65.26	80.80	102.32	93.71	92.28	2.59	3.01	2.74	2.78
Mean	**66.15**	**63.46**	**61.79**	**63.94**	**85.47**	**111.89**	**94.41**	**96.81**	**2.71**	**3.50**	**2.89**	**3.02**
S.Em. ±	0.87	1.09	1.93	1.79	4.52	9.73	5.63	9.35	0.15	0.20	0.16	0.28
C.D. (5 %)	2.52	3.17	5.61	5.20	13.15	28.28	16.38	27.17	0.42	0.59	0.48	0.82
C.V. (%)	2.27	2.98	5.41	4.86	9.17	15.06	10.33	16.64	9.35	9.99	9.85	16.12

Contd...

Genotypes	**Total yield (q ha^{-1})**				**100 seed weight (g)**				**Oil content (%)**			
	E_1	**E_2**	**E_3**	**Mean**	**E_1**	**E_2**	**E_3**	**Mean**	**E_1**	**E_2**	**E_3**	**Mean**
GCH-5	17.91	19.35	17.36	18.20	29.19*	29.83*	25.58	28.20*	48.69	49.16	48.16	48.67*
GCH-6	18.25	23.14	19.75*	20.38	28.88*	29.85*	27.38*	28.70*	47.74	48.07	48.76	48.19
GCH-7	14.03	31.15*	18.90	21.36	29.63*	26.23	27.38*	27.75	48.71	48.82	46.74	48.09
DCH-177	17.79	19.68	21.01*	19.49	27.21	26.52	24.87	26.20	47.92	47.87	48.42	48.07
DCH-519	14.21	17.84	15.59	15.88	28.60*	26.93	27.87*	27.80*	49.96*	49.28	48.12	49.12*
RHC-1	15.05	13.53	12.75	13.78	25.74	26.72	24.23	25.56	47.87	48.50	47.99	48.12
PCH-111	13.17	26.74*	18.04	19.32	28.49*	27.97	25.52	27.33	48.21	47.36	46.46	47.34
DCS-107	13.00	17.46	15.32	15.26	24.92*	26.07	25.95*	25.65	47.32	46.34	46.61	46.76
PCS-4	14.71	21.02	13.54	16.42	28.29*	25.88	25.38	26.52*	49.76	50.18	49.88	49.94
PCS-136	18.24	18.37	17.75	18.12	27.95*	27.08	22.63	25.89	50.23	50.55	50.21	50.33
PCS-262	16.58	15.31	16.82	16.24	25.94*	28.08*	26.12*	26.71*	49.81	49.55	48.42	49.26
GC-3	13.38	20.02	14.62	16.01	25.51*	27.32	24.67	25.83	49.20	49.03	48.52	48.92
Checks												
GCH-4	18.12	22.51	16.78	19.14	26.01	25.82	25.21	25.68	48.22	47.93	47.05	47.73
48-1	14.96	17.41	15.86	16.08	22.74	25.77	23.93	24.15	49.36	50.41	49.40	49.72
Mean	**15.67**	**20.25**	**16.72**	**17.50**	**27.08**	**27.15**	**25.48**	**26.44**	**48.79**	**48.79**	**48.20**	**48.58**
S.Em. ±	0.85	1.17	0.95	1.63	0.54	0.76	0.63	0.72	0.43	0.53	0.63	0.31
C.D. (5 %)	2.46	3.40	2.77	4.75	1.58	2.22	1.82	2.09	1.25	1.53	1.84	0.91
C.V. (%)	9.35	9.99	9.85	16.12	3.48	4.86	4.26	4.70	1.53	1.87	2.27	1.12

In E_2, all the hybrids, except GCH-7 (12.70) and PCH-111 (11.83), had more number of nodes upto primary spike than the check GCH-4 (11.63). Hybrids DCH-519 (13.53) and variety DCS-107 (13.53) recorded highest number of nodes upto primary spike and PCH-111 (11.83) recorded the least number of nodes upto primary spike. The population mean recorded was 12.78.

In E_3, number of nodes upto primary spike varied from 11.37 (PCS-262) to 13.95 (DCH-519) with the population mean of 12.65. Among hybrids, DCH-519 (13.95) had more number of nodes to primary spike than the check GCH-4 (12.93) and among varieties, GC-3 (12.43) and PCS-262 (11.37) recorded maximum number of nodes upto primary spike.

The pooled data for number of nodes upto primary spike ranged from 12.12 (PCS-262) to 14.82 (DCH-519) and the population mean recorded was 12.96. Hybrids *viz.,* GCH-5 (13.88), DCH-519 (14.82) and DCH-177 (13.67) were having more number of nodes to the primary spike than to the check GCH-4 (12.19).

4.1.2.4 Length of primary spike

In E_1, length of primary spike ranged from 38.66 cm (PCH-111) to 71.12 cm (GCH-7). Among varieties, DCS-107 (57.90 cm) recorded maximum length of primary spike.The checks GCH-4 and 48-1 recorded the mean primary spike length of 68.71 cm and 61.95 cm, respectively. The population mean was 55.15 cm.

In E_2, length of primary spike varied from 42.00 cm (PCS-4) to 54.28 cm (GCH-4). Among hybrids, DCH-177 (52.15 cm) and among varieties, PCS-262 (51.97 cm) recorded maximum length of primary spike. The population mean was 47.77 cm. Length of primary spike of checks, GCH-4 and 48-1 was 54.28 cm and 46.85 cm, respectively.

In E_3, length of primary spike varied between 37.79 cm (48-1) to 54.47 cm (PCS-262) with the population mean of 46.48 cm. Among varieties, PCS-262 (54.47 cm) and PCS-136 (51.98 cm) recorded superior length of primary spike over the check 48-1.

In pooled environments, the length of primary spike ranged between 42.79 cm (PCH-111) to 58.42 cm (GCH-4) with the population mean of 49.98 cm. Among hybrids, GCH-7 (56.66 cm) and among varieties, PCS-262 (54.66 cm) recorded maximum length of primary spike to the checks GCH-4 (58.42 cm) and 48-1 (48.86 cm), respectively.

4.1.2.5 Effective length of primary spike

In E_1, the effective length of primary spike ranged from 36.99 cm (PCH-111) to 65.28 cm (GCH-4). Among hybrids, GCH-7 (65.06 cm) and among varieties, DCS-107 (55.34 cm), recorded maximum effective length of primary spike. The population mean was 51.90 cm.

In E_2, the effective length of primary spike varied from 38.57 cm (PCS-4) to 48.50 cm (GCH-4). Among hybrids, DCH-177 (48.15 cm) was on par and among varieties, PCS-262 recorded maximum effective length of primary spike of 44.44 cm. The population mean was 44.65 cm.

In E_3, the effective length of primary spike varied from 36.32 cm (GCH-6) to 50.08 cm (PCS-262) with the population mean of 42.31 cm. Among varieties, PCS-262 (50.08 cm) and PCS-136 (48.71 cm) recorded significantly superior effective length of primary spike than the check 48-1 (37.22 cm).

The pooled data of effective length of primary spike ranged between 39.74 cm (PCH-111) to 53.91 cm (GCH-4) with the population mean of 46.49 cm. Among hybrids, GCH-7 (52.61 cm) and among varieties, PCS-262 (48.70 cm) recorded on par and maximum length of primary spike than the checks GCH-4 and 48-1 (51.62 cm), respectively.

4.1.2.6 Number of spikes per plant

In E_1, hybrid, GCH-6 (11.42) recorded maximum and significantly highest number of spikes per plant to the check GCH-4 (9.44). Hybrid RHC-1 (6.35) recorded lowest number of spikes per plant. Among varieties, maximum number of spikes per plant was observed for PCS-136 (9.88). The population mean recorded was 9.05.

In E_2, the number of spikes per plant ranged from 6.25 (RHC-1) to 8.84 (DCH-177) and the population mean recorded was 7.90. Among the varieties, PCS-262 (8.64) recorded highest number of spikes per plant and checks, GCH-4 and 48-1 recorded 8.79 and 8.26 spikes per plant, respectively.

In E_3, least number of spikes per plant recorded was 8.13 (DCS-107) and PCS-136 (10.33) recorded maximum number of spikes per plant. The population mean recorded was 8.98. Varieties, PCS-136 (10.33), PCS-262 (10.20) and GC-3 (9.40) were found to be significantly superior than the check 48-1 (8.67)

The polled data for number of spikes per plant ranged from 7.11 (RHC-1) to 9.32 (GCH-4) and among varieties, PCS-262 (9.19) recorded maximum number of spikes per plant. The population mean recorded was 8.63. Checks, GCH-4 and 48-1 recorded mean number of spikes per plant of 9.32 and 9.22, respectively.

4.1.2.7 Average number of capsules per spike

In E_1, the mean of average number of capsules per spike ranged from 62.74 (PCS-136) to 72.22 (GCH-7) and the population mean recorded was 66.15. Among hybrids, GCH-7 (72.22) was found significantly superior than the check GCH-4 (66.28). Among varieties, PCS-4 (67.93) recorded highest average number of capsules per spike against the check 48-1 (67.18).

In E_2, GCH-4 (70.07) recorded highest and PCS-4 (59.84) recorded least average number of capsules per spike. Among hybrids, GCH-7 (64.73) and among varieties, PCS-262 (66.00), recorded maximum number of capsules per spike. The population mean recorded was 63.46.

In E_3, average number of capsules per spike ranged from 56.60 (PCH-111) to 71.19 (PCS-262) and the population mean recorded was 61.79. Among hybrids, GCH-7 (61.45) recorded highest average number of capsules per spike and among varieties, PCS-136 (69.96) and PCS-262 (71.19) recorded significantly highest average number of capsules per spike than the check, 48-1 (62.61).

In pooled data, average number of capsules per spike ranged from 60.33 (GC-3) to 68.26 (PCS-262). Among hybrids, DCH-177 (66.44) and PCS-262 (68.26) recorded maximum number of capsules per spike over the check GCH-4 (66.32) and 48-1 (34.20), respectively. The population mean recorded was 63.94.

4.1.2.8 Yield per plant

In E_1, variety PCS-136 (99.42 g) recorded highest yield per plant and significantly superior than the check 48-1 (80.80 g) and least yield per plant was observed in DCS-107 (71.59 g). Among hybrids, GCH-6 recorded maximum yield per plant of 98.56 g compared to the check GCH-4 (97.84) and the population mean recorded was 85.47 g.

In E_2, range observed for yield per plant among genotypes was 81.31 g (PCS-262) to 166.88 g (PCH-111). Hybrids GCH-7 (154.80 g) and PCH-111were found significantly superior than the check GCH-4 (122.31 g) and the population mean recorded was 111.89 g.

In E_3, yield per plant varied from 69.59 g (RHC-1) to 126.24 g (GCH-6) with the population mean of 94.41 g. Among varieties, PCS-136 (97.80 g) and PCS-4 (74.73 g) recorded maximum and minimum yield per plant, respectively. Hybrids GCH-6 (126.24 g) and DCH-177 (117.30 g) recorded significantly superior yield per plant than the check GCH-4 (93.62 g)

The pooled mean yield per plant ranged from 79.87 g (RHC-1) to 116.50 g (GCH-6) and the population mean recorded was 96.81 g. Among varieties, highest yield per plant was recorded for PCS-136 (98.79 g).

4.1.2.9 Net plot yield

In E_1, net plot yield ranged from 2.25 kg (DCS-107) to 3.15 kg (GCH-6). Among varieties, PCS-136 (3.15 kg) recorded highest net plot yield and the population mean recorded was 2.71 kg.

In E_2, hybrids GCH-7 (5.38 kg) and PCH-111 (4.62 kg) were significantly superior than the check GCH-4 (3.89 kg). Among varieties, PCS-136 (3.17 kg) recorded maximum net plot yield. Net plot yield ranged from 2.34 kg (RHC-1) to 5.38 kg (GCH-7) and the population mean recorded was 3.50 kg.

In E_3, net plot yield varied from 2.20 kg (RHC-1) to 3.63 kg (DCH-177) with the population mean of 2.89 kg. Among varieties, PCS-136 (3.07 kg) recorded maximum net plot yield. Hybrids GCH-6 (3.41 kg) and DCH-177 (3.63 kg) were significantly superior than the check GCH-4 (2.90 kg).

The range of net plot yield in pooled data varied from 2.38 kg (RHC-1) to 3.69 kg (GCH-7). Among varieties, PCS-136 (3.13 kg) recorded maximum net plot yield. The population mean recorded was 3.02 kg.

4.1.2.10 Total yield

In E_1, net plot yield ranged from 13.00 q ha^{-1} (DCS-107) to 18.25 q ha^{-1} (GCH-6). Among varieties, PCS-136 (18.24 q ha^{-1}) recorded highest net plot yield and the population mean recorded was 15.67 q ha^{-1}, which is significantly superior than the varietal check 48-1. While in hybrids, GCH-6 (18.25 q ha^{-1}) was on par with the check (18.12 q ha^{-1}).

In E_2, hybrids GCH-7 (31.15 q ha^{-1}) and PCH-111 (26.74 q ha^{-1}) were significantly superior than the check GCH-4 (22.51 q ha^{-1}). Among varieties, PCS-4 (21.02 q ha^{-1}) recorded maximum net plot yield compared to the check 48-1 (17.41 q ha^{-1}). Net plot yield ranged from 13.53 q ha^{-1} (RHC-1) to 31.15 q ha^{-1} (GCH-7) and the population mean recorded was 20.25 q ha^{-1}.

In E_3, net plot yield varied from 12.75 q ha^{-1} (RHC-1) to 21.01 q ha^{-1} (DCH-177) with the population mean of 16.72 q ha^{-1}. Among varieties, PCS-136 (17.75 q ha^{-1}) recorded maximum net plot yield. Hybrids GCH-6 (19.75 q ha^{-1}) and DCH-177 (21.01 q ha^{-1}) were significantly superior than the check GCH-4 (16.78 q ha^{-1}).

The range of net plot yield in pooled data varied from 13.78 q ha^{-1} (RHC-1) to 21.36 q ha^{-1} (GCH-7). Among varieties, PCS-136 (18.12 q ha^{-1}) recorded maximum net plot yield compared the check 48-1 (15.86 q ha^{-1}). The population mean recorded was 17.50 q ha^{-1}.

4.1.2.11 100 Seed weight

In E_1, it was observed that the mean of 100 seed weight ranged from 22.74 g (48-1) to 29.63 g (GCH-7) and the population mean recorded was 27.08 g. Among hybrids, except DCH-177 (27.21 g) and RHC-1 (25.74 g), all were found superior to its check GCH-4 (26.01 g) and among varieties, all were found to be significantly superior than the check 48-1 (22.74 g).

In E_2, hybrids GCH-5 (29.83 g) and GCH-6 (29.85 g) recorded significantly superior 100 seed weight over the check GCH-4 (25.82 g) and among varieties, PCS-262 (28.08 g) was found significantly superior than the check 48-1 (25.77 g) for 100 seed weight. The mean of 100 seed weight ranged from 25.88 g (PCS-4) to 29.85 g (GCH-6) and population mean recorded was 27.15 g.

In E_3, 100 seed weight varied from 24.23 g (RHC-1) to 27.87 g (DCH-519) and the population mean recorded was 25.48 g. Among hybrids, DCH-519 (28.87 g), GCH-7 (27.38 g) and GCH-6 (27.38 g) were found significantly superior to the check GCH-4 (25.21 g). Among varieties, PCS-262 (26.12 g) and DCS-107 (25.95 g), recorded highest 100 seed weight and were superior than the check 48-1 (23.93).

In pooled data, hybrid GCH-6 (28.70 g),GCH-5 (28.20 g) and DCH-519 (27.80 g) recorded maximum 100 seed weight and it was found superior to the check GCH-4 (25.68 g). Among varieties, PCS-4 (26.52 g) and PCS-136 (26.71 g) were superior to its check, 48-1 (24.15 g), which recorded minimum 100 seed weight among the genotypes. The population mean recorded was 26.44 g.

4.1.2.12 Oil content

In E_1, oil content ranged from 47.32 per cent (DCS-107) to 50.23 per cent (PCS-136). Among hybrids, maximum oil content was observed in DCH-519 (49.96 %) and it was significantly superior than the check GCH-4 (48.22 %). The population mean was 48.79 per cent.

In E_2, oil content varied from 46.34 per cent (DCS-107) to 50.55 (PCS-136). Among hybrids, DCH-519 recorded highest oil content of 49.28 per cent. The population mean was 48.79. Oil content observed in checks, GCH-4 and 48-1 was 47.93 per cent and 50.41 per cent, respectively.

In E_3, varieties, PCS-136 (50.21 %) and DCS-107 (46.61 %) recorded highest and lowest oil content among the genotypes. Among hybrids, highest oil content was recorded for GCH-6 (48.76 %). The population mean was 48.20 per cent.

In pooled data the variation ranged from 46.76 per cent (DCS-107) to 50.33 per cent (PCS-136) was found among the genotypes for oil content. Among hybrids, GCH-5 (48.67 %) and DCH-519 (49.12 %) recorded significantly higher oil content over the check GCH-4 (47.73 %) and the population mean recorded was of 48.58 per cent.

4.1.3 Environmental index and experimental mean

The castor genotypes grown in three environments and the data collected on 12 characters for each genotype were analyzed environment wise to find out the performance of each genotype across location. The environmental index (I) and the environmental mean (E) for eleven characters studied over three environments and the overall environmental mean are presented in Table 6.

4.1.3.1 Plant height

Environmental index for plant height was found to be positive and maximum at E_2 (13.83) followed by E_1 (11.69). Environmental index was negative for E_3 (-25.52). Highest environmental mean was recorded for E_2 (170.25 cm) and lowest was recorded for E_3 (130.91 cm). Environmental mean for E_1 recorded was 168.12 cm and the overall mean observed was 156.42 cm.

Table 6. Environmental index (I) and Environmental mean (E) for traits in castor at different environments

Trait		E_1	E_2	E_3	Overall mean
Plant height (cm)	I	11.69	13.82	-25.52	156.42
	E	168.12	170.25	130.91	
Days to flower initiation	I	1.39	-0.25	-1.14	38.75
	E	40.14	38.50	37.62	
Number of nodes upto Primary spike	I	0.62	-0.25	-0.37	13.02
	E	13.64	12.78	12.65	
Length of primary spike (cm)	I	5.35	-2.03	-3.32	49.80
	E	55.15	47.78	46.48	
Effective length of primary spike (cm)	I	6.00	-2.41	-3.59	45.90
	E	51.90	43.49	42.31	
Number of spikes per plant	I	0.41	-0.75	0.34	8.64
	E	9.05	7.90	8.98	
Average number of capsules per spike	I	2.35	-0.34	-2.01	63.80
	E	66.15	63.46	61.79	
Yield per plant (g)	I	-11.79	14.63	-2.85	97.26
	E	85.47	111.89	94.41	
Net plot yield (kg)	I	-0.32	0.47	-0.14	3.03
	E	2.71	3.50	2.89	
Total yield (q/ha)	I	-1.88	2.70	-0.83	17.55
	E	15.67	20.25	16.72	
100 seed weight (g)	I	0.51	0.58	-1.09	26.57
	E	27.08	27.15	25.48	
Oil content (%)	I	0.20	0.19	-0.39	48.59
	E	48.79	48.78	48.19	

4.1.3.2 Days to flower initiation

Environmental index was positive only at E_1 (1.39) and negative at E_3 (-1.14) and E_2 (-0.25). Environmental mean recorded were 40.14 (E_1), 38.50 (E_2) and 37.60 (E_3). The overall mean recorded was 38.75.

4.1.3.3 Number of nodes upto primary spike

Negative environmental index was recorded at E_3 (-0.37) and E_2 (-0.25). Environmental index of E_1 was observed to be positive with 0.62. Environmental mean recorded were E_1 (13.64), E_2 (12.78) and E_3 (12.65). Overall mean observed was 13.02.

4.1.3.4 Length of primary spike

Positive environmental index of 5.35 was recorded for E_1 and environmental indices were negative, -3.32 and -2.03, for E_2 and E_3, respectively. Environmental means of E_1, E_2, and E_3 were 55.15 cm, 47.78 cm and 46.48 cm, respectively. Over all mean observed was 49.80 cm.

4.1.3.5 Effective length of primary spike

Environmental index for effective length of primary spike showed negative value for E_3 (-3.59) and E_2 (-2.41). Positive environmental index was recorded for E_1 (6.00). Highest environmental mean was observed for E_1 (51.90 cm) followed by E_2 (43.49 cm) and E_3 (42.31 cm) and overall mean recorded was 45.90 cm.

4.1.3.6 Number of spikes per plant

Positive environmental indices were recorded for E_1 (0.41) and E_3 (0.34) and negative values was recorded for E_2 (-0.75). Environmental mean was highest for E_1 (9.05). Environmental mean values of E_2 and E_3 were 7.90 and 8.98, respectively. The overall mean observed was 8.64.

4.1.3.7 Average number of capsules per spike

Environmental indices of average number of capsules for E_2 (-0.34) and E_3 (-2.01) were recorded negative. Positive and highest value of environmental index was observed for E_1 (2.35). Environmental mean was highest for E_1 (66.15) and least was recorded for E_3 (61.75). Environmental means of E_2 was 63.46 and overall mean recorded was 63.80.

4.1.3.8 Yield per plant

Negative environmental indices were recorded for E_1 (-11.79) and E_3 (-2.85), whereas, environmental index was positive for E_2 (14.63). Environmental mean was highest for E_2 (111.89 g). Environmental means of E_1 and E_3 were 85.47 g and 94.41 g, respectively. The overall mean recorded was 97.26 g.

4.1.3.9 Net plot yield

Environmental indices were found to be negative for E_1 (-0.32) and E_3 (-0.14). Positive environmental index was recorded for E_2 (0.47). Highest environmental mean was observed for E_2 (3.50 kg) and least was recorded for E_1 (2.71 kg). Environmental means of E_3 was 2.89 kg. Overall mean observed was 3.03 kg.

4.1.3.10 Total yield

Environmental indices were found to be negative for E_1 (-1.88) and E_3 (-0.83). Positive environmental index was recorded for E_2 (2.70). Highest environmental mean was observed for E_2 (20.25 q) and least was recorded for E_1 (15.67 q). Environmental means of E_3 was 16.72 q. Overall mean observed was 17.55 q.

4.1.3.11 100 seed weight

Positive environmental index was recorded for E_1 (0.51) and E_2 (0.58). Environmental index of 100 seed weight was negative for E_3 (-1.09). Environmental mean was maximum for E_2 (27.15 g) and minimum for E_3 (25.48 g). Environmental means of 100 seed weight recorded for E_1 was 27.08 g. The overall mean observed was 26.57 g.

4.1.3.12 Oil content

Environmental index was negative for E_3 (-0.39). Positive environmental indices were observed for E_1 (0.20) and E_2 (0.19). Environmental means recorded were 48.79 per cent, 48.78 per cent and 48.19 per cent for E_1, E_2 and E_3, respectively. The overall mean observed was 48.59 per cent.

4.1.4 Pooled analysis of variance

Pooled analysis of variance was carried out for 12 quantitative characters to partition the total variance (mean sum of squares) due to known and unknown causes which were worked out using the method suggested by Sundararaj *et al.* (1972). The analysis of variance for yield and its component characters under study indicated highly significant variation among the genotypes, environments and genotype x environment for all the characters across six environments (Table 7) permits for stability analysis.

4.1.5 Analysis of variance for performance stability

Eberhart and Russell (1996) model of stability analysis was used for the assessment of environment influence and genotype × environment interaction on genotype for each character. When the genotype × environment interaction were significant for the characters, then partitioning of total sum of squares due to genotype × environment interactions into predictable and unpredictable source of variations was done using the procedure given by Eberhart and Russell (1966).

Analysis of variance for stability of 12 different characters over three environments are given in Table 8. Genotypic pooled differences over environments were significant for most of the characters. Variance due to environments and environments (linear) was significant for all the characters. G × E was non-significant for all the characters except for length of primary spike, effective length of primary spike, yield per plant, net plot yield and total yield, whereas, G x E (linear) were found to be significant for all the characters except plant height, number of nodes to primary spike, number of spike per plant, average number of capsules per spike and 100 seed weight. As regard to pooled deviation, it was significant for the characters plant height, days to flower initiation, length of primary spike, number of spike per plant, average number of capsules per spike and 100 seed weight.

4.1.6 Stability parameters

The three stability parameters *viz.,* mean $(\overline{X})$, regression coefficient (b_i) and deviation from linear regression line (S^2d_i) were estimated for all the 12 traits and the same has been presented in the Table 9.

4.1.6.1 Plant height

Among the hybrids tested, DCH-519 with mean plant height of 173.93 cm was the tallest and RHC-1 (146.06 cm) was the shortest. The check GCH-4 with a mean plant height of 133.47 cm was the shortest among all the genotypes. Among the varieties GC-3 (169.21 cm) had maximum plant height and PCS-4 had least plant height of 145.95 cm. The check for varieties 48-1 recorded the mean plant height of 168.18 cm and the overall population mean observed was 156.42 cm.

Table 7. Analysis of variance for pooled data for twelve quantitative traits of castor (*Ricinus communis* L.) over three environments

	d.f.	Mean sum of squares											
		Plant height	**Days to flower initiation**	**Number of nodes to primary spike**	**Length of primary spike**	**Effective length of primary spike**	**Number of spikes/ plant**	**Average number of capsules per spike**	**Yield per plant**	**Net plot yield**	**Total yield**	**100 seed weight**	**Oil content**
Genotypes	13	353.29**	15.71**	1.69**	59.54**	52.73**	1.15**	17.68**	421.35**	0.43**	13.51**	4.71**	3.12**
Environments	5	6852.66**	22.97**	4.06**	306.20**	382.67**	5.84**	67.69**	2527.52**	2.41**	84.39**	12.45**	1.61**
Genotype x Environments	65	317.95**	5.47**	0.65**	23.55**	19.56**	0.82**	9.60**	262.05**	0.24**	8.76**	1.56**	0.29**
Error	84	17.63	1.46	0.13	8.50	7.95	0.14	1.89	48.95	0.03	0.99	0.42	0.29

* Significant at 0.05 probability level and ** Significant at 0.01 probability level

Table 8. Analysis of variance for stability of castor genotypes for twelve quantitative traits of castor (*Ricinus communis* L.) over three environments

Sources	d.f.	Plant height	Days to flower initiation	Number of nodes to primary spike	Length of primary spike	Effective length of primary spike	Number of spikes/ plant	Average number of capsules per spike	Yield per plant	Net plot yield	Total yield	100 seed weight	Oil content
Genotypes	13	353.29	15.71**	1.69**	59.54**	52.73**	1.15	17.68	421.35**	0.43**	13.51**	4.71*	3.12**
Env.+ (Genotypes × Env.)	28	784.72*	6.72*	0.89	43.74**	45.50**	1.18	13.75	423.87**	0.39**	14.16**	2.34	0.39*
Environments	2	6852.66**	22.97**	4.06**	306.20**	382.67**	5.84*	67.67**	2527.52**	2.41**	84.39**	12.45**	1.61**
Genotypes × Environments	26	317.95	5.47	0.65	23.55**	19.56*	0.82	9.60	262.05**	0.24**	8.76**	1.56	0.29
Environments (Linear)	1	13705.33**	45.94**	8.13**	612.39**	765.35**	11.69**	135.35**	5055.04**	4.81**	168.78**	24.90**	3.21**
Genotypes × Environments (Linear)	13	334.11	7.85*	0.84	41.43**	31.07**	0.48	9.95	449.11**	0.43**	15.87**	1.48	0.42*
Pooled Deviation	14	280.24**	2.88*	0.42**	5.26	7.48	1.08**	8.58**	69.64	0.041	1.54	1.51**	0.16
Pooled Error	78	17.63	1.46	0.13	8.50	7.95	0.14	1.89	48.95	0.030	1.52	0.42	0.29

* Significant at 0.05 probability level and ** Significant at 0.01 probability level

All the hybrids and varieties studied recorded non-significant regression coefficients (b_i). Hybrids GCH-5, GCH-7, DCH-519 and RHC-1 and varieties, DCS-107, PCS-136, PCS-262, and GC-3 had mean deviations from regression (S^2d_i) values which were significantly different from zero. Hybrids GCH-6, PCH-111 and variety GC-3 were having mean values higher than population mean and b_i and S^2d_i values not significantly deviating from unity and zero respectively. Hybrid DCH-177 and variety PCS-4 have shown lower mean than population mean with b_i and S^2d_i values not significantly deviating from unity and zero respectively.

4.1.6.2 Days to flower initiation

Among the genotypes tested in three environments, maximum number of days for flower initiation was observed for DCS-107 (43.11) and minimum number of days to flower initiation was recorded for PCH-111 (34.67). Hybrid check GCH-4 and varietal check 48-1 recorded 37.00 and 38.67 mean number of days for flower initiation. Over all mean observed was 38.75 days.

Most of the hybrids and varieties exhibited non-significant deviation from regression (b_i) value except RHC-1, which was significantly deviating from unity. Among the hybrids GCH-5 and among varieties, DCS-107 recorded the mean deviations from regression values (S^2d_i) significantly different from zero. Hybrids GCH-6, GCH-7, DCH-177, PCH-111 and GCH-4 (check) and varieties PCS-4, PCS-262 and 48-1 (check) a recorded lower mean over population mean with b_i and S^2d_i values not significantly deviating from unity and zero respectively.

4.1.6.3 Number of nodes upto primary spike

Among the hybrids, the maximum (14.82) and minimum (12.51) number of nodes are recorded for DCH-519 and RHC-1, respectively. Variety DCS-107 (13.39) recorded highest number of nodes and PCS-262 (12.12) recorded the minimum number of nodes upto primary spike. Mean number of nodes upto primary spike for checks GCH-4 and 48-1 were 12.19 and 13.24, respectively. The mean number of nodes of genotypes tested over six environments was 13.03.

Among the genotypes studied, GCH-6 and GC-3 shown the regression values (b_i) significantly deviating from unity. Mean deviation from regression was significantly deviating from zero for the genotypes RHC-1, PCH-111, DCS-107, PCS-4, PCS-262 and GCH-4 (check). Hybrids GCH-5, GCH-7, DCH-177, DCH-519 and variety 48-1 (check) recorded highest mean values over population mean with non-significant b_i values and significant S^2d_i values. Variety PCS-136 had lower mean values with b_i and S^2d_i values not significantly deviating from unity and zero respectively.

4.1.6.4 Length of primary spike

Among the hybrids studied across six environments, GCH-7 (56.66 cm) recorded maximum and PCH-111 (42.79 cm) had minimum length of primary spike among hybrids. In case of varieties, PCS-262 (54.66 cm) and PCS-4 (46.60 cm) recorded highest and lowest values for mean length of primary spike, respectively. Checks GCH-4 and 48-1 had mean values of 58.42 cm and 48.46 cm, respectively. Overall mean of six environments observed was 49.98 cm.

All the hybrids, except GCH-7, RHC-1 and GCH-4 (check), exhibited non- significant regression coefficient (b_i) value from unity and similar trend was observed for all varieties studied. Among hybrids and varieties studied, none of the genotypes recorded mean deviation from regression (S^2d_i) significant from zero. Population mean higher than over all mean with non-significant b_i values and S^2d_i values were recorded for the genotype DCH-177, PCS-136, PCS-262 and GCH-4 (check).

4.1.6.5 Effective length of primary spike

Table 9. Stability parameters for various traits of caster hybrids and varieties

Genotypes	Plant height (cm)				Days to flower initiation				Number of nodes to primary spike			
	μ	S^2d_i	b_i	Rank	μ	S^2d_i	b_i	Rank	μ	S^2d_i	b_i	Rank
GCH-5	165.95	270.53**	2.15	14	40.67	9.23**	1.14	2	13.88	-0.09	1.52	5
GCH-6	158.61	48.53	1.63	10	37.22	-0.41	0.36	6	12.88	-0.12	0.09*	9
GCH-7	159.48	453.39**	1.49	8	37.67	2.83	2.58	11	13.17	0.11	0.41	7
DCH-177	154.13	52.252	1.23	4	38.00	2.81	0.07	10	13.73	-0.02	1.84	8
DCH-519	173.93	525.34**	1.84	13	41.00	-0.30	0.69	5	14.82	0.23	3.39	13
RHC-1	146.06	1025.03**	0.68	5	40.11	-1.38	-1.73*	13	12.51	0.43*	-1.47	14
PCH-111	157.68	-3.308	0.90	2	34.67	-0.81	1.12	1	12.86	1.24**	0.59	3
DCS-107	152.22	92.39*	0.62	6	43.11	9.82**	1.64	7	13.39	0.65*	2.10	11
PCS-4	145.95	49.13	0.31	12	36.33	-1.08	1.80	9	12.53	0.43*	1.46	4
PCS-136	149.43	157.88**	0.33	11	40.56	-0.97	-0.99	12	12.28	-0.11	1.15	2
PCS-262	155.62	246.84**	0.45	9	37.11	0.79	1.18	4	12.12	0.66*	0.48	6
GC-3	169.21	712.63**	0.56	7	40.44	-0.36	1.15	3	12.76	-0.13	0.88*	1
Checks												
GCH-4	133.47	-5.64	1.05	1	37.00	-0.04	0.24	8	12.19	0.66*	-0.44	12
48-1	168.18	45.23	0.78	3	38.67	0.56	4.76	14	13.24	0.14	2.00	10
Population mean	**156.42**				**38.75**				**13.03**			

* Significant at 0.05 probability level, ** Significant at 0.01 probability level, **μ-** Overall mean, **b_i** – Regression coefficient and **S^2d_i** – Deviation from regression

Contd....

Genotypes	**Length of primary spike (cm)**				**Effective length of primary spike (cm)**				**Number of spikes/ plant**			
	μ	**S^2d_i**	**b_i**	**Rank**	**μ**	**S^2d_i**	**b_i**	**Rank**	**μ**	**S^2d_i**	**b_i**	**Rank**
GCH-5	47.51	-7.53	0.57	5	43.67	-6.04	0.51	6	8.81	1.18**	1.66	11
GCH-6	47.77	5.71	1.34	3	43.79	23.68	1.05	2	9.24	4.68**	1.67	12
GCH-7	56.66	-8.80	2.70*	13	52.61	-7.82	2.07*	12	8.81	-0.05	0.55	9
DCH-177	53.91	-8.53	0.66	4	48.88	-7.93	0.42	8	8.36	0.16	-0.68	13
DCH-519	48.38	-5.79	0.46	7	47.54	3.75	1.02	1	8.25	-0.07	0.71	5
RHC-1	46.29	-8.83	0.06*	11	41.42	-4.99	0.56	5	7.11	2.89**	1.05	1
PCH-111	42.79	-4.58	-0.73	14	39.74	-3.52	-0.43	14	8.65	0.44*	1.11	3
DCS-107	47.67	-7.57	1.89	9	44.35	-5.81	1.81	10	8.23	0.15	0.87	4
PCS-4	46.60	1.34	1.08	1	41.36	-8.04	1.23	4	7.94	1.11**	0.53	10
PCS-136	50.55	3.91	0.26	8	47.26	12.33	0.42	7	9.09	0.07	2.71	14
PCS-262	54.66	-3.85	0.49	6	48.70	10.89	0.41	9	9.19	1.04**	0.67	7
GC-3	47.16	-5.09	0.78	2	43.13	-4.22	0.91	3	8.81	-0.04	1.10	2
Checks												
GCH-4	58.42	-8.73	1.92*	10	53.91	-6.67	1.88	11	9.32	-0.08	0.70	6
48-1	48.86	8.21	2.53	12	46.20	-4.11	2.14	13	9.22	1.79**	1.36	8
Population mean	**49.98**				**45.90**				**8.64**			

* Significant at 0.05 probability level, ** Significant at 0.01 probability level, **μ-** Overall mean, **b_i** – Regression coefficient and **S^2d_i** – Deviation from regression

Contd....

Genotypes	**Average capsules per spike**				**Yield per plant (g)**				**Net plot yield (kg)**			
	μ	**S^2d_i**	**b_i**	**Rank**	**μ**	**S^2d_i**	**b_i**	**Rank**	**μ**	**S^2d_i**	**b_i**	**Rank**
GCH-5	61.99	0.29	1.12	3	103.13	-46.75	0.56*	6	3.15	-0.02	0.38	8
GCH-6	61.30	-1.69	1.42	7	116.50	181.74*	0.84	2	3.52	-0.03	1.04	1
GCH-7	66.13	-1.30	2.50	12	110.88	-46.72	3.00**	13	3.69	-0.01	3.67	14
DCH-177	66.44	22.81**	1.37	4	106.02	161.76*	0.11	10	3.37	0.11*	0.21	9
DCH-519	61.30	-0.05	0.63	5	85.77	-41.45	0.52	7	2.74	-0.02	0.75	4
RHC-1	63.94	1.79	1.63	10	79.87	94.45	0.26	9	2.38	0.04	-0.20	11
PCH-111	61.21	0.21	1.94	11	113.01	-31.48	3.61	14	3.34	0.03	2.83	13
DCS-107	62.99	5.18	1.48	8	83.90	-22.98	0.83	3	2.64	0.00	0.88	2
PCS-4	63.28	11.37**	1.50	9	91.59	177.09*	1.70	8	2.84	0.09*	1.56	7
PCS-136	64.42	26.95**	-1.43	14	98.79	-45.32	0.02*	11	3.13	-0.02	0.07	10
PCS-262	68.26	7.70	-0.70	13	87.91	-42.19	-0.41	12	2.81	-0.02	-0.32	12
GC-3	60.33	-0.14	0.91	2	87.37	-46.23	1.19	4	2.77	-0.03	1.47	5
Checks												
GCH-4	66.32	22.19**	0.63	6	104.59	53.81	1.03	1	3.31	0.07	1.13	3
48-1	65.26	-0.07	0.99	1	92.28	-26.41	0.77	5	2.78	-0.03	0.51	6
Population mean	**63.80**				**97.26**				**3.03**			

* Significant at 0.05 probability level, ** Significant at 0.01 probability level, **μ-** Overall mean, **b_i** – Regression coefficient and **S^2d_i** – Deviation from regression

Contd....

Genotypes	Total yield (q ha $^{-1}$)				100 seed weight (g)				Oil content (%)			
	μ	**S^2d_i**	**b_i**	**Rank**	**μ**	**S^2d_i**	**b_i**	**Rank**	**μ**	**S^2d_i**	**b_i**	**Rank**
GCH-5	18.56	-0.70	0.61	6	28.2	-0.3	2.42	13	48.67	-0.17	1.31	3
GCH-6	20.10	-1.23	0.82	3	28.7	-0.02	1.23	4	48.19	-0.24	-1.47	14
GCH-7	20.42	0.26	2.94	13	27.75	5.42**	0.27	9	48.08	-0.28	3.43*	13
DCH-177	19.26	3.83	0.04	10	26.2	-0.11	1.21	3	48.07	-0.29	-0.91*	12
DCH-519	15.48	-1.03	0.46	7	27.8	0.96	-0.1	11	49.13	-0.08	2.57	11
RHC-1	14.30	1.79	0.17	9	25.56	-0.01	1.24	5	48.12	-0.09	0.32	5
PCH-111	20.70	-0.96	3.73*	14	27.33	-0.2	1.65	8	47.33	0.09	2.25	10
DCS-107	15.21	-0.34	0.83	2	25.65	0.27	-0.26	12	46.76	0.2	0.37	4
PCS-4	16.79	3.39	1.78	8	26.52	2.67**	1	1	49.94	-0.21	0.14	8
PCS-136	17.93	-1.35	-0.07	11	25.89	0.17	2.97	14	50.33	-0.24	0.29	6
PCS-262	16.15	-1.24	-0.37	12	26.71	1.80*	0.59	6	49.26	-0.25	2.12	9
GC-3	15.81	-1.44	1.30	4	25.83	1.1	1.1	2	48.92	-0.28	1.02	1
Checks												
GCH-4	19.11	1.76	1.08	1	25.68	-0.38	0.43	7	47.74	-0.25	1.76	7
48-1	16.33	-1.42	0.67	5	24.15	4.14*	0.26	10	49.72	0.25	0.81	2
Population mean	**17.58**				**26.57**				**48.59**			

* Significant at 0.05 probability level, ** Significant at 0.01 probability level, **μ-** Overall mean, **b_i** – Regression coefficient and **S^2d_i** – Deviation from regression

Maximum effective length of primary spike observed for hybrids was GCH-7 (52.61 cm) and minimum effective length of primary spike was recorded for PCH-111 (39.74 cm). Variety PCS-262 (48.70 cm) had higher mean value among the varieties and PCS-4 (41.36 cm) shown the minimum effective primary spike length. Checks GCH-4 and 48-1 recorded the mean effective length of 53.91 cm and 46.20 cm, respectively. The overall mean of genotypes across six environments was 45.90 cm.

All the genotypes, except GCH-7, shown b_i values not significantly deviating from unity including checks and significant S^2d_i values deviating from the zero was recorded for none of the genotypes. Among the genotypes studied hybrids DCH-177, DCH-519 and GCH-4 (check) and varieties PCS-136, PCS-262 and 48-1 (check) recorded mean values higher than the population mean with b_i and S^2d_i values not significantly deviating from unity and zero respectively.

4.1.6.6 Number of spikes plant^{-1}

Among the hybrids tested across three environments, highest number of spikes plant^{-1} was observed for GCH-6 (9.24) and RHC-1 (7.11) had least number of spikes. Among varieties PCS-262 (9.19) had maximum number spikes and minimum was observed for PCS-4 (7.94). Population mean of genotypes across the environments was 8.64.

Regression coefficient (b_i) was non-significant for all the genotypes studied. Mean deviations from regression coefficients (S^2d_i) were significantly deviating from zero for hybrids GCH-5, GCH-6, RHC-1, PCH-111, and varieties PCS-4, PCS-136 and 48-1 (check). Mean values higher than the overall mean with b_i and S^2d_i values not significantly deviating from unity and zero respectively was recorded for hybrids studied *viz.*, GCH-7, GCH-4 (check) and variety PCS-136.

4.1.6.7 Average number of capsules spike^{-1}

Among the hybrids studied, highest number of capsules per spike was observed in DCH-177 (66.44) and lowest number of capsules was recorded in PCH-111 (61.21). Among varieties, number of capsules ranged from 60.33 for GC-3 to 68.26 for PCS-262. Checks GCH-4 and 48-1 recorded the mean values of 66.32 and 65.26, respectively. Population mean observed was 63.80.

All the hybrids tested shown positive and non-significant regression coefficient (b_i) values. Varieties also exhibited positive non-significant regression coefficient (b_i) values except, PCS-136 and PCS-262 which were negative. Mean deviation from regression (S^2d_i) was significantly deviating from zero for the hybrids DCH-177 and check GCH-4. Varieties PCS-4 and PCS-136 exhibited S^2d_i values significantly deviating from zero. Mean values higher than population mean with non-significant b_i values and S^2d_i values was observed in hybrid GCH-7 and varieties, PCS-262 and 48-1 (check).

4.1.6.8 Yield plant^{-1}

Among the hybrids tested across three environments, GCH-6 (116.50 g) recorded highest mean yield plant $^{-1}$ and RHC-1 (79.87 g) has the lowest yield plant $^{-1}$. Among varieties, PCS-136 (98.79 g) exhibited highest yield plant $^{-1}$ and lowest yield plant $^{-1}$ was recorded for DCS-107 (83.90 g). Mean yield plant $^{-1}$ of 104.59 g and 92.28 g was observed for GCH-4 and 48-1, respectively. Population mean across the environments was 97.26 g. Genotypes GCH-5 and GCH-7 also recorded mean yield plant $^{-1}$ higher than the population mean.

Among the genotypes studied, hybrids GCH-5, GCH-7 and variety PCS-136 shown regression coefficient (b_i) values significantly deviating from zero and variety PCS-262 recorded negative regression coefficient (b_i) values not deviating from zero. Most of the hybrids had mean deviation from regression (S^2d_i) values non-significantly deviating from zero except GCH-6 and DCH-177. Among the varieties, except PCS-4, all the genotypes exhibited non-significant mean deviation from regression (S^2d_i) values. Among the genotypes studied, PCH-111 and check GCH-4 had higher mean yield plant $^{-1}$ over the population mean and non-significant b_i values and S^2d_i values. Non-significant b_i values with significant S^2d_i values and higher mean over the population mean was recorded for hybrid GCH-6 and DCH-177.

4.1.6.9 Net plot yield

Among the hybrids, the maximum (3.69 kg) and minimum (2.38 kg) net plot yield were shown by GCH-7 and RHC-1, respectively. Variety PCS-136 had highest (3.13 kg) mean net plot yield and lowest (2.64 kg) mean net plot yield was recorded for DCS-107. Checks GCH-4 and 48-1 exhibited the mean net plot yield of 3.31 kg and 2.78 kg respectively. The overall mean for net plot yield across six environments was 3.03 kg.

All the hybrids and varieties tested, all the genotypes recorded non significant positive regression coefficients (b_i) values except RHC-1 and PCS-262. Hybrid DCH-177 had values of mean deviation from regression (S^2d_i) significantly deviating from zero, while the remaining were non-significant. Among varieties, PCS-4 exhibited mean deviation from regression (S^2d_i) significantly deviating from zero. Genotype GCH-5, GCH-6, GCH-7, PCH-111, PCS-136 and GCH-4 (check) had higher mean yield with b_i and S^2d_i values not significantly deviating from unity and zero respectively.

4.1.6.10 Total yield

The maximum (20.70 q ha^{-1}) and minimum (14.30 q ha^{-1}) net plot yield were shown by PCH-111 and RHC-1, respectively among the hybrids. Variety PCS-136 had highest (17.93 q ha^{-1}) mean net plot yield and lowest (15.21 q ha^{-1}) mean net plot yield was recorded for DCS-107. Checks GCH-4 and 48-1 exhibited the mean net plot yield of 19.11 q ha^{-1} and 16.33 q ha^{-1} respectively. The overall mean for net plot yield across six environments was 17.58 q ha^{-1}.

All the hybrids and varieties tested across the locations, all the genotypes recorded non significant regression coefficients (b_i) values except PCH-111. Hybrid DCH-177 had values of mean deviation from regression (S^2d_i) significantly deviating from zero, while the remaining were non-significant. Among varieties, PCS-4 exhibited mean deviation from regression (S^2d_i) significantly deviating from zero. Genotype GCH-5, GCH-6, GCH-7, DCH-177, PCH-111, PCS-136 and GCH-4 (check) had higher mean yield with b_i and S^2d_i values not significantly deviating from unity and zero respectively.

4.1.6.11 100 seed weight

Among the hybrids tested, GCH-6 (28.70 g) recorded highest 100 seed weight and lowest was reported for RHC-1 (25.56 g). Variety PCS-262 (26.71 g) exhibited highest 100 seed weight and lowest mean 100 seed weight was observed for 48-1 (24.15 g). Checks exhibited the mean 100 seed weight of 25.68 g for GCH-4 and 24.15 g for 48-1. Overall 100 seed weight across the environments was 26.57 g.

Regression coefficient (b_i) values of all the genotypes studied were not deviating significantly from unity. Hybrid DCH-519 and variety DCS-107 recorded non significant b_i values. All the hybrids studied shown non-significant deviation from zero for mean deviation from regression values except GCH-7. All the varieties studied exhibited non-significant deviation from zero for mean deviation from regression values except PCS-4 and PCS-262. Among hybrids, GCH-5, GCH-6, DCH-519 and PCH-111 recorded higher mean over the population mean and non-significant b_i values and S^2d_i values. Mean value higher than population mean with non-significant b_i value and significant S^2d_i values was shown by hybrid GCH-7 and PCS-262.

4.1.6.12 Oil content

Among hybrids, DCH-519 (49.13 %) recorded maximum oil content and PCH-111 (47.33 %) recorded minimum oil content. Maximum oil content found in the varieties was 50.33 per cent for PCS-136 and DCS-107 (46.76 %) had minimum oil content. Check GCH-4 and 48-1 recorded the mean oil content of 47.74 per cent and 49.72 per cent, respectively. Observed mean oil content for six environments was 48.59 per cent.

All the genotypes recorded non significant b_i values except GCH-7 and DCH-177. Mean deviation from regression were also non significant for all the genotypes. Mean values higher than population mean with non-significant b_i values and S^2d_i values was observed for the hybrids GCH-5, DCH-519 and varieties PCS-4, PCS-136, PCS-262, GC-3 and 48-1 (check).

4.2 Character association and path coefficient analysis

4.2.1 Correlation analysis of yield and its yield component traits

Among all traits, selection for seed yield is a complex phenomenon that involved interaction among different growth and yield contributing character of a genotype. In the present investigation an attempt was made to understand association of different traits at population level contributing towards yield improvement in different environments. The phenotypic correlation of grain yield per plant with other yield components among the hybrids and varieties of castor in different environments are worked out and same is presented in Table 10, 11 & 12.

The different characters under study revealed that seed yield exhibited significant positive correlation with few yield traits, but also exhibited significant negative association with few other traits. The results obtained in different environments on the basis of association of individual trait with grain yield are presented below.

4.2.1.1 Correlation analysis of yield and its yield component traits in Environment-1 (Dharwad)

The phenotypic correlation of grain yield per plant with other yield components among the hybrids and varieties of castor in environment-I are worked out and same is presented in Table 10.

4.2.1.1.1 Plant height

The data revealed the plant height has highly significant positive association with days to flower initiation (0.52) and number nodes up to primary spike (0.50). It showed negative non-significant association with length of primary spike (-0.08) and number capsules per spike (-0.10).

Table 10. Phenotypic correlations among different quantitative traits of castor (*Ricinus communis* L.) at Dharwad (E_1)

Characters	**X1**	**X2**	**X3**	**X4**	**X5**	**X6**	**X7**	**X8**	**X9**	**X10**
X1 : Plant height	1.00	0.52**	0.50**	-0.08	0.04	0.28	-0.10	0.16	0.14	0.04
X2 : Days to flower initiation		1.00	0.62**	-0.24	-0.20	-0.11	-0.18	-0.11	-0.01	-0.19
X3 : Number of nodes upto primary spike			1.00	-0.11	-0.17	-0.20	-0.30	0.10	0.14	-0.18
X4 : Length of primary spike				1.00	0.88**	0.35*	0.58**	-0.19	-0.17	0.72**
X5 : Effective length of primary spike					1.00	0.44**	0.55**	-0.19	-0.21	0.71**
X6 : Number of spikes per plant						1.00	0.52**	0.00	-0.24	0.58**
X7 : Number of capsules per spike							1.00	-0.35*	-0.44**	0.74**
X8 : 100 seed weight								1.00	0.66**	-0.34*
X9 : Oil content									1.00	-0.30
X 10 : Yield per plant										1.00

* Significant at 0.05 probability level, ** Significant at 0.01 probability level.

4.2.1.1.2 Days to flower initiation

Days to flower initiation showed significant and positive association with number nodes up to primary spike (0.62) and plant height (0.52) and negative non-significant association with all the remaining characters.

4.2.1.1.3 Number of nodes upto primary spike

Number of nodes upto primary spike recorded significant and positive association with days to flower initiation (0.62) and plant height (0.50). Non-significant positive relationship was observed for 100 seed weight (0.10) and oil content (0.14) at phenotypic level.

4.2.1.1.4 Length of primary spike

Length of primary spike observed highly significant positive phenotypic association with effective length of primary spike (0.88) which was highest among all the characters studied and it also recorded significant positive association with yield per plant (0.72), number of capsules per spike (0.58) and number of spikes per plant (0.35).

4.2.1.1.5 Effective length of primary spike

Effective length of primary spike revealed the existence of high significant positive association with length of primary spike (0.88), yield per plant (0.71), number of capsules per spike (0.55) and number of spikes per plant (00.44).

4.2.1.1.6 Number of spikes per plant

Number of spikes per plant showed its high significant positive association with yield per plant (0.58), and number of capsules per spike (0.52), effective length of primary spike (0.44) and length of primary spike (0.35).

4.2.1.1.7 Average number of capsules per spike

There was high significant positive correlation between number of capsules per spike and yield per plant (0.74) followed by length of primary spike (0.58), effective length of primary spike (0.55), and number of spikes per plant (0.52). Negative significant association was recorded for 100 seed weight (-0.35) and oil content (-0.44).

4.2.1.1.8 100 seed weight

100 seed weight recorded highly significant positive correlation with oil content (0.66) and negative significant association was recorded for number of capsules per spike (-0.35) and yield per plant (-0.34).

4.2.1.1.9 Oil content

Oil content showed significant positive correlation with 100 seed weight (0.66) and negative significant association was recorded for number of capsules per spike (-0.35) and negative non-significant association with yield per plant (-0.44).

4.2.1.1.10 Yield per plant

Yield per plant revealed highly significant positive correlation with number of capsules per spike (0.74), length of primary spike (0.72), effective length of primary spike (0.71), and number of spikes per plant (0.58). Negative significant correlation was recorded for 100 seed weight (-0.34) and negative non-significant association with oil content (-0.30).

Table 11. Phenotypic correlations among different quantitative traits of castor (*Ricinus communis* L.) at Devihosur (E_2)

Characters	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
X1 : Plant height	1.00	0.39*	0.35*	-0.12	-0.14	-0.14	-0.11	0.16	0.16	-0.17
X2 : Days to flower initiation		1.00	0.08	-0.22	-0.21	-0.32*	-0.18	0.23	0.31*	-0.31*
X3 : Number of nodes upto primary spike			1.00	-0.24	-0.23	-0.39*	-0.33*	-0.19	0.07	-0.32*
X4 : Length of primary spike				1.00	0.96**	0.74**	0.72**	0.10	-0.07	0.77**
X5 : Effective length of primary spike					1.00	0.70**	0.67**	0.04	-0.07	0.73**
X6 : Number of spikes per plant						1.00	0.71**	0.15	-0.08	0.82**
X7 : Number of capsules per spike							1.00	0.01	-0.23	0.81**
X8 : 100 seed weight								1.00	0.26	-0.04
X9 : Oil content									1.00	-0.15
X 10 : Yield plant^{-1}										1.00

* Significant at 0.05 probability level, ** Significant at 0.01 probability level.

4.2.1.2 Correlation analysis of yield and its yield component traits in Environment-2 (Devihosur)

The phenotypic correlation of grain yield per plant with other yield components among the hybrids and varieties of castor in environment-II are worked out and same is presented in Table 11.

4.2.1.2.1 Plant height

Plant height recorded significant positive phenotypic correlation with days to flower initiation (0.39) and number of nodes up to primary spike (0.35). 100 seed weight (0.16) and oil content (0.16) recorded positive non-significant association at phenotypic level.

4.2.1.2.2 Days to flower initiation

Days to flower initiation showed significant and positive association with oil content (0.31) and significant negative association was observed for number of spikes per plant (-0.32) and yield per plant (-0.31).

4.2.1.2.3 Number of nodes upto primary spike

Number of nodes upto primary spike recorded significant negative phenotypic association with number of spikes per plant (-0.39), number of capsules per spike (-0.33) and yield per plant (-0.32), whereas, it recorded significant positive phenotypic association with plant height (0.35).

4.2.1.2.4 Length of primary spike

Highly significant positive phenotypic association was found between length of primary spike and effective length of primary spike (0.96) followed by yield per plant (0.77), number of spikes per plant (00.74) and number of capsules per spike (0.72).

4.2.1.2.5 Effective length of primary spike

Effective length of primary spike showed highly significant phenotypic association with length of primary spike (0.96), yield per plant (0.73), number of spikes per plant (0.70) and number of capsules per spike (0.67).

4.2.1.2.6 Number of spikes per plant

Number of spikes per plant recorded highly significant and positive correlation with yield per plant (0.82), length of primary spike (0.74), number of capsules per spike (0.71), effective length of primary spike (0.67). Negative significant phenotypic association was observed for days to flower initiation (-0.32) and number of nodes upto primary spike (-0.39).

4.2.1.2.7 Average number of capsules per spike

Number of capsules per spike was found having high significant positive correlation with yield per plant (0.81) followed by length of primary spike (0.72), number of spikes per plant (0.71) and effective length of primary spike (0.67).

4.2.1.2.8 100 seed weight

100 seed weight recorded non-significant negative correlation with yield per plant (-0.04) and number of nodes upto primary spike (-0.19) and positive non-significant association was recorded for remaining characters.

4.2.1.2.9 Oil content

Oil content showed significant positive correlation with days to flower initiation (0.31) and its association with remaining characters is non-significant.

4.2.1.2.10 Yield per plant

Yield per plant revealed high significant positive correlation with number of spikes per plant (0.82), number of capsules per spike (0.81), length of primary spike (0.77), effective length of primary spike (0.73), whereas, days to flower initiation (-0.31) and number of nodes upto primary spike (-0.32) recorded negative significant association.

4.2.1.3 Correlation analysis of yield and its yield component traits in environment-3 (Hanumanamatti)

The phenotypic correlation of grain yield per plant with other yield components among the hybrids and varieties of castor in environment-III are worked out and same is presented in Table 12.

4.2.1.3.1 Plant height

The result revealed positive highly significant phenotypic association between plant height and days to flower initiation (0.36). Negative significant correlation was recorded for length of primary spike (-0.44), effective length of primary spike (-0.38) and yield per plant (-0.32).

4.2.1.3.2 Days to flower initiation

Days to flower initiation showed significant and negative association with number of capsules per spike (-0.48), length of primary spike (-0.40), yield per plant (-0.40) and effective length of primary spike (-0.37). Significant positive association was observed for plant height (0.36).

4.2.1.3.3 Number of nodes upto primary spike

Number of nodes upto primary spike recorded significant positive phenotypic association with 100 seed weight (0.51). It recorded significant positive and negative phenotypic association with other traits.

4.2.1.3.4 Length of primary spike

High and significant positive phenotypic association was found between length of primary spike and effective length of primary spike (0.82) followed by yield per plant (0.68), number of capsules per spike (0.64) and number of spikes per plant (00.32). It recorded negative and non-significant phenotypic association with plant height (-0.44) and days to flower initiation (-0.40).

4.2.1.3.5 Effective length of primary spike

Effective length of primary spike showed highly significant phenotypic association with length of primary spike (0.96), yield per plant (0.73), number of spikes per plant (0.70) and number of capsules per spike (0.67).

4.2.1.3.6 Number of spikes per plant

Number of spikes per plant recorded highly significant and positive correlation with length of primary spike (0.82), yield per plant (0.67), number of capsules per spike (0.65) and effective length of primary spike (0.37). Negative non-significant phenotypic association was observed for days to flower initiation (-0.22).

4.2.1.3.7 Average number of capsules per spike

Average number of capsules per spike was found having high significant positive correlation with yield per plant (0.77) followed by effective length of primary spike (0.65), length of primary spike (0.64) and number of spikes per plant (0.33). Negative significant phenotypic association was observed for days to flower initiation (-0.48).

Table 12. Phenotypic correlations among different quantitative traits of castor (*Ricinus communis* L.) at Hanumanamatti (E_3)

Characters	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
X1 : Plant height	1.00	0.36*	0.07	-0.44**	-0.38*	0.03	-0.26	0.21	-0.04	-0.33*
X2 : Days to flower initiation		1.00	0.08	-0.40**	-0.37*	-0.22	-0.48**	-0.18	0.24	-0.40**
X3 : Number of nodes upto primary spike			1.00	-0.04	-0.10	0.08	-0.09	0.51**	-0.25	-0.07
X4 : Length of primary spike				1.00	0.82**	0.32*	0.64**	0.08	-0.23	0.68**
X5 : Effective length of primary spike					1.00	0.37*	0.65**	0.04	-0.26	0.67**
X6 : Number of spikes per plant						1.00	0.33*	0.41**	0.00	0.47**
X7 : Number of capsules per spike							1.00	0.01	-0.07	0.77**
X8 : 100 seed weight								1.00	-0.26	0.04
X9 : Oil content									1.00	-0.12
X 10 : Yield plant^{-1}										1.00

* Significant at 0.05 probability level, ** Significant at 0.01 probability level.

4.2.1.3.8 100 seed weight

100 seed weight recorded significant positive correlation with number nodes upto primary spike (0.51) and number of spikes per plant (0.33).

4.2.1.1.9 Oil content

Oil content showed non-significant negative correlation with most of the characters except number nodes upto primary spike (0.24).

4.2.1.3.10 Yield per plant

Yield per plant revealed high significant positive correlation with number of capsules per spike (0.77), length of primary spike (0.68), effective length of primary spike (0.67) number of spikes per plant (0.47). Negative significant correlation was recorded for plant height (-0.33) and days to flower initiation (-0.40).

4.2.2 Path coefficient analysis

To get the idea about the actual effects of a character on the yield, path analysis was employed. Improve of dependent character like yield, which is governed by many independent characters, is possible by careful study of direct or indirect effects of other characters. Hence, sometimes even character showing significant correlation with the yield may not be considered for improvement as its correlation with yield may be due to the indirect effects of this trait through other characters. Under these circumstances, it is always more appropriate to split the correlation value into direct and indirect effects through path coefficient analysis. This would facilitate the final weightage to be given while considering a character for selection to improve economic yield. Path coefficient values showing direct and indirect effects of components traits on grain yield per plant in different environments are presented in the Table 13, 14 & 15.

4.2.2.1 Path coefficient analysis of yield and its yield component traits in environment-1 (Dharwad)

Path coefficient values showing direct and indirect effects of components traits on yield per plant are presented in the Table 13.

4.2.2.1.1 Direct effects of different component characters on yield per plant

The results revealed that, among the characters studied, number of capsules per spike had highest positive direct effect of 0.346 on yield per plant followed by number of spikes per plant (0.274), length of primary spike (0.248), oil content (0.171), effective length of primary spike (0.151), number of nodes upto primary spike (0.084) and plant height (0.074), while, 100 seed weight (-0.267) and days to flower initiation (-0.101) showed negative indirect effect.

4.2.2.1.2 Indirect effects of different component characters on yield per plant

Plant height showed high values of positive indirect effects on yield per plant via days to flower initiation (0.038) and number of nodes upto primary spike (0.027), whereas negative indirect effects on yield per plant were very negligible.

Days to flower initiation showed positive indirect effects to yield per plant via most of the characters except plant height (-0.058) and number of nodes upto primary spike (-0.059).

Number of nodes upto primary spike recorded high positively indirect effects via days to flower initi ation (0.046) and plant height (0.017). High negative indirect effects on yield per plant were recorded for number of capsules per spike (-0.022), number of spikes per plant (-0.015) and effective length of primary of spike (-0.012).

Table 13. Direct (diagonal) and indirect effects of yield component traits on yield per plant at phenotypic level in castor (*Ricinus communis* L.) at Dharwad (E_1)

Characters	X1 : Plant height	X2 : Days to flower initiation	X4 : Length of primary spike	X4 : Length of primary spike	X5 : Effective length of primary spike	X6 : Number of spikes per plant	X7 : Number of capsules per spike	X8 : 100 seed weight	X9 : Oil content	X 10 : Yield plant^{-1} r value
X1	**0.074**	0.038	0.027	-0.004	0.002	0.015	-0.006	0.009	0.008	0.04
X2	-0.058	**-0.101**	-0.059	0.027	0.022	0.013	0.020	0.012	0.001	-0.193
X3	0.017	0.046	**0.084**	-0.008	-0.012	-0.015	-0.022	0.008	0.010	-0.182
X4	-0.019	-0.06	-0.027	**0.248**	0.218	0.086	0.143	-0.047	-0.042	0.716**
X5	0.006	-0.03	-0.025	0.133	**0.151**	0.066	0.084	-0.029	-0.031	0.712**
X6	0.076	-0.031	-0.054	0.095	0.119	**0.274**	0.144	0.000	-0.066	0.584**
X7	-0.036	-0.063	-0.103	0.200	0.192	0.181	**0.346**	-0.122	-0.174	0.737**
X8	-0.043	0.029	-0.027	0.051	0.051	0.000	0.094	**-0.267**	-0.177	-0.337*
X9	0.022	-0.002	0.021	-0.026	-0.031	-0.036	-0.067	0.100	**0.171**	-0.3

Note : Residual effect= 0.295

Indirect contribution of length of primary spike to yield per plant was positive and highest for effective length of primary spike (0.218) and number of capsules per spike (0.143) and negative and highest for 100 Seed weight (-0.047) and oil content (-0.042). The direct and indirect contributions to yield per plant by remaining traits were in negligible magnitude.

A highest positive indirect effect of effective length of primary spike on yield per plant was highest and positive through length of primary spike (0.133) and contributions from rest of the traits were lower in magnitude.

Indirect effects of number of spikes per plant on yield per plant was positive for most of the traits except for oil content (-0.066), days to flower initiation (-0.031) and number of nodes upto primary spike (-0.025).

Highest and positive indirect effects of number of capsules per spike on yield per plant was recorded for length of primary spike (0.200), effective length of primary spike (0.192) and number of spikes per plant (0.181) and rest of the characters shown negative indirect contributions to yield per plant.

The Phenotypic correlation of 100 Seed weight had negative contribution to grain yield in most of the traits except for days to flower initiation (0.029), length of primary spike (0.051), effective length of primary spike (0.051) and number of capsules per spike (0.094).

Indirect effects of oil content on yield per plant was negative via most of the traits except through plant height (0.022), number of nodes upto primary spike (0.021) and 100 seed weight (0.100)

4.2.2.2 Path coefficient analysis of yield and its yield component traits in environment-2 (Devihosur)

Path coefficient values showing direct and indirect effects of components traits on yield per plant are presented in the Table 14.

4.2.2.2.1 Direct effects of different component characters on yield per plant

The results indicated that, among the characters studied, number of spikes per plant had highest positive direct effect of 0.422 on yield per plant followed by number of capsules per spike (0.361), length of primary spike (0.297) and oil content (0.068). Negative direct effects on yield per plant was recorded highest for 100 seed weight (-0.086) followed by, days to flower initiation (-0.037), plant height (-0.022), effective length of primary spike (-0.009) and number of nodes upto primary spike (-0.008).

4.2.2.2.2 Indirect effects of different component characters on yield per plant

Plant height showed negative indirect effects on yield per plant via days to flower initiation (-0.008), number of nodes upto primary spike (-0.008), 100 seed weight (-0.003) and oil content (-0.003) and rest of the characters have shown positive indirect contributions.

Highest positive indirect effects on yield per plant by days to flower initiation was observed via number of spikes per plant (0.012) and highest negative indirect effects was recorded for 100 seed weight (-0.028), plant height (-0.014) and oil content (-0.012).

Number of nodes upto primary spike recorded positive indirect effects on yield per plant through most of the characters except for plant height (-0.003), days to flower initiation (-0.001) and oil content (-0.001).

Table 14. Direct (diagonal) and indirect effects of yield component traits on yield per plant at phenotypic level in castor (*Ricinus communis* L.) at Devihosur (E_2)

Characters	X1 : Plant height	X2 : Days to flower initiation	X4 : Length of primary spike	X4 : Length of primary spike	X5 : Effective length of primary spike	X6 : Number of spikes per plant	X7 : Number of capsules per spike	X8 : 100 seed weight	X9 : Oil content	X 10 : Yield plant^{-1} r value
X1	**-0.022**	-0.008	-0.008	0.003	0.003	0.003	0.002	-0.003	-0.003	-0.174
X2	-0.014	**-0.037**	-0.003	0.008	0.008	0.012	0.007	-0.028	-0.012	-0.308*
X3	-0.003	-0.001	**-0.008**	0.002	0.002	0.003	0.003	0.002	-0.001	-0.324*
X4	-0.030	-0.057	-0.061	**0.297**	0.245	0.189	0.185	0.025	-0.019	0.772**
X5	0.008	0.012	0.014	-0.056	**-0.009**	-0.041	-0.040	-0.023	0.004	0.727**
X6	-0.058	-0.133	-0.164	0.291	0.294	**0.422**	0.300	0.063	-0.065	0.824**
X7	-0.039	-0.064	-0.121	0.261	0.242	0.257	**0.361**	0.005	-0.082	0.810**
X8	-0.020	-0.029	0.025	-0.032	-0.046	-0.019	-0.002	**-0.086**	-0.043	-0.038
X9	0.004	0.009	0.002	-0.002	-0.012	-0.002	-0.006	0.007	**0.068**	-0.153

Note : Residual effect= 0.327

Contribution of length of primary spike to yield per plant was high and positive via effective length of primary spike (0.245), number of spikes per plant (0.189) and number of capsules per spike (0.185). Negative indirect effects were high for number of nodes upto primary spike (-0.061) and days to flower initiation (-0.057). Indirect effects of remaining characters were in negligible magnitude.

Contribution of effective length of primary spike to yield per plant was positive and negligible in magnitude for most of the traits except for length of primary spike (-0.056), number of spikes per plant (-0.041) and 100 seed weight (-0.023) whose correlation coefficients are low in magnitude.

Number of spikes per plant recorded high and positive indirect effects on yield per plant through number of capsules per spike (0.300), effective length of primary spike (0.294) and length of primary spike (0.291). Negative indirect effects on yield per plant was observed via number of nodes upto primary spike (-0.164) and days to flower initiation (-0.133).

Number of capsules per spike's contribution to yield per plant was positive and high through length of primary spike (0.261), number of spikes per plant (0.257) and effective length of primary spike (0.242). This trait contributed negatively to yield per plant mainly through number of nodes upto primary spike (-0.121).

Both positive indirect effects and negative indirect effects of oil content on yield per plant were in negligible magnitude.

4.2.2.3 Path coefficient analysis of yield and its yield component traits in environment-3 (Hanumanamatti)

Path coefficient values showing direct and indirect effects of components traits on yield per plant are presented in the Table 15.

4.2.2.3.1 Direct effects of different component characters on yield per plant

Among the characters studied, number of capsules per spike (0.520), number of spikes per plant (0.257), effective length of primary spike (0.230), length of primary spike (0.206) and days to flower initiation (0.040) had highest positive direct effect on yield per plant. Negative direct effects on yield per plant was recorded highest for plant height (-0.102), 100 seed weight (-0.066), oil content (-0.059) and number of nodes upto primary spike (-0.033).

4.2.2.3.2 Indirect effects of different component characters on yield per plant

Plant height showed negative indirect effects on yield per plant via days to flower initiation (-0.036), 100 seed weight (-0.022), number of nodes upto primary spike (-0.007), and number of spikes per plant (-0.003) and rest of the characters have shown positive indirect contributions.

Highest positive indirect effects on yield per plant by days to flower initiation were observed via plant height (0.014), oil content (0.010) and number of nodes upto primary spike (0.003), and rest of the traits recorded negative indirect effects.

Number of nodes upto primary spike recorded positive indirect effects on yield per plant through most of the characters except for 100 seed weight (-0.007), plant height (-0.001), days to flower initiation (-0.001) and number of capsules per spike (-0.001).

Table 15. Direct (diagonal) and indirect effects of grain yield component traits on grain yield per plant at phenotypic level in castor (*Ricinus communis* L.) at Hanumanamatti (E$_3$)

Characters	X1 : Plant height	X2 : Days to flower initiation	X4 : Length of primary spike	X4 : Length of primary spike	X5 : Effective length of primary spike	X6 : Number of spikes per plant	X7 : Number of capsules per spike	X8 : 100 seed weight	X9 : Oil content	X 10 : Yield plant^{-1} r value
X1	-0.102	-0.036	-0.007	0.045	0.039	-0.003	0.026	-0.022	0.004	-0.329*
X2	0.014	0.040	0.003	-0.016	-0.115	-0.009	-0.019	-0.007	0.010	-0.395**
X3	-0.001	-0.001	-0.033	0.001	0.001	-0.001	0.001	-0.007	0.003	-0.072
X4	-0.090	-0.082	-0.009	0.206	0.169	0.065	0.131	0.018	-0.047	0.679**
X5	-0.011	-0.011	-0.003	0.024	0.230	0.011	0.019	0.001	-0.008	0.67**
X6	0.007	-0.056	0.040	0.081	0.095	0.257	0.085	0.107	0.000	0.465**
X7	-0.134	-0.247	-0.045	0.331	0.339	0.172	0.520	0.005	-0.037	0.766**
X8	-0.014	0.012	-0.033	-0.006	-0.103	-0.027	-0.001	-0.066	0.017	0.044
X9	0.002	-0.014	0.015	0.013	0.015	0.000	0.004	0.015	-0.059	-0.117

Note : Residual effect= 0.2465

Contribution of length of primary spike to yield per plant was high and positive via effective length of primary spike (0.169), number of capsules per spike (0.131), number of spikes per plant (0.065) and 100 seed weight (0.018). Negative indirect effects were exhibited by plant height (-0.090), days to flower initiation (-0.082), oil content (-0.047) and number of nodes upto primary spike (-0.009).

Contribution of effective length of primary spike to yield per plant was positive though the traits length of primary spike (0.024), number of capsules per spike (0.019), number of spikes per plant (0.011) and 100 seed weight (0.001). Plant height (-0.011), days to flower initiation (-0.011), oil content (-0.008) and number of nodes upto primary spike (-0.003) showed negative indirect effects for effective length of primary spike to yield per plant.

Number of spikes per plant recorded high and positive indirect effects on yield per plant through all the characters except for days to flower initiation (-0.056). Highest positive indirect effects were recorded for 100 seed weight (0.107).

Number of capsules per spike contribution to yield per plant was positive and high through effective length of primary spike (0.339), length of primary spike (0.331) and number of spikes per plant (0.172).This trait contributed negatively to yield per plant mainly through days to flower initiation (-0.247), plant height (-0.134) and number of nodes upto primary spike (-0.045).

100 seed weight contributed negatively to yield per plant in lower magnitude via majority of characters except oil content (0.017) and days to flower initiation (0.012).

Oil content recorded positive indirect effects on yield per plant in lower magnitude via majority of characters except days to flower initiation (-0.014).

4.3 Genetic variability among castor genotypes for various morpho-physiological traits and their relationship with productivity

4.3.1 Analysis of variance for 14 genotypes of castor

Analysis of variance for 15 characters of 14 castor genotypes, grown at three locations *viz.,* Dharwad (E_1), Devihosur (E_2) and Hanumanamatti (E_3) during *kharif*-2015, was carried out and presented in the Table 3. Highly significant differences have been observed among the genotypes for all the characters studied.

4.3.2 Genetic variability, heritability and genetic advance

Variability parameters *viz.*, mean, range, phenotypic co-efficient of variation (PCV), genotypic co-efficient of variation (GCV), broad sense heritability and genetic advance expressed as per cent of mean with respect to all 15 characters in 14 genotypes of castor are presented in Table 16.

4.3.2.1 Plant height

In E_1, plant height ranged between 130.89 cm to 212.48 cm with a mean value of 168.00 cm, indicating high variation for this trait, which was coupled with moderate value of both GCV (14.68 %) and PCV (16.07 %). Broad sense heritability was high (83.41 %) coupled with high (27.60 %) genetic advance expressed as per cent of mean.

In E_2, plant height varied from 144.89 cm to 183.81 cm with a mean value of 168.72 cm, which was coupled with low value of both GCV (6.19 %) and PCV (7.19 %). Broad sense heritability was high (74.14 %) coupled with moderate genetic advance (10.99 %) expressed as per cent of mean.

In E_3, plant height ranged between 109.67 cm to 157.33 cm with a mean value of 133.97 cm, which was coupled with moderate value of both GCV (10.49 %) and PCV (11.64 %). Broad sense heritability was high (81.30 %) coupled with moderate genetic advance (19.49 %) expressed as per cent of mean.

4.3.2.2 Days flowering initiation

In E_1, days flowering initiation varied from 35.67 days to 46.33 days with a mean value of 39.95 days. GCV (6.86 %) and PCV (9.20 %) registered moderate values. Moderate broad sense heritability (55.59 %) and moderate genetic advance (10.53 %) expressed as per cent of mean was observed for this trait.

In E_2, days flowering initiation ranged between 34.67 days to 43.33 days with a mean value of 38.33 days, which was coupled with low value of both GCV (6.51 %) and PCV (8.36 %). Broad sense heritability was high (60.55 %) coupled with moderate genetic advance (10.43 %) expressed as per cent of mean.

In E_3, days flowering initiation varied from 33.33 days to 43.33 days with a mean value of 37.81 days. GCV (7.78 %) and PCV (10.09 %) registered low and moderate values, respectively. Moderate broad sense heritability (59.43 %) and moderate genetic advance (12.36 %) expressed as per cent of mean was observed for this trait.

4.3.2.3 Number of nodes upto primary spike

In E_1, number of nodes upto primary spike ranged between 12.27 and 16.80 with a mean value of 13.65 and low and moderate values of GCV (8.76 %) and PCV (10.81 %), respectively were recorded. Broad sense heritability was high (65.64 %) coupled with moderate (14.62 %) genetic advance expressed as per cent of mean.

In E_2, number of nodes upto primary spike ranged between 11.60 and 15.20 with a mean value of 13.32 indicating moderate range of variability. Low and moderate values of GCV (6.75 %) and PCV (9.30 %), respectively, were observed. Broad sense heritability was moderate (52.76 %) coupled with moderate (10.10 %) genetic advance expressed as per cent of mean.

In E_3, number of nodes upto primary spike varied from 12.13 and 14.87 with a mean value of 13.42 indicating less range of variability which is further confirmed by Low values of both GCV (4.59 %) and PCV (7.77 %). Broad sense heritability was moderate (34.98 %) coupled with low (5.60 %) genetic advance expressed as per cent of mean.

4.3.2.4 Length of primary spike

In E_1, length of primary spike varied between 39.47 cm and 70.42 cm with a mean value of 55.09 cm indicating high range of variability. The values of GCV (13.20 %) and PCV (15.73 %) were moderate coupled with high broad sense heritability (70.39 %) and high genetic advance (22.81 %) expressed as per cent of mean.

Table 16. Mean, range, genetic variability, heritability and genetic advance parameters for yield and its component traits in castor

Sl. No.	Characters	Environment	Mean	Range		GCV (%)	PCV (%)	h^2 (%)	GA	GAM (%)
				Min	Max					
1	Plant height (cm)	E_1	168.00	130.89	212.48	14.68	16.07	83.41	46.38	27.61
		E_2	168.72	144.89	183.81	6.19	7.19	74.14	18.54	10.99
		E_3	133.97	109.67	157.33	10.49	11.64	81.30	26.11	19.49
2	Days to flower initiation	E_1	39.95	35.67	46.33	6.86	9.20	55.59	4.21	10.53
		E_2	38.33	34.67	43.33	6.51	8.36	60.55	4.00	10.43
		E_3	37.81	33.33	43.33	7.78	10.09	59.43	4.67	12.36
3	Number of nodes upto primary spike	E_1	13.65	12.27	16.80	8.76	10.81	65.64	2.00	14.62
		E_2	13.32	11.60	15.20	6.75	9.30	52.76	1.35	10.10
		E_3	13.42	12.13	14.87	4.59	7.77	34.98	0.75	5.60
4	Length of primary spike (cm)	E_1	55.09	39.47	70.42	13.20	15.73	70.39	12.57	22.81
		E_2	48.74	41.63	58.25	7.48	11.27	44.02	4.98	10.22
		E_3	48.41	42.85	53.89	4.46	8.54	27.32	2.33	4.80
5	Effective length of primary spike (cm)	E_1	49.72	36.55	62.62	11.52	14.59	62.31	9.31	18.73
		E_2	43.79	38.48	47.78	4.71	8.58	30.14	2.33	5.33
		E_3	42.57	36.83	48.23	4.88	9.29	27.56	2.25	5.28
6	Number of spikes per plant	E_1	9.21	6.47	11.60	13.81	16.64	68.94	2.18	23.63
		E_2	7.86	6.21	8.80	7.91	10.71	54.58	0.95	12.04
		E_3	9.13	8.26	10.51	7.31	8.74	69.96	1.15	12.59
7	Average number of capsules per spike	E_1	40.94	37.54	46.95	5.78	6.80	72.07	4.14	10.10
		E_2	38.15	33.71	44.72	9.19	10.41	77.96	6.38	16.72
		E_3	35.91	30.86	45.14	9.83	13.36	54.13	5.35	14.89
8	Yield per plant (g)	E_1	86.29	72.39	100.11	11.46	14.61	61.52	15.98	18.52
		E_2	110.66	80.37	165.70	20.10	25.34	62.93	36.35	32.85
		E_3	91.68	67.51	122.89	14.96	18.31	66.70	23.07	25.16

Contd...

Sl. No.	Characters	Environment	Mean	Range		GCV (%)	PCV (%)	h^2 (%)	GA	GAM (%)
				Min	Max					
1	Net plot yield (kg)	E_1	2.64	2.19	3.08	11.93	15.17	61.90	0.51	19.34
		E_2	3.41	2.28	5.26	21.88	24.00	83.10	1.40	41.08
		E_3	2.82	2.15	3.55	12.64	16.03	62.15	0.58	20.53
2	Total yield (q ha^{-1})	E_1	15.02	12.46	17.48	11.93	15.17	61.90	2.90	19.34
		E_2	19.38	12.95	29.85	21.88	24.00	83.10	7.96	41.08
		E_3	16.02	12.21	20.13	12.64	16.03	62.15	3.29	20.53
3	100 seed weight (g)	E_1	26.45	22.21	28.93	7.03	7.85	80.25	3.43	12.98
		E_2	26.40	24.92	28.93	3.84	6.50	34.86	1.23	4.67
		E_3	24.88	22.11	27.21	5.06	6.61	58.63	1.99	7.99
4	Oil content (%)	E_1	47.70	46.62	49.06	1.54	2.21	48.59	1.05	2.21
		E_2	49.34	46.77	51.24	2.13	2.89	54.51	1.60	3.24
		E_3	47.58	45.10	49.73	2.37	3.13	57.19	1.75	3.69
5	SPAD at 75 DAS	E_1	36.23	33.2	40.83	5.91	6.9	73.44	3.78	10.43
		E_2	38.33	33.6	46.47	9.54	11.08	74.14	6.49	16.93
		E_3	35.62	32.33	39.6	5.5	7.04	61.00	3.15	8.85
6	SPAD at 90 DAS	E_1	49.67	43.7	58.13	7.65	10.14	56.87	5.9	11.88
		E_2	41.04	36.3	46.97	6.59	8.33	62.57	4.41	10.74
		E_3	45.3	37.93	51.03	7.01	8.65	65.68	5.3	11.71
7	SPAD at 120 DAS	E_1	54.64	49.07	61.07	5.81	8.56	46.08	4.44	8.13
		E_2	47.57	42.43	54.8	6.79	8.4	65.3	5.37	11.3
		E_3	53.58	48.77	59.43	4.95	6.33	61.27	4.28	7.99

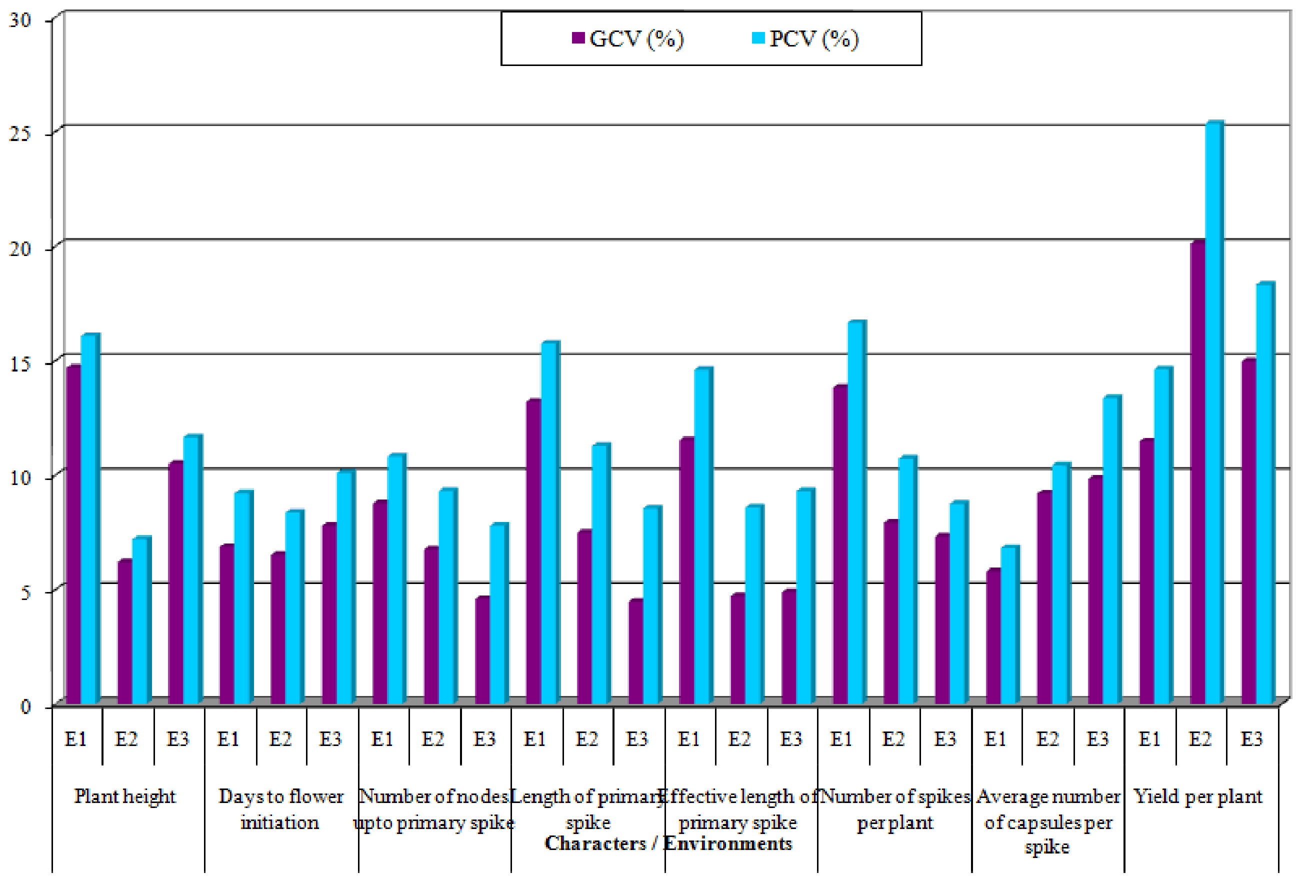
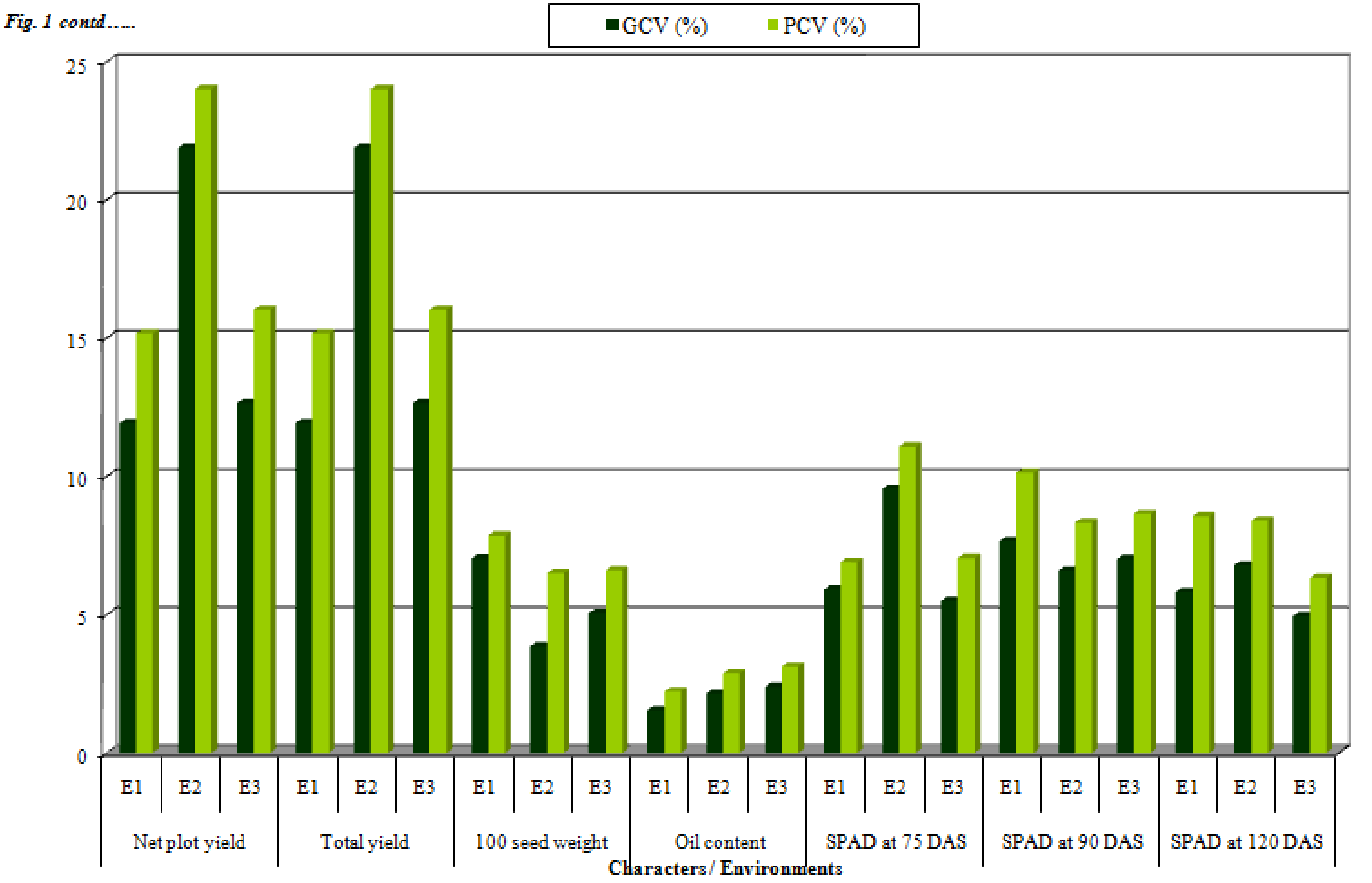


Fig.1: GCV and PCV parameters for yield and yield attributing characters of castor over three environments during *kharif*-2015

Fig. 1: GCV and PCV parameters for yield and yield attributing characters of castor over three environments during *kharif*-2015

Fig. 1 contd…..


GCV (%)
PCV (%)
25
20
15
10
5
0
E1
E2
E3
E1
E2
E3
E1
E2
E3
E1
E2
E3
E1
E2
E3
E1
E2
E3
E1
E2
E3
Net plot yield
Total yield
100 seed weight
Oil content
SPAD at 75 DAS
SPAD at 90 DAS
SPAD at 120 DAS
Characters / Environments

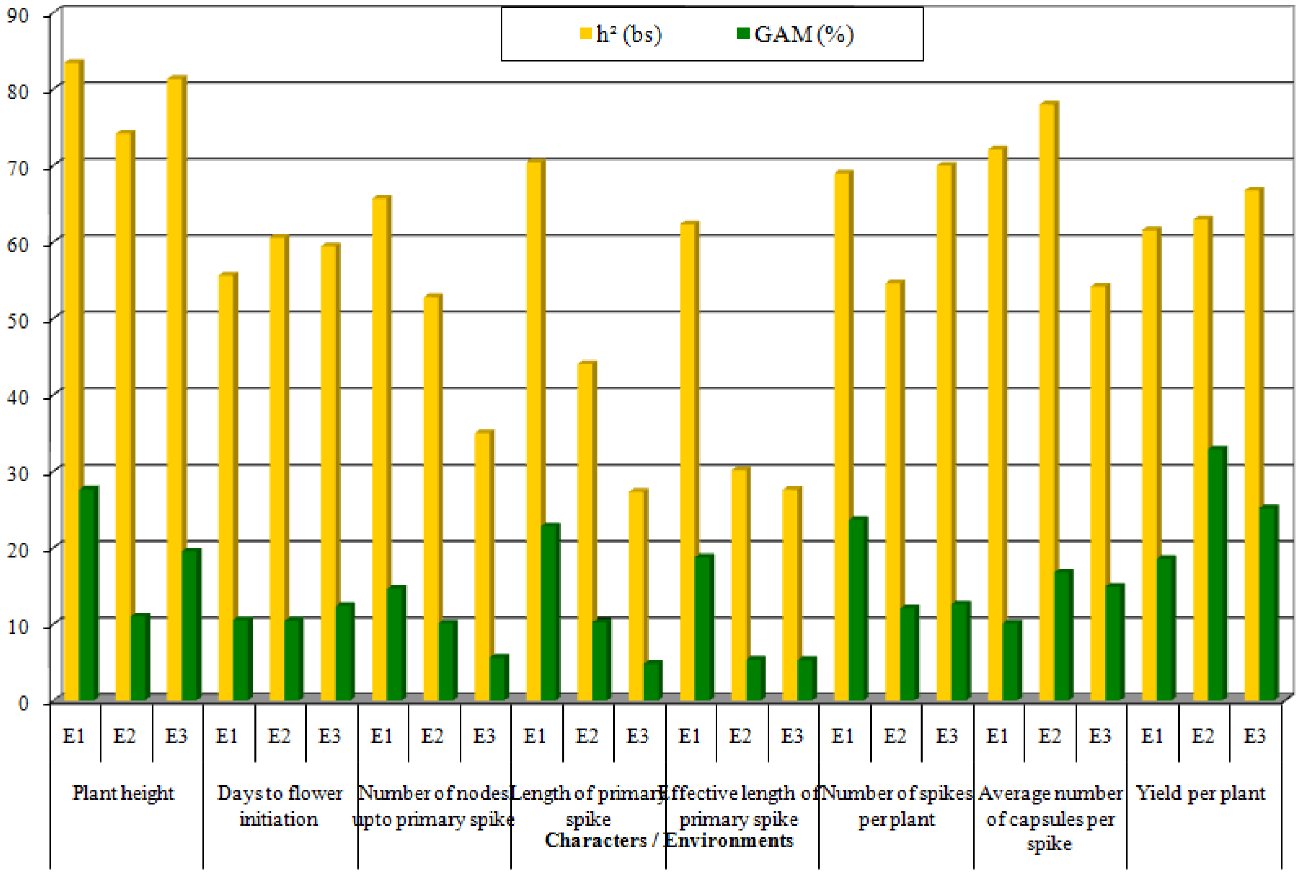
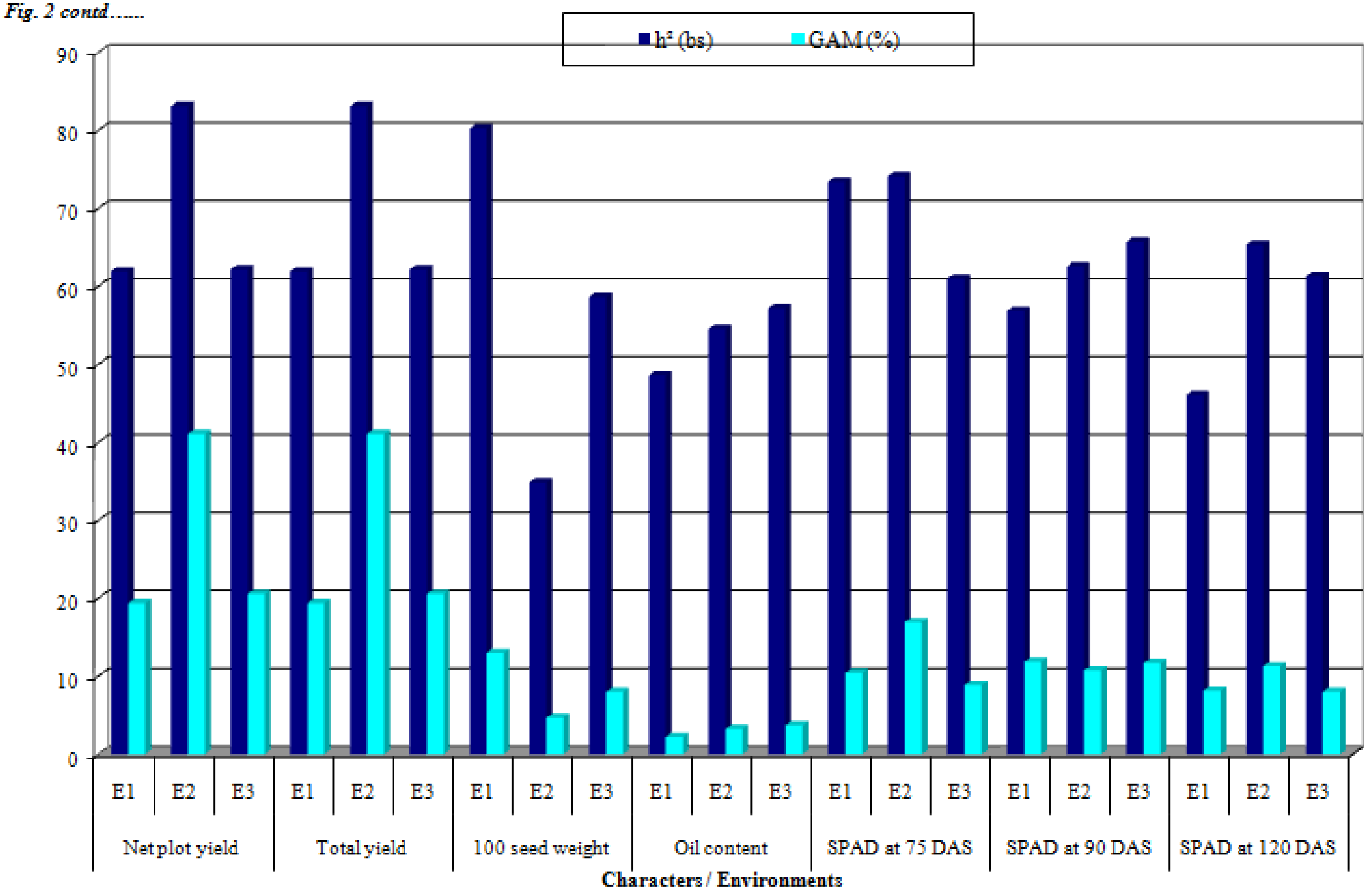


Fig. 2: Heritability (%) and genetic advance over mean (%) for yield and yield attributing characters of castor over three environments during *kharif*-2015

Fig. 2: Heritability (%) and genetic advance over mean (%) for yield and yield attributing characters of castor over three environments during *kharif*-2015

Fig. 2 contd……


h² (bs)
GAM (%)
90
80
70
60
50
40
30
20
10
0
E1
E2
E3
Net plot yield
Total yield
100 seed weight
Oil content
SPAD at 75 DAS
SPAD at 90 DAS
SPAD at 120 DAS
Characters / Environments

In E_2, length of primary spike ranged between 41.63 cm and 58.25 cm with a mean value of 48.74 cm indicating moderate range of variability. Low and moderate values of GCV (7.48 %) and PCV (11.27 %), respectively, were observed. Broad sense heritability was moderate (44.02 %) coupled with moderate (10.22 %) genetic advance expressed as per cent of mean.

In E_3, length of primary spike varied from 42.85 cm and 53.89 cm with a mean value of 48.41 cm indicating less range of variability which is further confirmed by Low values of both GCV (4.46 %) and PCV (8.54 %). Broad sense heritability was low (27.32 %) coupled with low (4.80 %) genetic advance expressed as per cent of mean.

4.3.2.5 Effective length of primary spike

In E_1, effective length of primary spike varied from 36.55 cm to 62.62 cm with a mean value of 49.72 cm. The values of GCV (11.52 %) and PCV (14.59 %) were moderate coupled with high broad sense heritability (62.31 %) and moderate genetic advance (18.73 %) expressed as per cent of mean.

In E_2, effective length of primary spike ranged between 38.48 cm and 47.78 with a mean value of 43.79 cm indicating moderate range of variability. Low values of GCV (4.71 %) and PCV (8.58 %) were observed. Broad sense heritability was moderate (30.14 %) coupled with low (5.33 %) genetic advance expressed as per cent of mean.

In E_3, effective length of primary spike varied from 36.83 cm and 48.23 cm with a mean value of 42.57 cm indicating less range of variability which is further confirmed by Low values of both GCV (4.88 %) and PCV (9.29 %). Broad sense heritability was low (27.56 %) coupled with low (5.28 %) genetic advance expressed as per cent of mean.

4.3.2.6 Number of spikes per plant

In E_1, number of spikes per plant ranged from 6.47 to 11.60 with a mean value of 9.21. The GCV (13.81 %) and PCV (16.64 %) values were moderate. Broad sense heritability (68.94 %) was high coupled with high genetic advance (23.63 %) expressed as per cent of mean.

In E_2, number of spikes per plant ranged between 6.21 and 8.80 with a mean value of 7.86 indicating less range of variability. Low and moderate values of GCV (7.91 %) and PCV (10.71 %), respectively, were observed and broad sense heritability was moderate (54.58 %) coupled with moderate (12.04 %) genetic advance expressed as per cent of mean.

In E_3, number of spikes per plant varied from 8.26 and 10.51 with a mean value of 9.13 indicating less range of variability which is further confirmed by Low values of both GCV (7.31 %) and PCV (8.74 %). Broad sense heritability was high (69.96 %) coupled with moderate (12.59 %) genetic advance expressed as per cent of mean.

4.3.2.7 Average number of capsules per spike

In E_1, average number of capsules per spike ranged from 37.54 to 46.95 with an average value of 40.94 indicating narrow range of variability. This was further confirmed by lower values of GCV (5.78 %) and PCV (6.80 %). Further, broad sense heritability (72.07 %) and genetic advance (10.10 %) expressed as per cent of mean recorded higher and moderate values, respectively.

In E_2, average number of capsules per spike varied from 33.71 to 44.72 with a mean value of 38.15. The GCV (9.19 %) and PCV (10.41 %) values were low and moderate, respectively. Broad sense heritability (77.96 %) was high coupled with moderate genetic advance (16.72 %) expressed as per cent of mean.

In E_3, average number of capsules per spike varied between 30.86 and 45.14 with a mean value of 35.91 indicating moderate range of variability. Low and moderate values of GCV (9.83 %) and PCV (13.36 %), respectively, were recorded and broad sense heritability was moderate (54.13 %) coupled with moderate (14.89 %) genetic advance expressed as per cent of mean.

4.3.2.8 Yield per plant

In E_1, yield per plant varied between 72.39 g to 100.11 g with a mean value of 86.29 g. This moderate range of variability was further confirmed by moderate GCV (11.46 %) and PCV (14.61 %) values. Further, the values of broad sense heritability (61.52 %) and genetic advance (18.52 %) expressed as per cent of mean were high and moderate, respectively.

In E_2, yield per plant ranged between 80.37 g and 165.70 g with a mean value of 110.66 g indicating wide range of variability and it is further confirmed by high values of both GCV (20.10 %) and PCV (25.34 %). Broad sense heritability was high (62.93 %) coupled with high (32.85 %) genetic advance expressed as per cent of mean.

In E_3, yield per plant ranged between 67.51 g and 122.89 g with a mean value of 91.68 g and moderate values of GCV (14.96 %) and PCV (18.31 %) were recorded. Broad sense heritability was high (66.70 %) coupled with high (25.16 %) genetic advance expressed as per cent of mean.

4.3.2.9 Net plot yield

In E_1, net plot yield ranged from 2.19 kg to 3.08 kg with an average value of 2.64 kg. The GCV (11.93 %) and PCV (15.17 %) values were moderate. Broad sense heritability (61.90 %) was high coupled with moderate genetic advance (19.34 %) expressed as per cent of mean.

In E_2, net plot yield ranged from 2.28 kg to 5.26 kg with an average value of 3.41 kg indicating wide range of variability. This was further confirmed by higher values of GCV (21.88 %) and PCV (24.00 %). Further, broad sense heritability (83.10 %) and genetic advance (41.08 %) expressed as per cent of mean recorded higher values.

In E_3, net plot yield varied from 2.15 kg to 3.55 kg with a mean value of 2.82 kg. The GCV (12.64 %) and PCV (16.03 %) values were moderate and broad sense heritability (62.15 %) was high coupled with high genetic advance (20.53 %) expressed as per cent of mean.

4.3.2.10 Total yield

In E_1, total yield ranged between 12.46 q and 17.48 q with a mean value of 15.02 q. The GCV (11.93 %) and PCV (15.17 %) values were moderate. Broad sense heritability (61.90 %) was high coupled with moderate genetic advance (19.34 %) expressed as per cent of mean.

In E_2, total yield ranged between 12.95 q and 29.85 q with a mean value of 19.38 q indicating wide range of variability. High values of GCV (21.88 %) and PCV (24.00 %) were observed and broad sense heritability was high (83.10 %) coupled with high (41.08 %) genetic advance expressed as per cent of mean.

In E_3, total yield varied from 12.21q and 20.13 q with a mean value of 16.02 q indicating moderate range of variability which is further confirmed by moderate values of both GCV (12.64 %) and PCV (16.03 %). Broad sense heritability was high (62.15 %) coupled with high (20.53 %) genetic advance expressed as per cent of mean.

4.3.2.11 100 seed weight

In E_1, 100 seed weight varied from 22.21 g to 28.93 g with a mean value of 26.45 g. Further, the values of GCV (7.03 %) and PCV (7.85 %) were high indicating narrow range of variability. Broad sense heritability registered high value (80.25 %) coupled with moderate genetic advance (12.98 %) expressed as per cent of mean.

In E_2, 100 seed weight ranged between 24.92 g and 28.93 g with a mean value of 26.40 g indicating less range of variability. Low values of GCV (3.84 %) and PCV (6.50 %) were observed and broad sense heritability was moderate (34.86 %) coupled with low (4.67 %) genetic advance expressed as per cent of mean.

In E_3, 100 seed weight varied from 22.11 g and 27.21 g with a mean value of 24.88 g indicating less range of variability which is further confirmed by low values of both GCV (5.06 %) and PCV (6.61 %). Broad sense heritability was moderate (58.63 %) coupled with low (7.99 %) genetic advance expressed as per cent of mean.

4.3.2.12 Oil percentage

In E_1, oil percentage ranged from 46.62 per cent to 49.06 per cent with a mean value of 47.70 per cent. However, both GCV (1.54 %) and PCV (2.21 %) values were low. But the value of broad sense was moderate (48.59 %) coupled with low (2.21 %) genetic advance expressed as per cent of mean.

In E_2, oil percentage ranged between 46.77 per cent and 51.24 per cent with a mean value of 49.34 per cent indicating narrow range of variability. Lower values of GCV (2.13 %) and PCV (2.89 %) were observed and broad sense heritability was moderate (54.51 %) coupled with low (3.24 %) genetic advance expressed as per cent of mean.

In E_3, oil percentage varied from 45.10 per cent and 49.73 per cent with a mean value of 47.58 per cent indicating narrow range of variability which is further confirmed by lower values of both GCV (2.37 %) and PCV (3.13 %). Broad sense heritability was moderate (57.19 %) coupled with low (3.69 %) genetic advance expressed as per cent of mean.

4.3.2.13 SPAD at 75 DAS

In E_1, SPAD varied from 33.2 to 40.83 with a mean value of 36.23. Further, the values of GCV (5.91 %) and PCV (6.90 %) were low indicating narrow range of variability. Broad sense heritability registered high value (73.44 %) coupled with moderate genetic advance (10.43 %) expressed as per cent of mean.

In E_2, SPAD ranged from 33.60 to 46.47 with an average value of 38.33 indicating moderate range of variability. This was further confirmed by low and moderate values of GCV (9.54 %) and PCV (11.08 %). Further, broad sense heritability (74.14 %) and genetic advance (16.93 %) expressed as per cent of mean recorded higher and moderate values.

In E_3, SPAD varied from 32.33 to 39.60 with a mean value of 35.62. The GCV (5.50 %) and PCV (7.04 %) values were low and broad sense heritability (61.00 %) was high coupled with low genetic advance (8.85 %) expressed as per cent of mean.

4.3.2.14 SPAD at 90 DAS

In E_1, SPAD varied from 43.70 to 58.13 with a mean value of 49.67. Further, the values of GCV (7.65 %) and PCV (10.14 %) were low and moderate indicating narrow range of variability. Broad sense heritability registered moderate value (56.87 %) coupled with moderate genetic advance (11.88 %) expressed as per cent of mean.

In E_2, SPAD ranged from 36.30 to 46.97 with an average value of 41.04 indicating moderate range of variability. This was further confirmed by low values of GCV (6.59 %) and PCV (8.33 %). Further, broad sense heritability (62.57 %) and genetic advance (10.74 %) expressed as per cent of mean recorded higher and moderate values.

In E_3, SPAD varied from 37.93 to 51.03 with a mean value of 45.30. The GCV (7.01 %) and PCV (8.65 %) values were low and broad sense heritability (65.68 %) was high coupled with moderate genetic advance (11.71 %) expressed as per cent of mean.

4.3.2.15 SPAD at 120 DAS

In E_1, SPAD varied from 49.07 to 61.07 with a mean value of 54.64. Further, the values of GCV (5.81 %) and PCV (8.56 %) were low indicating narrow range of variability. Broad sense heritability registered moderate value (46.08 %) coupled with low genetic advance (8.13 %) expressed as per cent of mean.

In E_2, SPAD ranged from 42.43 to 54.8 with an average value of 47.57 indicating moderate range of variability. The values of GCV (6.79 %) and PCV (8.4 %) recorded were low. Further, broad sense heritability (65.3 %) and genetic advance (11.3 %) expressed as per cent of mean recorded higher and moderate values.

In E_3, SPAD varied from 48.77 to 59.43 with a mean value of 53.58. The GCV (4.95 %) and PCV (6.33 %) values were low and broad sense heritability (61.27 %) was high coupled with low genetic advance (7.99 %) expressed as per cent of mean.

4.3.3 Relationship between various morpho-physiological traits and productivity of castor genotypes

The phenotypic correlation of grain yield per plant with other yield components among the hybrids and varieties of castor in different environments are worked out for *kharif*-2015 and same is presented in Table 17.

The different characters under study revealed that productivity of castor genotypes exhibited significant positive correlation with few yield traits, but also exhibited significant negative association with few other traits. The results obtained in different environments on the basis of association of individual trait with grain yield are presented below.

4.3.3.1 Correlation analysis of total yield (q ha^{-1}) and various morpho-physiological traits in Dharwad (E_1) during *kharif*-2015

A highly significant positive phenotypic association was found between total yield and effective length of primary spike (0.69), followed by length of primary spike (0.67). It also recorded positive and significant relationship with average number of capsules per spike (0.58), number of spikes per plant (0.42) and SPAD at 75 DAS (0.42). Positive and non-significant association was also recorded between total yield and SPAD at 90 DAS (0.28).

Table 17. Phenotypic relationship among different quantitative traits of castor

Characters		X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13
Total yield (q ha^{-1})	**E$_1$**	-0.13	-0.29	-0.31*	0.67**	0.69**	0.42**	0.58**	-0.08	-0.16	0.42**	0.28	-0.2	1
	E$_2$	-0.17	-0.36*	-0.23	0.42**	0.44**	0.52**	0.50**	-0.21	-0.15	0.47**	0.47**	-0.16	1
	E$_3$	-0.44**	-0.13	-0.46**	0.58**	0.55**	0.73**	0.74**	-0.19	0.02	0.34*	0.00	0.15	1

Note : * Significant at 0.05 probability level, ** Significant at 0.01 probability level.

E$_1$-Dharwad E$_2$- Devihosur E$_3$- Hanumanamatti
X1- Plant height X2- Days to flower initiation X3- Number of nodes upto primary spike
X4- Length of primary spike X5- Effective length of primary spike X6- Number of spikes per plant
X7- Avg. no. of capsules per spike X8-100 seed weight X9- Oil content
X10- SPAD at 75 DAS X11- SPAD at 90 DAS X12- SPAD at 120 DAS
X13- Total yield

High negative significant phenotypic association was recorded for number of nodes upto primary spike (-0.31). Negative non-significant phenotypic correlation was observed for days to flower initiation (-0.29), SPAD at 120 DAS (-0.20), oil content (-0.16), plant height (-0.13) and 100 seed weight (-0.08).

4.3.3.2 Correlation analysis of yield and its yield component traits in Devihosur (E_2) during *kharif*-2015

Total yield recorded highest significant positive phenotypic correlation between number of spikes per plant (0.52) and followed by its association with number of capsules per spike (0.50), SPAD at 75 DAS (0.47), SPAD at 90 DAS (0.47), effective length of primary spike (0.44) and length of primary spike (0.42).

Negative significant correlation was recorded for days to flower initiation (-0.36). Negative non-significant association was also observed for the traits like, number of nodes upto primary spike (-0.23), 100 seed weight (-0.21), plant height (-0.17), SPAD at 120 DAS (-0.16) and oil content (-0.15).

4.3.3.2 Correlation analysis of yield and its yield component traits in Hanumanamatti (E_3) during *kharif*-2015

Association of total yield between number of capsules per spike (0.74) was highest and positive significant. Phenotypic associations recorded were significant and positive also for other traits like number of spikes per plant (0.73), length of primary spike (0.58), effective length of primary spike (0.55) and SPAD at 75 DAS (0.34). SPAD at 120 DAS (0.15) and oil content recorded positive and non-significant association.

Plant height (-0.44) showed highest significant negative correlation with total yield following number of nodes upto primary spike (-0.46). 100 seed weight (-0.19) and days to flower initiation (-0.13) were non- significant and negatively associated with total yield.

5. DISCUSSION

The knowledge about the extent of fluctuations of yield and yield attributes over environments is very important to identify genotypes which are widely adapted. Grain yield is quantitatively inherited character and there is considerable interaction between genotypes and environments. Some of the genotypes are widely adapted, whereas others do not. Multilocation testing of genotypes provides an opportunity to the plant breeders to study the adaptability of genotypes to a particular environment and the stability of the genotype over different environments. The proportion of genotypic, environmental variance and their interaction (G × E) can be determined by employing useful biometrical and genetical methods. The information on genotype × environment interaction is of major importance to the plant breeder in developing improved stable varieties/hybrids. The ability of a genotype to produce a narrow range of phenotype in different environments can be called as stable. The genotypes will be stable in the absence of the environmental influence as well as genotype × environment interaction.

Eberhart and Russell (1966) model of stability analysis was used for the assessment of environmental influence and genotype × environmental interaction on genotypes for each character. When the genotype × environment interaction was significant for the characters, then partitioning of total sum of squares due to genotype × environment interactions into predictable and unpredictable source of variations is done.

The potential progress expected in accomplishing the objectives demands knowledge of interrelationships among various traits and component characters contributing to yield, which helps the breeder in the simultaneous improvement of several characters in the selection programme. Characters association may vary with environmental conditions. Association of economically important yield components of quantitative nature, which is statistically determined by correlation coefficient, is quite useful as a basis of selection. Path coefficient analysis is used to partition the association among characters into direct and indirect effects and measures the relative importance of the causal factors involved. It is simply a standardized partial regression coefficient and as such measures the direct influence of one variable upon another. The characters associated can be considered together as criteria for selection by plant breeders to identify traits that are useful as selection criteria to improve the crop yield.

Crop improvement largely depends on the extent of variability and its proper exploitation by the plant breeder. The plant breeder has to identify sources of favourable genes, incorporate them into breeding populations/lines and select for a combination of desirable traits that might result in the isolation of productive accessions/cultivars. To achieve these goals, plant breeders need to know the extent of variability present in a population. Some of the parameters like genotypic (GCV) and phenotypic (PCV) coefficients of variation are useful. High value of these coefficients indicates wider diversity. Similarly, narrow difference between GCV and PCV reveals low sensitivity to the environmental effects. Another indicator of variability is heritability, which is the ratio of genetic variance to total variance. This is broad sense heritability and gives an idea about that portion of observed variability which is attributable to genetic differences.

The estimates of heritability, however do not give indication of the amount of progress expected from the selection process. These estimates will be highly meaningful when accompanied by genetic advance (GA). GA is the measure of improvement that can be achieved by practicing selection. High genetic advance coupled with high heritability estimates is an indicator of high additive gene action.

In the present investigation, 12 castor genotypes were evaluated for various characters under fairly uniform and congenial environment along with 2 checks. During this study, an attempt was made to analyse stability of the genotypes across environments and also to understand the association among various characters related to grain yield and to investigate the direct and indirect effects of certain yield attributes. An attempt was also made to assess the genotypic and phenotypic variability and to estimate heritability in broad sense along with genetic advance as per cent mean in respect of different characters. The results obtained are discussed under the following heads:

5.1 Analysis of variance
5.2 Mean performance of genotypes in different locations
5.3 Stability analysis
5.4 Character association
5.5 Path coefficient analysis
5.6 Genetic variability, heritability and genetic advance as per cent mean at different location and their relationship with productivity.

5.1 Analysis of variance

The analysis of variance for mean data of all the 12 characters revealed the significant differences among the genotypes studied. This information indicates that sizable variability exists for all the characters studied and considerable improvement can be achieved in these characters by selection. However the analysis of variance by itself is inconclusive in explaining all the inherent genetic variability in the collection. This is evident by partitioning the total variability inherent in the genotypes from the phenotypic variance. Thus, it is necessary to work out the phenotypic and genotypic coefficients of variation which indicate the extent of variability existing for various traits. Earlier workers like Koutroubas *et al.* (1999), Joshi *et al.* (2002b), Halilu *et al.* (2013), Patel and Patel (2015b), and Gila and Manga (2015) have reported the significant differences among the genotypes for all the characters they have considered under different environments.

5.2 Mean performance of genotypes in different locations

The performance of 14 genotypes was studied for 12 different characters in three environments.

Out of three locations, Devihosur (170.25 cm) was more favourable for higher plant height followed by Dharwad (168.12 cm). Among the genotypes studied, hybrids GCH-5, GCH-6, GCH-7 and DCH-519 were significantly taller while the hybrid PCH-111 was numerically taller than the check GCH-4 and variety GC-3 was significantly superior to its check 48-1 in two environments and numerically superior than pooled over environments.

The comparison of environmental means for days to flower initiation and number of nodes upto primary spike indicated that more number of days to flowering (40.14) and maximum number of nodes (13.64) was observed at Dharwad. This might be due to favourable growing conditions compared to other locations. Hybrid PCH-111 and variety PCS-4 were early flowering in all the three environments as well as over environments. Hybrid RHC-1 and variety PCS-4 had lesser number of nodes than the checks GCH-4 and 48-1, respectively, under environments E_1 and E_2, while variety PCS-262 had lesser number of nodes than the check 48-1 over the environments.

With respect to length of primary spike and effective length of primary spike, expression of genotypes was better at Dharwad followed by Devihosur.

Dharwad recorded maximum number of spikes per plant (9.05) and Devihosur recorded the least number of spikes (7.90) over the locations. Hybrid GCH-6 registered significantly highest number of spikes per plant at E_1, while none of the hybrids were superior to the check in E_2 and E_3 and pooled environments. Among varieties, PCS-262 was found to be superior across the locations and in pooled environment along with PCS-136.

Among three environments, Dharwad (66.15) was found to be more favourable for better expression of number of capsules per spike followed by Devihosur (63.46). Considering the mean performance over locations for number of capsules per spike, hybrid DCH-177 and variety PCS-262 registered numerical superiority over the checks GCH-4 and 48-1, respectively, in pooled over environments analysis.

Environment had greater influence on yield per plant (-0.34 to 2.35), net plot yield (-0.32 to 0.47) and total yield (-0.32 to 0.47) as indicated by the range of environmental indices. Among the three locations, Dharwad was found to be more favourable for higher seed yield per plant followed by Devihosur and Hanumanamatti, whereas, Devihosur was found to be the most favourable environment for net plot yield and total yield. Hybrids GCH-6, GCH-7, DCH-177 and PCH-111, and varieties PCS-4, PCS-136 and PCS-262 recorded superiority for yield per plant (g), net plot yield (kg plot^{-1}) and total yield (q ha^{-1}) over the checks GCH-4 and 48-1, respectively, for all environments and also in pooled over environments analysis.

Out of three locations, Devihosur was more favourable for higher 100 seed weight (27.15 g) followed by Dharwad (27.08). Among the genotypes tested over three locations for 100 seed weight, most of the hybrids and varieties, expect hybrid RHC-1, recorded higher values than the checks GCH-4 and 48-1, respectively.

Environment had very little influence on oil content as indicated by very narrow range of environmental indices (-0.39 to 0.20) over the locations. All the hybrids, except DCH-177 and RHC-1, and varieties PCS-136 and PCS-4 recorded consistent performance across the environments and pooled over environments analysis, over the checks GCH-4 and 48-1, respectively.

5.3 Stability analysis

Castor is grown on a wide range of soil types of varying physical and chemical characteristics. Also, this crop is grown in all seasons and either as rain fed or inter cropped. Hence yield stability becomes a factor of prime importance. A precise knowledge of the nature and magnitude of genotype x environment interaction is important in understanding the stability in yield of a particular genotype before it is recommended for general cultivation. Hence, experiment was conducted in three locations *viz.,* Dharwad, Devihosur and Hanumanamatti for two years *viz., kharif*-2014 and *kharif*-2015. In the present study three locations were considered as different environments for the effective evaluation of hybrids and varieties.

Measurement of genotype x environment interaction however, has always intriguing problem in the past, though many attempts were made to resolve it. Proper evaluation of environments, which involves both predictable and unpredictable component, was never arrived at. By early 1950s the dead lock began to melt and a clearer concept of G x E interactions and stability of phenotypic performance has emerged. It was Finlay and Wilkinson (1963) who put forth a brilliant concept of the measure of both adaptability and environment. Later Eberhart and Russel (1966) modified and elaborated this method based on the regression technique for measuring the stability of genotypes. This method of stability analysis was then used by many scientist (Perkins and Jinks, 1971 and Lauret, 1995). Eberhart and Russell's method was preferable because of its explicit nature (Jowett, 1972).

Stability parameters were worked out for the hybrids and varieties to identify the genotypes for their adaptation over environments and to establish the interaction between genotypes and the different environments in which they are grown. Whatever is the adaptability of the genotypes under different environments, the primary requirement of a good variety or hybrid will be its superior mean performance across the environments. A genotype, which possesses universal adaptation, is recognized as a well-buffered genotype possessing high genetic homeostasis (Perkins and Jinks, 1971).

In the present investigation 12 genotypes and 2 checks were raised under three different environments and the stability parameters were worked out.

5.3.1 Analysis of variance for phenotypic stability

The analysis of variance revealed significant differences for most of the characters due to genotypes, environments and genotype x environmental interactions, showing enough diversity among genotypes and among environments. The analysis of variance for stability performance revealed the existence of genotype x environment interaction for the traits like length of primary spike, effective length of primary spike, yield per plant, net plot yield and total yield, indicating differential response of the genotypes to varying environments. MSS due to environment (linear) was significant for all the character indicating that environment effects are additive. The linear component of G x E interaction was also significant for character *viz.,* days to flower initiation, length of primary spike, effective length of primary spike, yield per plant, net plot yield, total yield and oil content indicating significant rate of linear response of the genotypes to environmental changes. The pooled deviation was also significant for the characters *viz.*, plant height, days to flower initiation, number of nodes upto primary spike, number of spikes per plant and average number of capsules per spike. Similar significant differences were also recorded by Kabariya and Gopani (1971), Ramaswamy and Madhav (1973), Henry and Daulbey (1985), Lauret (1988), Lauret (1995), Joshi *et al.* (2002b), Madariya *et al*. (2010), Patel *et al*. (2010a), Onkarappa *et al.* (2014), Patel and Patel (2015a) and Patel and Patel (2015b).

5.3.2 Stability analysis of individual characters

The main objective of the present investigation was to identify the stable genotype(s) over the three locations for different quantitative traits. The stability analysis was carried out by employing linear regression model given by Eberhart and Russell (1966). Although, there are number of models available to characterize the genotypes for their G × E interactions, but this model is widely used for its simplicity and reliability.

An ideal genotype is defined as the one possessing high mean performance with regression coefficient around unity ($b_i = 1$) and deviation from regression (S^2d_i) close to zero.

The linear regression is regarded as the measure of linear response of a particular genotype to the changing environment. If the regression coefficient (b_i) is greater than unity, the genotype is said to be highly sensitive to environmental fluctuations but adapted to high yielding environments. If the regression coefficient (b_i) is equal to unity, it indicates the average sensitivity to environmental fluctuations and adaptable to all environments. If the regression coefficient (b_i) is less than unity, it indicates less sensitivity to environmental changes and if it is accompanied by a high mean value, then the genotype is said to be better adapted for poor conditions.

In the present study, stability parameters such as mean (X) regression coefficient ($b_i = 1$) and deviation from regression (S^2d_i) as suggested by Eberhart and Russell (1966) were considered to explain and discuss the stability of different genotypes for various characters under consideration.

5.3.2.1 Plant height

Among the 14 genotypes tested, PCH-111 and 48-1 (c) possessed higher mean than the population with regression coefficient value (b_i) near to one and non-significant deviation from regression (S^2d_i). These genotypes had mean optimum plant height indicating that these genotypes are most stable and ideal across environments for plant height. While, the GCH-7 and GC-3 had high mean value with regression coefficient value nearer to unity and significant deviation from regression (S^2d_i # 0), thus, indicating its suitability for all environments with unpredictable performance. Genotypes with higher mean *viz.,* GCH-5 and DCH-519 with significant deviation from regression (S^2d_i) and GCH-6 with non-significant deviation from regression (S^2d_i) having regression coefficient (b_i) value more than one indicated that these genotypes are highly sensitive to environmental fluctuations but adapted to favourable environments with unpredictable and stable performances, respectively. The present results were in conformity with those of Patel *et al.* (2010a) and Manivel and Hussain (2001).

5.3.2.2 Days to flower initiation

The genotype which require minimum number of days to flower initiation are more desirable. So, the stability parameters for days to flower initiation showed that genotypes GCH-6, PCH-111 and PCS-262 were stable across the environments for earliness as they recorded lower mean than that of population and regression coefficient near to unity with non-significant deviation from regression. GC-3 recorded the maximum number of days to flower initiation, which was found to be late type with higher mean than that of population and regression coefficient near to unity with non-significant deviation from regression. So, GC-3 was also stable and ideal genotype for days to flower initiation as late flowering type. GCH-7 and 48-1 (c) recorded high and low mean values, respectively, and regression coefficient value more than one and non-significant deviation from regression indicating that the genotype is highly sensitive to environmental fluctuation but adapted to favourable environments. The present findings were in conformity with those of Patel *et al.* (2010a) and Manivel and Hussain (2001).

5.3.2.3 Number of nodes upto primary spike

The stability parameters for number of nodes upto primary spike showed that hybrids GCH-5 and GCH-7 were found stable across environments with mean values higher than the population mean. Among them, GCH-7 is the ideal genotype with minimum number of nodes upto primary spike. While, DCH-177, DCH-519 and 48-1 (c) had high mean value with regression coefficient value more than unity and non-significant deviation from regression, indicating that it is highly sensitive to environmental changes but adapted to favourable conditions. Genotypes GCH-6 had lower mean with the regression values less than unity, indicating their suitability to poor environments with lesser sensitivity to the changing environments. Similar type of results was also reported by Joshi *et al*. (2002a) and Thakkar *et al*. (2010) and Patel *et al*. (2011).

5.3.2.4 Length of primary spike

For length of primary spike, the genotypes DCH-177, PCS-136 and PCS-262 exhibited high mean with regression coefficient near to one and non-significant deviation from regression, indicating their wider adaptability across environments. Hence, they are stable. Among these, PCS-262 had highest mean values, so, it is ideal the genotype. GCH-7 and GCH-4 (c) with high mean and regression value more than unity and non-significant deviation from regression, indicating that it is highly sensitive to environmental changes but adapted to favourable conditions. These results are in accordance as reported by Manivel and Hussain (2001), Joshi *et al*. (2002a) and Thakkar *et al*. (2010).

5.3.2.5 Effective length of primary spike

Out of 14 genotypes tested over environments DCH-519, DCH-177 and PCS-136 showed higher mean, regression coefficient value near to one and non-significant deviation from regression. Hence, these genotypes are ideal genotypes with stable performance. Whereas, genotypes GCH-7, GCH-4 (c) and 48-1 (c) also had higher mean, but regression value more than one and non-significant deviation from regression indicating that these are highly sensitive to environmental changes but adapted to favourable environment. Variety PCS-262 recorded high mean value with regression value less than one and non-significant deviation from regression indicating its suitability to poor conditions. These results were in agreement with the results of Manivel and Hussain (2001).

5.3.2.6 Number of spike per plant

For number of spikes per plant, genotypes GCH-7, GC-3 and GCH-4 (c) exhibited higher mean number of spike per plant along with unit regression coefficient and non-significant deviation from regression indicating their stable performance. PCS-136 recorded higher mean value with regression value more than one and non-significant deviation from regression indicating that these are highly sensitive to environmental changes but adapted to favourable environment. GCH-6, PCH-111, PCS-262 and 48-1 (c) also had mean higher than population along with regression values near to unity and significant deviation from regression indicating average sensitivity of the genotype with unpredictable performances. Stable genotypes for number of spikes per plant were also reported earlier by Manivel and Hussain (2001).

5.3.2.7 Average number of capsules per spike

The stability parameters for average number of capsules per spike showed that genotypes RHC-1 and 48-1 (c) were stable across environments with unit regression coefficient and non-significant deviation from regression indicating their stable performance in the tested environments. The genotypes DCH-177 and PCS-4 had their mean higher than population along with regression values near to unity and significant deviation from regression indicating average sensitivity of the genotype with unpredictable performance. Genotype GCH-7 recorded higher mean value with regression value more than one and non-significant deviation from regression indicating that these are highly sensitive to environmental changes but adapted to favourable environment, while, PCS-136 and PCS-262 also recorded higher mean value but regression value was less than one with significant and non-significant deviation from regression, respectively, indicating its suitability to poor conditions with unpredictable and stable performances. These results were in agreement with the findings of Thakkar *et al.* (2010).

5.3.2.8 Seed yield per plant

Based on stability parameters, two genotypes GCH-5 and check GCH-4 (c) were stable across environments and GCH-4 (c) had higher mean than GCH-5 for seed yield per plant. So, among the 12 genotypes studied GCH-5 is the only genotype that is found stable across environments for yield per plant. While, GCH-7 and PCH-111 also had higher mean value for seed yield per plant with regression value more than one and non-significant deviation from regression indicating their higher sensitivity to environmental changes but adapted to favourable environment. The genotype GCH-6 had mean higher than population mean along with regression values near to unity and significant deviation from regression indicating average sensitivity of the genotype with unpredictable performance. Genotypes DCH-177 and PCS-136 also recorded higher mean value but regression value was less than one with significant and non-significant deviation from regression, respectively, indicating its suitability to poor conditions with unpredictable and stable performances. These results were in accordance with the reports of Manivel and Hussain (2001), Joshi *et al.* (2002), Kumara *et al.* (2003), Thakkar *et al.* (2010) and Sodavadiya and Dhaduk (2011).

5.3.2.9 Net plot yield

The stability parameters for net plot yield showed that genotypes GCH-5, GCH-6 and GCH-4 (c) are stable across environments with unit regression and non-significant deviation from regression. DCH-177 and PCS-136 had mean higher than population and regression values less than unity with significant and non-significant deviation from regression, respectively, indicating its suitability to poor conditions with unpredictable and stable performances. Genotypes GCH-7 and PCH-111 also recorded higher mean value for net plot yield with regression value more than one and non-significant deviation from regression indicating their higher sensitivity to environmental changes but adapted to favourable environment.

5.3.2.10 Total yield

The stability parameters for total yield showed that genotypes GCH-5, GCH-6 and GCH-4 (c) are stable across environments with unit regression and non-significant deviation from regression. DCH-177 and PCS-136 had mean higher than population along with regression values less than unity and non-significant deviation from regression indicating its suitability to poor conditions. Genotypes GCH-7 and PCH-111 recorded higher mean values over the population mean along with regression value more than one and non-significant deviation from regression indicating that these are highly sensitive to environmental changes but better adapted to favourable environments. The present findings were in consonance with those of Madariya *et al*. (2010), Solanki and Joshi (2000) and Kumara *et al*. (2003).

5.3.2.11 100 seed weight

The genotypes GCH-6 and PCH-111 showed stable performance with higher mean 100-seed weight across environments and considered as ideal for this trait. While, genotypes GCH-7 and PCS-262 had mean higher than population along with regression values near to unity and significant deviation from regression indicating average sensitivity of the genotype with unpredictable performance. Genotypes GCH-5 recorded higher mean 100 seed weight over the population mean along with regression value more than one and non-significant deviation from regression indicating that these are highly sensitive to environmental changes but better adapted to favourable environments, whereas, DCH-519 had mean higher than population along with regression values less than unity and non-significant deviation from regression indicating its suitability to poor conditions.

5.3.2.12 Oil content

Out of 12 genotypes, GCH-5, GC-3 and 48-1 (c) showed stable performance across the environments with higher mean oil content and regression value near to one and non-significant deviation from coefficient indicating that these genotypes were average sensitive to environmental variations and adapted to all environments. Genotypes DCH-519 and PCS-262 recorded higher mean oil content over the population mean along with regression value more than one and non-significant deviation from regression indicating that these are highly sensitive to environmental changes but better adapted to favourable environments, whereas, PCS-4 and PCS-136 had mean higher than population along with regression values less than unity and non-significant deviation from regression indicating its suitability to poor conditions.

The genotypes identified as stable for each character across the environments are given in the Table 18.

5.3.3 Stability of genotypes for different characters and frequency of stable genotypes for different traits under different environments

The genotypes exhibiting stability for each character was given a score of 1 and total score obtained by each genotype for twelve traits were calculated (Table 19). Of the 14 genotypes, the genotype GCH-4 was found to be stable for as many as five characters followed by genotypes GCH-7, DCH-177 and PCS-262 which were stable for five characters each. Genotypes GCH-5, GCH-6, PCH-111 and 48-1 (c) were stable for four characters each and genotypes DCH-519 and GC-3 were stable for two character each. Genotype RHC-1 was stable for only one trait and DCS-107 was not stable for even a single character.

Table 18. Stable genotypes identified for each characters over locations

Traits	Genotypes
Plant height	PCH-111 and 48-1 (c)
Days to flower initiation	GCH-6, PCH-111 and PCS-262,
Number of nodes upto primary spike	GCH-5, GCH-7, PCS-136 and GC-3
Length of primary spike	DCH-177, PCS-136, PCS-262
Effective length of primary spike	DCH-177, DCH-519 and PCS-136
Number of spikes per plant	GCH-7, GC-3 and GCH-4 (c)
Average number of capsules per spike	RHC- 1 and 48-1 (c)
Yield per plant	GCH-5 and GCH-4 (c)
Net plot yield	GCH-5, GCH-6 and GCH-4 (c)
Total yield	GCH-5, GCH-6 and GCH-4 (c)
100 seed weight	GCH-6 and PCH-111
Oil content	GCH-5, GC-3 and 48-1 (c)

Table 19. Stability of genotypes for different characters based on stability parameters

Genotypes	Plant height	Days to flower initiation	Number of nodes to primary spike	Length of primary spike	Effective length of primary spike	Number of spikes/ plant	Average capsules per spike	Yield per plant	Net plot yield	Total yield	100 seed weight	Oil content	Total traits
GCH-5	-	-	1	-	-	-	-	-	1	1	-	1	4
GCH-6	-	1	-	-	-	-	-	-	1	1	1	-	4
GCH-7	-	-	1	-	-	1	-	-	-	-	-	-	2
DCH-177	1	-	-	1	1	-	-	-	-	-	-	-	3
DCH-519	-	-	-	-	1	-	-	-	-	-	-	1	2
RHC-1	-	-	-	-	-	-	1	-	-	-	-	-	1
PCH-111	1	1	-	-	-	-	-	1	-	-	1	-	4
DCS-107	-	-	-	-	-	-	-	-	-	-	-	-	0
PCS-4	1	-	-	-	-	-	-	-	-	-	-	-	1
PCS-136	-	-	1	1	1	-	-	-	-	-	-	-	3
PCS-262	-	1	-	1	-	-	-	-	-	-	-	-	2
GC-3	-	-	1	-	-	1	-	-	-	-	-	1	3
Checks													
GCH-4	1	-	-	-	-	1	-	1	1	1	-	-	5
48-1	-	-	-	-	-	-	1	-	-	-	-	1	2

Plate 2: Stable genotypes identified for yield

5.4 Correlation analysis

Yield is the end product of interactions of many factors known as contributing components and hence it is a complex trait. Selection directly based on this complex trait is usually not very useful. But, the selection based on its component traits could be more effective. To make effective selections for this complex trait basic information on major contributing characters and their interrelationships is essential to the plant breeder to ensure efficient selection involving two or more characters. As seed yield is the principle factor and influenced by various characters directly and indirectly, hence it is essential to know the relationship between them in order to improve the yield potential through its components (Frageria and Kokli, 1997). In this direction maximum utilization of the desirable characters for the development of an ideal genotype is important (Halilu *et al.*, 2013). Identification of significant yield contributing parameters are necessary for improving the yield of castor and towards this endeavour 12 genotypes of castor were evaluated at 3 different field conditions along with 2 popular checks. This identification of better lines would be helpful in the process of improving castor productivity and production.

The various associations worked out between yield and principle component characters have been discussed.

In the present study, seed yield per plant had strong positive association at phenotypic level at all the three locations with number of capsules per spike, length of primary spike, effective length of primary spike and number of spikes per plant and the association was significant. Thatikunta *et al.* (2001), Dhedhi *et al.* (2010), Ghulam *et al.* (2010), Patel *et al.* (2010b), Goodarzi *et al.* (2012), Hafiz *et al.* (2012), Abimiku *et al.* (2012), Nalini and Yadavendrakumar (2013), Gila and Manga (2015), Sowmya *et al.* (2015) and Dapke *et al.* (2016) reported similar findings. Hence, simultaneous selection for these traits will be more reliable to develop high yielding castor genotypes over environments.

It is observed that plant height exhibited negative association with seed yield in Devihosur and significant negative association at Hanumanamatti. Existence of strong negative association between these components was also reported by Ghulam *et al.* (2010), Hafiz *et al.* (2012) and Msaakpa and Obasi (2014). On the contrary, positive association was reported at Dharwad. Similar findings have been reported by Thatikunta *et al.* (2001), Dhedhi *et al.* (2010), Patel *et al.* (2010b), Abimiku *et al.* (2012), Msaakpa and Obasi (2014) and Dapke *et al.* (2016).

Days to flower initiation had significant negative association with seed yield per plant at phenotypic level at two locations *viz.,* Devihosur and Hanumanamatti, while, non-significant negative association was observed at Dharwad. Reports of Dhedhi *et al.* (2010), Abimiku *et al.* (2012), Hafiz *et al.* (2012), Nalini and Yadavendrakumar (2013) and Msaakpa and Obasi (2014) emphasize the existence of negative association between days to flower initiation and yield per plant.

Out of three locations, number of nodes upto primary spike showed negative non-significant association with seed yield per plant at Dharwad and Hanumanamatti, while, it showed negative significant association with seed yield per plant in Devihosur. Similar observations of negative association have been reported by Abimiku *et al.* (2012) and Nalini and Yadavendrakumar (2013)

100 seed weight recorded significant negative association with seed yield per plant only at Dharwad but non-significant negative association at Devihosur. On the contrary positive non-significant positive association was observed at Hanumanamatti. Similar results for negative association have been reported by Abimiku *et al.* (2012), Hafiz *et al.* (2012) and Nalini and Yadavendrakumar (2013). And positive non-significant association have been reported by Thatikunta *et al.* (2001), Dhedhi *et al.* (2010), Ghulam *et al.* (2010), Hafiz *et al.* (2012) and Dapke *et al.* (2016).

Oil content showed non-significant negative association with seed yield per plant at all the three locations at phenotypic levels. Existence of strong negative association between these components also reported by Goodarzi *et al.* (2012) and Nalini and Yadavendrakumar (2013).This indicates that any increase in seed yield is not coupled with increase in oil content of the genotypes.

Correlation analysis revealed that number of capsules per spike, length of primary spike, effective length of primary spike and number of spikes per plant were observed to be important yield contributing characters in castor irrespective of the environment. Hence, selection criteria should consider these traits for the improvement of seed yield per plant in castor.

5.5 Path analysis

Yield is a complex character influenced by several genetic factors, which interact with the environment. Success of any breeding programme depends on the efficiency of selection. For successful selection, it is necessary to study the nature of association of characters with other relevant traits.

The correlation values decide only the nature and degree of association existing between pairs of characters. The economic character like yield is dependent on several mutually associated component characters; hence change in any one of the components is likely to affect the whole network of cause and effect. This in turn might affect the true association of component characters both in magnitude and direction and tend to vitiate the association of yield with its attributes. Hence, it has to be analyzed through path analysis, where the two types of action namely direct effect of component characters on the yield and the indirect effects through other component characters on the yield are obtained which cannot be ascertained correlation studies.

Path coefficient is the standardized partial regression coefficient of correlation, which splits correlation co-efficient into direct and indirect effects of component characters on complex dependent character like yield. The concept of path co-efficient analysis was developed by Wright (1921), but the technique was first used in plant breeding by Dewey and Lu (1959).

If the correlation between dependent variable and the independent variables is due to the direct effects of the character, it reflects a true relationship between them and selection has to be invariably practiced for such a character in order to improve dependent variable. The correlation co-efficient measures the sum total effects (direct and indirect) of all the characters to which it is correlated either positively or negatively and hence selection based on this value alone will be sometimes misleading unless the direct effect is very high and operates in the same direction. Hence, the study of direct and indirect effects through path analysis enables the breeders to judge the important component characters during selection.

As a guideline for interpretation of results of path analysis, the following broad points may be kept in view.

If the correlation coefficient between a causal factor and the effect is almost equal to its direct effect, then correlation explains the true relationship and direct selection though this trait will be effective.

If the correlation coefficient is positive, but the direct effect is negative or negligible, the indirect effects seem to be the cause of positive correlation. In such situations, the indirect causal factors are to be considered simultaneously for selection.

Further, correlation coefficient may be negative but the direct effect is positive and high. Under these circumstances, a restricted simultaneous selection model is to be followed, that is, restrictions are to be imposed to nullify the undesirable indirect effects in order to make use of the direct effect is also negative, then we have to drop the selection based on that character.

The residual effect determines how best the causal factors account for the variability of the dependent factor. If the residual effect is high, some other factors which have not been considered here need to be included in this analysis to account fully for the variation in yield.

The path coefficient analysis for seed yield per plant was carried out considering 9 characters. Across environments, length of primary spike, number of capsules per spike, number of spikes per plant and effective length of primary spike had positive direct effect on seed yield per plant except at Hanumanamaatti, where, effective length of primary spike had negative direct effect and its contribution towards seed yield per plant was indirectly through length of primary spike.

This indicates that length of primary spike, number of capsules per spike, number of spikes per plant and effective length of primary spike would improve the seed yield per plant in castor by direct selection as they are combined with high and positive correlation with yield per pant irrespective of the environment. Positive direct effects on seed yield by length of primary spike, number of capsules per spike, number of spikes per plant and effective length of primary spike was reported by Moshkin (1986), Thatikunta *et al.* (2001), Manivel and Manivannan (2006), Patel *et al.* (2010b), Goodarzi *et al.* (2012), Lakshmamma *et al.* (2014) and Destaw (2014). Hafiz *et al.* (2012) and Dapke *et al.* (2016) reported negative direct effects of effective length of primary spike on seed yield. Hence, selection for these traits would improve seed yield per plant.

Other characters which had direct positive influence on seed yield per plant were oil content. However, at Devihosur, contribution of this character was mainly through its negative direct effect, which indicates its negative relation with seed yield per plant. Similar results for negative effects were reported by Destaw (2014). Positive influence through oil content was reported earlier by Mehta and Vashil (1998), Dhedhi *et al.* (2010) and Dapke *et al.* (2016).

Plant height and number of nodes upto primary spike showed negative direct effects on seed yield per plant at Devihosur and Hanumanamatti and positive direct effects in Dharwad. Days to flower initiation recorded negative direct effects with seed yield per plant at Dharwad and Hanumanamatti and positive direct effects in Devihosur. 100 seed weight appear to have low or negative association with seed yield per plant across the locations.

Similar results of negative direct effects of plant height were reported by Ghulam *et al.* (2010), Hafiz *et al.* (2012) and Destaw (2014). For number of nodes upto primary spike by Thatikunta *et al.* (2001) ; for days to flower initiation by Dapke *et al.* (2016) and for 100 seed weight Thatikunta *et al.* (2001) and Dhedhi *et al.* (2010) reported similar results emphasizing negative direct effects.

Similar results of positive direct effects via plant height was reported by Thatikunta *et al.* (2001) and Hafiz *et al.* (2012); for number of nodes upto primary spike by Dhedhi *et al.* (2010) and Dapke *et al.* (2016); for days to flower initiation by Dhedhi *et al.* (2010) and Destaw (2014) and for 100 seed weight Dapke *et al.* (2016) reported similar results.

From the results of path coefficient analysis in castor, it may be concluded that improvement in seed yield per plant could be brought through by selection for component characters like length of primary spike, number of capsules per spike, number of spikes per plant and effective length of primary spike irrespective of environments and due weightage should be given to these characters on castor breeding programme for enhancing yield.

The study revealed a change in pattern of association characters and also in their direct or indirect effect contribution towards seed yield per plant from location to location. This is obvious in view of range of environments influencing genetic manifestation of genotypes for a character due to role of G × E interactions. This is also evident by the significant deviations of regression coefficient from the unity indicating the differential behaviour of genotypes in different environments. However, the characters evaluated over locations being mostly quantitative and the study enables to confirm the performance of genotypes for a character being similar in more than one location.

5.6 Genetic variability among castor genotypes for various morpho-physiological traits and their relationship with productivity

5.6.1 Genetic variability, heritability and genetic advance

Effectiveness of selection and identification of superior genotypes depends on the magnitude of inherent variability for a particular character. Hence it is prerequisite to study the estimates of genetic parameters such as coefficients of genotypic and phenotypic variability, heritability and genetic advance. Improvement of any characters in a crop depends upon the amount of variability present in the base population, in absence of which there shall be no response to selection. In the present study, the parameters like phenotypic and genotypic coefficients of variation (PCV and GCV), heritability in broad sense and genetic advance as per cent mean were estimated to know the nature and magnitude of variation existing among genotypes under study.

The study of coefficient of variability indicated high variability (Abimiku *et al.,* 2012, Nalini and Yadavendrakumar, 2013, Udaya *et al.,* 2013, Dapke *et al.,* 2016) at both phenotypic and genotypic level for seed yield per plant, net plot yield and total yield recorded at Devihosur, whereas, moderate values of coefficient of variability (Halilu *et al.,* 2013) at both phenotypic and genotypic level for same traits was observed at Dharwad and Hanumanamatti.

The results indicated that plant height had moderate variability at both phenotypic and genotypic levels (Abimiku *et al.,* 2012, Dapke *et al.,* 2016) in Dharwad and Hanumanamatti, whereas, low variability for the same character was recorded at Devihosur. These results are in accordance with the studies of Halilu *et al.* (2013) and Getinet *et al.* (2014).

Length of primary spike, number of spikes per plant and effective length of primary spike recorded moderate GCV and PCV value at Dharwad and lower values were recorded at Hanumanamatti. At Devihosur, GCV values of these traits were low, whereas PCV values of length of primary spike and number of spikes per plant were moderate and effective length of primary spike recorded low PCV value at all the environments.

Similar results of moderate GCV and PCV value were reported for length of primary spike by Dapke *et al.* 2016, number of spikes per plant by Halilu *et al.* 2013; Nalini and Yadavendrakumar, 2013, and effective length of primary spike Dapke *et al.* 2016. Low GCV values of these traits were reported by Halilu *et al.* 2013 and moderate PCV values of length of primary spike and number of spikes per plant reported by Halilu *et al.* (2013).

Low GCV values were observed at all the three environments for days to flower initiation (Abimiku *et al.,* 2012, Dapke *et al.,* 2016) and number of nodes upto primary spike (Getinet *et al.,* 2014) and PCV values of days to flower initiation (Dapke *et al.,* 2016) and number of nodes upto primary spike were also low at all the environments except at Hanumanamatti and Dharwad, respectively, where they showed moderate variability. Similar results of moderate value are reported by Nalini and Yadavendrakumar (2013), Getinet *et al.* 2014 and Dapke *et al.* (2016).

Low GCV values were observed at all the three environments for average number of capsules per spike, whereas, its PCV values were moderate (Halilu *et al.,* 2013, Nalini and Yadavendrakumar, 2013) at all the environments except at Dharwad, where they showed low variability.

Both GCV and PCV value of 100 seed weight (Nalini and Yadavendrakumar, 2013), oil content (Udaya *et al.,* 2013, Dapke *et al.,* 2016), SPAD at 75 DAS, SPAD at 90 DAS and SPAD at 120 DAS were low at all the environments studied except for SPAD at 75 DAS and SPAD at 90 DAS, where they recorded moderate coefficient of variation at Devihosur and Dharwad, respectively.

Heritability values for plant height, seed yield per plant, net plot yield, total yield and SPAD at 75 DAS were high at all the environments and similar results were reported by Abimiku *et al.* (2012), Nalini and Yadavendrakumar (2013), Dapke *et al.* (2016), indicating that, relatively it is less influenced by environmental factors.

Days to flower initiation recorded higher heritability values (Abimiku *et al.,* 2012, Nalini and Yadavendrakumar, 2013 and Dapke *et al.,* 2016), except at Dharwad, where moderate values (Getinet *et al.,* 2014) were recorded and similar trend was observed for SPAD at 90 DAS and SPAD at 120 DAS. Number of spikes per plant and average number of capsules per plant also recorded high heritability, except at Devihosur and Hanumanamatti, respectively, which are in accordance with the report of Abimiku *et al.* (2012), Nalini and Yadavendrakumar (2013) and Dapke *et al.* (2016).

Heritability values of 100 seed weight (Dapke *et al.,* 2016), oil content (Nalini and Yadavendrakumar, 2013, Dapke *et al.,* 2016) and number of nodes upto primary spike were moderate in all the locations, except for number of nodes upto primary spike which showed low heritability at Dharwad.

High heritability values (Dapke *et al.,* 2016) of length of primary spike and effective length of primary spike were recorded in Dharwad, whereas it was moderate and low at Devihosur and Hanumanamatti, respectively.

The genetic advance as per cent of mean was high for seed yield per plant, net plot yield and total yield at all the environments (Nalini and Yadavendrakumar, 2013; Dapke *et al.,* 2016), except at Dharwad, where moderate values were observed. Higher values of GAM were observed for plant height (Dapke *et al.,* 2016) and number of spikes per plant (Dapke *et al.,* 2016) in Dharwad and for number of nodes upto primary spike at Hanumanamatti. Similar results have been reported by Nalini and Yadavendrakumar (2013).

Days to flower initiation (Dapke *et al.,* 2016), number of capsules per spike and SPAD at 90 DAS recorded moderate values GAM irrespective of the locations under study. SPAD at 90 DAS recorded moderate GAM value except at Hanumanamatti. Effective length of primary spike, 100 seed weight and SPAD at 120 DAS recorded low GAM value except at Dharwad and Devihosur where they recorded moderate values (Nalini and Yadavendrakumar, 2013). Oil content recorded low values at all the locations (Nalini and Yadavendrakumar, 2013, Dapke *et al.,* 2016) and length of primary spike recorded low, medium (Dapke *et al.,* 2016) and high values at Hanumanamatti, Devihosur and Dharwad.

The results of the present study clearly indicated the importance of plant height, number of spikes per plant, average number of capsules pr spike, yield per plant, yield per plot, yield per hectare and SPAD at 75 DAS, which exerted high heritability, wide variability and moderate to high genetic advance. High heritability coupled with high genetic advance indicated that these traits were controlled by additive gene action; hence, phenotypic selection could be effective in improvement of such traits. High heritability with moderate GCV, PCV and GA registered by some of these traits suggested selection will also effective for these traits. Hence, there is a potential possibility of improvement of the above characters and the results in line with the studies of Najan *et al.* (2010), who also observed high heritability for all the characters. 100 seed eight and oil content registered high heritability estimates coupled with Low GCV, PCV and GAM suggesting selection will be less effective for these traits.

5.6.2 Relationship between various morpho-physiological traits and productivity among castor genotypes

In the present study, productivity had strong positive significant relationship with number of capsules per spike, length of primary spike, effective length of primary spike, number of spikes per plant and SPAD at 75 DAS at all the three environments. SPAD at 90 DAS also recorded positive relationship with yield at all the locations and relationship was significant at Devihosur. Hence, simultaneous selection for these traits will be more reliable to increase the productivity of castor genotypes over environments.

It is observed that plant height, days to flower initiation, number of nodes upto primary spike, 100 seed weight, oil content and SPAD at 120 DAS exhibited negative association with seed yield in at all the environments. This indicates that any increase in productivity is not coupled with increase in oil content of the genotypes.

Future line of work

1. The genotypes such as GCH-5, GCH-6, PCH-111, DCH-177, PCS-136 and GC-3 exhibited excellent stability parameters; hence these genotypes may be included in developing better hybrid combinations and heterotic pools for wider adaptability.
2. The grain yield attributing characters such as length of primary spike, effective length of primary spike, number of spikes per plant and average number of capsules per spike exhibited significant positive association and direct effects with grain yield at all three environments. Hence, these characters can be targeted in future breeding programs to achieve the higher yield.
3. Genetic variability studies indicated that there is ample quantum of variability for number of spikes per plant, average number of capsules per spike, yield per plant, yield per plot and yield per hectare on account of their high to moderate phenotypic and genotypic coefficients of variance coupled with high heritability and genetic advance as per cent over mean indicating more additive gene action. Hence the selection for these traits could be effective. Variability present for these traits can be exploited either by selection for their further improvement.

6. SUMMARY AND CONCLUSIONS

The present investigation was carried out to elucidate the genotype × environment interaction in order to assess the stability of genotypes for productivity traits, information on nature of association and their direct and indirect effects of component characters on seed yield per plant in various environments and an attempt was also made to know the amount of variability present in the component traits of yield and the amount of which it is heritable.

Twelve genotypes along with two checks were evaluated in a randomized block design with three replications in three environments *viz.*, Dharwad, Devihosur and Hanumanamatti over two years *viz., kharif*-2014 and *kharif*-2015. The observations were recorded for twelve quantitative traits during *kharif*-2014 and *kharif*-2015 *viz.*, plant height, days to flower initiation, number of nodes upto primary spike, length of primary spike, effective length of primary spike, number of spikes per plant, average number of capsules per spike, seed yield per plant, net plot yield, total yield, 100-seed weight and oil content. The physiological traits *viz.,* for SPAD at 75 DAS, SPAD at 90 DAS and SPAD at 120 DAS were recorded during *kharif*-2015. The results obtained in the present study are summarized below.

Mean performance of genotypes in three different locations for twelve characters indicated that Dharwad was the most favourable environment for the better expression of most of the characters (days to flower initiation, number of nodes upto primary spike, length of primary spike, effective length of primary spike, number of spikes per plant, average number of capsules per spike, 100-seed weight and oil content). Devihosur was also favourable for the better expression of traits like seed yield per plant, net plot yield, and total yield.

Analysis of variance revealed significant differences among the genotypes at all the locations suggesting a high degree of variability among the genotypes tested. Pooled analysis of variance revealed significant differences among the genotypes and environments for all the characters indicating that the genotypes and environments tested are diverse in nature. The analysis of variance for performance stability revealed genotype x environment interaction was significant for the traits *viz.,* length of primary spike, effective length of primary spike, number of spikes per plant, seed yield per plant, net plot yield and total yield, suggesting that genotypes interacted significantly with the environments for these traits. While, genotype × environment (linear) interaction was significant for days to flower initiation, length of primary spike, effective length of primary spike, seed yield per plant, net plot yield, total yield and oil content indicating genotypes responded linearly to the changing environment for these traits. The non-linear component (pooled deviation) was highly significant for most of the traits (except length of primary spike, effective length of primary spike, seed yield per plant, net plot yield, total yield and oil content) indicating that this part of the variation in terms of performance of the genotype is unpredictable.

On the basis of stability parameters GCH-5, GCH-6 and PCH-111 were promising genotypes for majority of characters with higher mean performance across the locations. Among checks, GCH-4 was promising genotype showing stable performance for majority of traits across the tested environments.

The association analysis revealed that seed yield per plant exhibited significant positive association with length of primary spike, effective length of primary spike, number of spikes per plant and average number of capsules per spike at three environments and path analysis indicated that number of spikes per plant and average number of capsules per spike have high direct effect in all the locations under study. Therefore, irrespective of locations, these traits can be considered as principal yield determining components and it is suggested to use these as selection criteria for seed yield improvement in castor.

Genetic variability analysis of various traits for *kharif*-2015 across three environments revealed that, wide range of variation was observed for all the characters studied. Genotypes differed significantly for all the characters as evidenced by 'F' test of ANOVA. Genetic variability analysis revealed that, GCV and PCV values ranged from high to moderate for seed yield per plant, net plot yield and total yield, whereas, the remaining characters showed moderate to low GCV and PCV value across the environments.

Heritability in broad sense was high for the characters *viz.,* plant height, seed yield per plant, net plot yield, total yield and SPAD at 75 DAS at all the environments. Irrespective of environments under study genetic advance as per cent mean was highest for seed yield per plant, net plot yield and total yield.

Plant height, number of spikes per plant, average number of capsules per spike, yield per plant, yield per plot, yield per hectare and SPAD at 75 DAS, which exerted high heritability, wide variability and moderate to high genetic advance. High heritability coupled with high genetic advance indicated that these traits were controlled by additive gene action; hence, phenotypic selection could be effective in improvement of such traits

REFERENCES

Abimiku, O. E., Azagaku, E. D. and Ndor, E., 2012, Genetic variability and correlation studies in some quantitative characters in castor (*Ricinus cummunis*. L) accessions. *Asian J. Agric. Sci.,* 4 (6): 368-372.

Adeyanju, A. O., Usman, A. and Mohammed, S. G., 2010, Genetic correlation and path-coefficient analysis of oil yield and its components in castor. *Int. J. Appl. Agric. Res.,* 5 (2): 243–250.

Anastasi, U., Sortino, O., Cosentino, S. L. and Patanè, C., 2015, Seed yield and oil quality of perennial castor bean in a mediterranean environment. *Int. J. Pl. Prod.,* 9 (1): 99-116.

Annappan, R. S., 1981, Genetic analysis in castor *(Ricinus communis* L.*). Ph.D.* thesis, Tamil Nadu Agricultural University, Coimbatore.

Anonymous, 2016a, Comprehensive castor oil report, http://castoroil.in.

Anonymous, 2016b, Castor crop survey, SEA data book and Neilson crop survey; February report.

Burton, G. W. and Devane, E. M., 1953, Estimating heritability in Tall Fescue (*Festuca circunclinaceae*) from replicated clonal-material. *Agron. J.,* 45: 478-481.

Comstock, R. E., 1955, Theory of quantitative genetics. *Synthesis, Cold Spring Harbor, Symposia Ceuant. Biol.,* 20: 93-102.

Dapke, J. S., Naik, M. R., Singh, A. P., Baraskar, V. V., Narwade, A. V. and Prasad, I., 2016, Genetic association yield with different agronomic traits in castor (*Ricinus communis* L.). *Int. J. Bio. Res.,* 1 (1): 47-49.

Destaw M., 2014, Phenotypic variability and association of traits among yield and yield-related traits in castor *(Ricinus communis* L.*)* accessions at Melkassa, central rift valley of Ethiopia. *M. Sc. (Agri.) Thesis*, College of Natural and Computational Science, Department of Biology, School of Graduate Studies, Haramaya University.

Dewey, D. R. and Lu, K. H., 1959, Correlation and path coefficients analysis of components of crested wheat grass seed production. *Agron. J.,* 51: 515-518.

Dhedhi, K. K., Ghelani, Y. H., Joshi, H. J. and Dangaria, C. J., 2010, Correlation and Path co-efficient analysis in castor (*Ricinus communis* L.) over environments. *Agric. Sci. Digest.,* 30 (4): 286- 289.

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

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

Fisher, R. A., 1918, The correlation between relatives on the supposition of Mendelian inheritance. *Trans. Roy. Society Edn.,* 52: 399-433.

Frageria, M. S. and Kokli, U. K., 1997, Correlation studies in tomato. *Haryana J. Hort. Sci.,* 25: 158-160.

Getinet A., Beemnet M. K., Girma T. and Chalachew E., 2014, Phenotypic variability in Ethiopian castor (*Ricinus communis* L.) accessions. *Int. J. Adv. Biol. Biom. Res.,* 2 (12): 2909-2914.

Ghulam S., Hafiz M. A. and Jafar H., 2010, Evaluation of castor bean (*Ricinus communis* L.) mutants for genetic parameters and cluster analysis. *J. Agric. Res.,* 48 (3):289-301.

Gila and Manga A., 2015, Evaluation of yield and yield components of castor (*Ricinus communis* L.) germplasm from rain forest and southern guinea savannah agro-ecological zones of Nigeria. *Int. J. Curr. Res. Aca. Rev.,* 3 (6): 366-373.

Golakia, P. R., Kavani, R. H. and Monpara, B, A., 2007, Genetic variation and trait relationship in castor. *National J. Pl. Improv.,* 9 (1): 60-62.

Goodarzi, F., Darvishzadeh, R., Hassani, A. and Hassanzaeh, A., 2012, Study on genetic variation in Iranian castor bean (*Ricinus communis* L.) accessions using multivariate statistical techniques. *J. Med. Plants. Res.,* 6 (7): 1160-1167.

Goodarzi, F., Darvishzadeh, R., Hassani, A. and Hassanzaeh, A., 2015, Genetic variability and traits association in castor bean (*Ricinus communis* L.). *Genetika,* 6 (7): 1160-1167.

Gopani, D. D., Joshi, S. N. and Kabaria, M. M., 1972, Expression of hybrid vigour in castor under different agro climatic conditions in Gujarat. *Indian J. Agric. Sci.,* 42 (1): 946 - 949.

Hafiz M. A., Ghulam, S. and Muhammad, A. H., 2012, Genetic variability and interdependence of morphological traits in castor bean (*Ricinus communis* L.) mutants. *Songklanakarin J. Sci. Technol.,* 34 (3): 279-286.

Halilu, A. D., Aba, D.A. and Ogunwole, J.O., 2013, Genetic variability, genetic gain and relationships of yield and yield components in castor (*Ricinus communis* L.). *Bio sci.,* 7 (5): 181-186.

Henry, A. and Daulbey, H. S., 1985. Genotype x environment interaction for seed yield in castor bean. *Madras Agric. J.,* 72 (4): 196 -198.

Hirasingh and Yadava, T. P., 1982, Genetic analysis of plant height in castor *(Ricinus communis* L*). Haryana Agri. Univ. J. Res.,* 12 (3): 467 - 470.

Johnson, H.W., Robinson, H. E. and Comstock, R.E., 1955. Estimates of genetic and environmental variability in soybean. *Agron. J.,* 47: 314-318.

Joshi, H. J. Mehta, D. R. and Jadon, B. S., 2002a, Genotype and environment interaction for yield and yield components in castor (*Ricinus communis* L.) *Adv. in Pl. Sci.,* 15 (1):261-266.

Joshi, H. J., Mehta, D. R. and Jadon, B. S., 2002b, Phenotypic stability and adaptability of castor hybrids. *Indian J. Agric.* Res., 36 (4): 269- 273

Jowett, D., 1972, Yield stability parameters for sorghum in east Africa. *Crop Sci.,* 12: 314 - 317.

Kabariya, M. N. and Gopani, D. D., 1971, Note on heterosis and F_2 performance in castor. *Indian J. Agric. Sci.,* 41 (3):71.

Koutroubas, S.D., Papakosta, D.K. and Doitsinis, A., 1999, Adaptation and yielding ability of castor plant (*Ricinus communis* L.) genotypes in a Mediterranean climate. *European J. Agron.,* 11: 227–237.

Kulmi, G. S. and Soni, S. N., 1995, Performance of castor *(Ricinus communis* L.) varieties in Kymore plateau of Madhya Pradesh. *Indian J. Agric. Sci.,* 65 (11): 813-815.

Kumara, T. R., Subramanyam, D. and Sreedhar, N., 2003, Stability analysis in castor (*Ricinus communis* L.). *Crop Res.,* 25: 96-102.

Lakshmamma, P., Lakshmi P., Lavanya, C. and Sarada, C., 2014, Genetic diversity, variability and heritability for root, shoot and water use efficiency traits in castor *(Ricinus communis* L.) genotypes. *Indian J. Pl. Genet. Resour.,* 27 (3): 230-237.

Lauret, D., 1995, Genotype and Genotype x Environment interaction effects on yield and yield components in castor *(Ricinus communis* L.*). J. Genet. and Breed.,* 49 (1): 27 - 30.

Lauret, D., l988, Genotype environment interaction and stability of castor *(Ricinus communis* L.*)* cultivars. *Agricultura Ricera*, 10 (89): 39 - 42.

Lenka, D. and Mishra, B., 1973, Path coefficient analysis of yield in rice. *Indian J. Agril. Sci.,* 43: 376-379.

Lonquist, J. H., 1964. A modification of the ear to row procedures for the improvement of maize populations. *Crop Sci.,* 4: 227-228.

Lush, J. L., 1940, Inter-size correlation regression of offspring on dary as a method of estimating heritability of characters. *Prov. Amer. Soc. Animal Prod.*, 33: 293-301.

Madariya, R. B., Chovatia, V. P., Kavani, R. H., Barad, V. G. and Padhur, P. R., 2010, Phenotypic stability in castor (*Ricinus communis* L.). *J. Oilseeds Res.*, 27: 27-30.

Maiti, S., Hegde, M. R. and Chattopadhyay, S. B., 1988. Hand Book of Oilseed Crops. Oxford & IBH Publishing Co. (Pvt). Ltd. New Delhi, p. 251

Mandal, N. and Dana, L., 1994, Phenotypic stability in castor *(Ricinus communis* L.*). Anals of Agrl. Res.,* 15 (4): 504 - 505.

Manivel, P. and Hussain, H. S. J., 2001, Genotype × environment interaction in castor. *Madras Agric. J.,* 87: 394-397.

Manivel, P. and Manivannan, N., 2006, Path analysis under different environments in castor (*Ricinus communis* L.). *J Oilseeds Res.,* 23 (1): 89-92.

Mehta, D. R. and Vashi, P. S., 1998, Correlation and path analysis of seed yield and its components in castor. *Indian J. Agric. Res.,* 32:160-164.

Moshkin, V. A., 1986, Castor, Amerind Publishing Co. (Pvt). Ltd. New Delhi, p.1-315.

Moshkin. V. A and Sachli, I. K., 1972, A study of the variability of quantitative characters in the castor oil plant. *Pl. Breed. Abst.*, 10: 323.

Msaakpa, T. S. and Obasi, M. O., 2014, Correlated Studies between growth and yield characters of castor bean (*Ricinus communis* L.). *Int. J. Sci. Res. Pub.*, 4 (7): ISSN 2250-3153.

Najan, B. R., Kadam, J. R. and Kadlag, A. D., 2010, Genetic variability studies in castor (*Ricinus communis* L.). *J. Oilseeds Res.,* 27: 77-79

Nalini, T. and Yadavendrakumar, 2013, Genetic variability and character association in castor (*Ricinus communis* L.). *Curr. Advances in Agric. Sci.,* 5 (2): 256-258.

Onkarappa, T., Shivanna, H., Sunil Kumar, S. V. and Marappa, N., 2014, Studies on stability parameters for yield and its component characters in castor (*Ricinus communis* L.). *Res. Environ. Life Sci.,* 7 (2):119-122.

Panse, V. G. and Sukhatme, D. V., 1964, Statistical Methods for Agricultural Workers, ICAR. Pub. New Delhi, p. 115.

Patel, C. M. and Patel, J. M., 2015a, Genotype x Environment interaction and stability analysis for seed yield and sex attributing traits in castor (*Ricinus communis* L.). *Electronic J. Pl. Breed.,* 6 (4): 996-1003.

Patel, C. M. and Patel, J. M., 2015b, Gene - Environment interaction and stability analysis for yield and yield determinant traits in castor (*Ricinus communis* L). *IOSR J. Agri. and Vet. Sci.,* 8 (6):68-72.

Patel, D. K., Ravindrababu, Y. and Patel, P. J., 2011, Genotype x environmental interaction and stability parameters for yield and yield component traits in castor (*Ricinus communis* L.). *Int. J. Forestry and Crop Impt*., 2 (1):64-67

Patel, J. A., Patel, B. N., Alpesh, R. and Patel, R. K., 2010a, Genotype × environment interaction and stability parameters for yield and component characters in castor (*Ricinus communis* L.). *J. Oilseeds Res.,* 2: 47-49.

Patel, J. R., Saiyed, M. P., Patel, C. G., Bhatt, R. K. and Bhatt, J. P., 2010b, Genetic variability and correlation studies in castor (*Ricinus communis* L.). *Int. J. Agric. Sci.,* 6 (1):129-131.

Patel, P. S. and Jaimini, S. N., 1988, Variability in castor *(Ricinus commnis* L*.). Indian J. Agric. Sci.,* 56 (5): 394 - 396.

Perkins, J. M. and Jinks, J. L., 1971, Specificity of interaction of genotypes with contrasting environments. *Heredity*, 26: 463 - 474.

Prasad, M. V. R. and Francisco B. F. M., 1984, Evaluation of some varieties and hybrids of castor *(Ricinus communis* L.). *Ciên. Agron., Fortaleza,* 15 (1): 71-74.

Radhamani, T., Ushakumari, R. and Veni, K*.,* 2014*,* Genetic analysis to identify drought tolerant genotypes in castor (*Ricinus communis* L.) under rainfed conditions. *Vegetos.,* 27 (3): 192-197.

Raghuram Reddy, P., Vanaja, M., Hanumantha R. C., Maruthi S. G. R., Venkateswarlu, S. and Eastin, J. D., 1999, Performance of castor *(Ricinus communis* L*.)* genotypes with normal and delayed seeding under irrigated and rainfed conditions. *Indian J. Agril. Sci.,* 69 (2): 96-100.

Ramaswamy, N. M. and Menon, M. P., 1973, Genetic analysis of yield components in *Ricinus communis L. Madras Agric. J.,* 60: 1491- 1498.

Robinson, H. F., Comstock, R. E. and Harvey, P. H., 1949, Estimates of heritability and degree of dominance in corn. *Agon. J.,* 41: 353-359.

Sarada, C., Lavanya, C., Prabhakaran, A. J. and Alivelu, K., 2012, GGE Bi-Plot analysis for multilocation trials of castor short duration genotypes. *Agrotechnol.,* 1 (2): 28.

Shah, S. K., Patel, D. K., Patel, R. M. and Patel, P. S., 2015, Seed and oil quality characteristics of some castor (*Ricinus communis* L.) inbred lines. *Int. J. Agri., Environ. Biotech.,* 8 (1): 177-181.

Shaik, Z. B. and Jabeen, F., 2011, Evaluation of genotypes for genetic divergence and *fusarium* wilt resistance in castor (*Ricinus communis* L.). *J. Res. ANGRAU.*, 39 (4):129.

Singh, R. K. and Chaudhary, B. D., 1979, Biometrical Methods in Quantitative Genetic analysis, 3rd Edn. Kalyani Publishers, New Delhi, pp. 39-69.

Sivasubramanian, S. and Menon, M., 1973, Heterosis and inbreeding depression in rice. *Madras Agric. J.,* 60: 11-39.

Sodavadiya, P. R. and Dhaduk, L. K., 2011, Genotype x environment interaction and stability analysis in castor (*Ricinus communis* L.). *J. Oilseeds Res*., 28 (1): 74-76.

Solanki, S. S. and Joshi, P., 2000, Stability parameters for sex expression in castor (*Ricinus communis* L.). *J. Oilseeds Res.,* 17: 242-248.

Solanki, S. S. and Joshi, P., 2001, Genetic architecture of oil content over environments in castor *(Ricinus communis* L.*). Indian J. Agri. Sci.,* 71 (3): 209-211.

Sowmya. P., Vanaja, M., Sunitha Vaidya, Anitha, Y. and Vijay Kumar, G., 2015, Variability and correlation studies for seed yield and yield contributing components of castor (*Ricinus communis* L.) germplasm under rainfed conditions. *Int. J. Curr. Sci.,* 15: 59-65.

Sunderaraj, N., Nagaraj, V. S., Venkataramu, M. N. and Jagannath, M. K., 1972, *Design and Analysis of Field Experiments.* University of Agricultural Sciences, Bangalore, p. 424.

Thakkar, D. A,, Gami, R. A. and Patel, P. S., 2010, G × E and stability studies on castor hybrids for yield and its attributing characters. *J. Oilseeds Res.,* 27: 74-77.

Thatikunta, R., Venkateswarlu, O. and Durga Prasad, M. M. K., 2001, Path coefficient analysis in castor (*Ricinus communis* L.). *Agric. Sci. Digest.,* 21 (1): 59 – 60.

Torres, F. E., Paulo, E. T., Larissa, P. R., Caio, C. G. C., Fernanda, B. H., Reliane Lima, F., Anna, C. G. and Kamila, V. L., 2015, Correlations and path analysis on oil content of castor genotypes. *Biosci. J.,* 31 (5):1363-1369.

Travis Witt, A. S. B. S. and Dick Auld, 2014, Performance of five castor (*Ricinus communis* L.) genotypes in geographically diverse environments of North America. *M. Sc. (Agri.) Thesis*, Texas Tech University.

Udaya Bhanu Kote, Satyanarayana Rao, V. and Srinivasa Rao, M., 2013, Genetic variability in castor (*Ricinus communis* L.) for yield and its contributing traits. *Int. J. Food, Agri. Vet. Sci.,* 3 (3):103-108.

Warner, J. N., 1952, A method for estimating heritability. *Agron. J.,* 44: 227-430.

Weiss, E. A. 2000, Oilseed Crops. 2nd edn. Blackwell Science, Oxford, pp. 13-52.

Wright, S., 1921, Correlation and causation. *J. Agric. Res.,* 20: 202-209.

Appendix I: Monthly meteorological data during crop growth period (2014-15) at MARS, UAS, Dharwad

Months	Rainfall (mm)	Temperature (^{0}c)		Relative humidity (%)	
		Maximum	Minimum	Maximum	Minimum
July 2014	242.2	27.1	20.8	90.0	82.0
August 2014	158.4	26.8	20.5	91.3	82.7
September 2014	100.2	28.0	20.3	87.4	75.4
October 2014	103.4	29.7	16.7	82.3	69.7
November 2014	48.8	29.0	15.5	72.5	49.0
December 2014	26.2	27.9	14.6	76.9	52.6
January 2015	0.0	29.5	14.7	66.6	38.1
February 2015	0.0	31.1	16.1	55.8	32.1

Appendix II: Monthly meteorological data during crop growth period (2014-15) at ARS, Hanumanamatti (Haveri)

Months	Rainfall (mm)	Temperature (^{0}c)		Relative humidity (%)	
		Maximum	Minimum	Maximum	Minimum
July	189.0	33.12	20.89	99.4	34.7
August	246.75	28.73	21.23	99.2	63.9
September	72.75	34.28	19.89	99.5	48.4
October	97.5	34.73	16.78	100.0	40.0
November	41.75	32.89	-5.0	99.9	21.7
December	9.75	32.84	10.89	99.3	21.3
January	-	-	-	-	-
February	-	-	-	-	-

Appendix III: Monthly meteorological data during crop growth period (2014-15) at Horticulture Research and Extension Station (Devihosur)

Months	Rainfall (mm)	Temperature (^{0}c)		Relative humidity (%)	
		Maximum	Minimum	Maximum	Minimum
July	244.8	21.37	26.58	84.06	84.06
August	233.8	21.16	27.09	80.22	80.22
September	56.8	20.84	29.26	74.53	74.53
October	172.4	20.39	30.45	64.74	64.74
November	36.6	16.62	29.53	52.46	52.46
December	7.0	15.36	28.82	61.69	61.61
January	0.0	13.69	29.50	41.93	41.93
February	0.0	15.42	32.33	25.28	25.28

Appendix IV: Monthly meteorological data during crop growth period (2015-16) at MARS, UAS, Dharwad

Months	Rainfall (mm)	Temperature (^{0}c)		Relative humidity (%)	
		Maximum	Minimum	Maximum	Minimum
July	42.8	28.7	21.2	87.1	72.5
August	34.4	28.7	20.6	87.9	75.5
September	22.4	30.9	20.6	91.6	80.0
October	179.8	31.2	19.6	77.3	60.2
November	28.6	30.0	18.4	81.4	63.5
December	0.0	30.6	15.7	73.4	42.9
January	0.2	28.6	13.3	63.6	40.7
February	0.0	31.8	14.6	52.6	24.2

Appendix V: Monthly meteorological data during crop growth period (2015-16) at ARS, Hanumanamatti (Haveri)

Months	Rainfall (mm)	Temperature (^{0}c)		Relative humidity (%)	
		Maximum	Minimum	Maximum	Minimum
July	57.0	35.2	10.4	97.0	37.0
August	54.1	32.2	13.4	97.0	63.0
September	73.7	33.4	16.2	90.0	64.0
October	144.6	34.6	10.1	79.0	32.0
November	00.0	35.3	10.0	54.0	58.0
December	00.0	34.6	19.6	84.0	38.0
January	00.0	33.39	13.73	93.8	12.9
February	3.0	34.78	15.62	92.2	7.7

Appendix VI: Monthly meteorological data during crop growth period (2015-16) at Horticulture Research and Extension Station (Devihosur)

Months	Rainfall (mm)	Temperature (^{0}c)		Relative humidity (%)	
		Maximum	Minimum	Maximum	Minimum
July	66.6	21.36	28.65	77.06	77.06
August	71.0	21.07	28.50	79.12	79.12
September	89.8	20.8	29.65	74.96	74.96
October	140.6	19.56	31.92	55.32	55.32
November	8.0	18.72	30.62	54.23	54.23
December	0.0	17.21	31.66	45.67	45.67
January	0.2	14.01	30.54	37.61	37.61
February	0.0	17.56	33.82	38.86	38.86

Appendix VII. ***Per se*** **performance of twelve genotypes and two checks of castor (*****Ricinus communis*** **L.) at three environments during** ***kharif*****-2014**

Genotypes	**Plant height (cm)**			**Days to flower initiation**			**Number of nodes upto primary spike**		
	E1	**E2**	**E3**	**E1**	**E2**	**E3**	**E1**	**E2**	**E3**
GCH-5	204.01	204.01	204.01	41.67	42.67	37.33	15.93	12.93	13.00
GCH-6	184.44	184.44	184.44	38.33	36.67	37.00	13.53	12.07	13.53
GCH-7	191.67	191.67	191.67	40.67	38.67	33.33	12.00	12.40	12.87
DCH-177	162.22	162.22	162.22	39.33	37.00	39.33	14.47	11.07	13.67
DCH-519	212.27	212.27	212.27	41.67	41.33	39.33	17.13	11.87	13.03
RHC-1	130.30	130.30	130.30	37.00	40.67	42.33	10.20	14.07	11.00
PCH-111	166.02	166.02	166.02	36.33	35.33	32.67	12.93	12.07	13.13
DCS-107	151.57	151.57	151.57	46.67	40.00	42.67	15.47	12.73	11.47
PCS-4	143.82	143.82	143.82	38.67	36.67	34.00	14.00	11.93	10.60
PCS-136	143.06	143.06	143.06	39.33	42.00	41.00	13.60	11.47	10.33
PCS-262	149.49	149.49	149.49	38.67	38.67	34.67	12.40	12.73	9.60
GC-3	195.55	195.55	195.55	42.33	39.00	39.00	12.87	12.47	10.87
Checks									
GCH-4	148.51	148.51	148.51	37.67	36.33	37.00	11.20	10.67	11.73
48-1	172.09	172.09	172.09	45.67	36.33	33.67	15.20	12.80	11.53
Mean	**168.22**	**168.22**	**168.22**	**40.29**	**38.67**	**37.38**	**13.64**	**12.23**	**11.88**
S.Em. ±	6.47	3.73	3.86	1.36	0.79	1.26	0.52	0.53	0.55
C.D. (5 %)	18.82	10.84	11.21	3.94	2.31	4.95	1.51	1.54	1.60
C.V. (%)	9.15	3.74	5.23	5.83	3.55	5.83	6.58	7.50	8.02

Contd...

Appendix VII contd….

Genotypes	**Length of primary spike (cm)**			**Effective length of primary spike (cm)**			**Number of spikes per plant**		
	E1	**E2**	**E3**	**E1**	**E2**	**E3**	**E1**	**E2**	**E3**
GCH-5	50.94	52.68	46.32	47.05	47.45	43.14	10.19	7.70	8.38
GCH-6	55.12	49.10	43.46	49.94	43.77	39.80	11.33	8.18	8.05
GCH-7	71.85	51.53	52.05	65.75	45.47	43.65	8.76	8.46	9.03
DCH-177	58.22	52.59	53.76	51.79	47.85	48.71	7.66	8.93	8.39
DCH-519	51.62	47.63	45.16	48.92	47.42	40.06	8.29	7.79	8.52
RHC-1	46.98	46.41	47.60	45.17	42.73	44.54	6.29	6.32	8.57
PCH-111	39.05	46.09	44.93	37.36	41.66	40.40	9.54	7.94	8.31
DCS-107	58.64	43.40	43.46	52.62	42.68	39.77	8.85	7.68	7.99
PCS-4	53.39	43.40	46.48	49.16	38.30	38.76	7.32	7.58	8.78
PCS-136	52.86	47.75	52.96	50.28	38.89	44.71	9.79	7.13	10.16
PCS-262	58.08	52.37	54.86	52.04	43.15	47.73	8.66	8.73	10.03
GC-3	51.63	47.43	49.41	48.48	45.06	45.43	8.97	8.05	9.25
Checks									
GCH-4	69.39	54.77	52.96	48.82	42.80	47.07	9.33	8.89	9.57
48-1	62.66	47.30	45.69	58.00	49.15	39.52	10.64	8.33	8.51
Mean	**55.75**	**48.75**	**48.51**	**50.38**	**44.03**	**43.09**	**8.97**	**7.98**	**8.82**
S.Em. ±	3.12	1.73	2.35	2.91	1.87	2.01	0.50	0.33	0.24
C.D. (5 %)	9.06	5.02	6.84	8.45	5.44	5.84	1.44	0.95	0.70
C.V. (%)	9.68	6.14	8.40	9.99	7.37	8.08	9.59	7.13	4.73

Contd...

Appendix VII contd….

Genotypes	Average number of capsules per spike			Yield per plant (g)			Net plot yield (kg)		
	E1	**E2**	**E3**	**E1**	**E2**	**E3**	**E1**	**E2**	**E3**
GCH-5	40.46	35.82	36.45	95.99	112.79	104.50	3.19	3.45	3.09
GCH-6	40.15	35.93	34.55	97.74	126.60	130.27	3.26	3.51	3.52
GCH-7	47.73	39.81	37.16	75.06	156.63	104.63	2.50	5.55	3.37
DCH-177	43.54	45.16	36.92	96.19	104.74	120.33	3.17	4.13	3.74
DCH-519	38.23	35.39	36.71	77.68	94.17	87.56	2.53	3.18	2.78
RHC-1	42.58	40.32	35.71	82.39	88.07	71.14	2.68	2.41	2.27
PCH-111	40.74	37.01	32.49	72.05	168.41	102.67	2.35	4.77	3.22
DCS-107	41.05	40.01	34.33	70.93	96.09	88.17	2.32	3.11	2.73
PCS-4	43.35	35.18	37.80	78.88	122.02	77.09	2.62	3.75	2.41
PCS-136	38.12	35.88	46.23	98.93	100.54	100.91	3.25	3.27	3.16
PCS-262	43.00	41.39	47.18	91.01	82.38	93.03	2.96	2.73	3.00
GC-3	38.27	34.32	34.78	73.19	106.24	86.02	2.38	3.57	2.61
Checks									
GCH-4	41.67	45.17	38.68	97.08	124.00	96.59	3.23	4.01	2.99
48-1	42.63	41.71	38.68	80.15	103.69	96.64	2.67	3.10	2.83
Mean	**41.54**	**38.79**	**37.69**	**84.80**	**113.31**	**97.11**	**2.79**	**3.61**	**2.98**
S.Em. ±	0.89	1.20	1.94	4.55	9.81	5.74	0.15	0.25	0.17
C.D. (5 %)	2.58	3.48	5.64	13.23	28.52	10.24	0.44	0.72	0.49
C.V. (%)	3.69	5.35	8.91	9.29	15.00	8.12	9.37	11.90	9.85

Contd...

Appendix VII contd….

Genotypes	Total yield (q ha^{-1})			100 seed weight (g)			Oil content (%)		
	E1	**E2**	**E3**	**E1**	**E2**	**E3**	**E1**	**E2**	**E3**
GCH-5	18.13	19.58	17.56	30.12	30.24	26.39	50.07	48.77	50.56
GCH-6	18.48	19.92	19.99	29.80	30.24	28.25	49.09	47.68	49.44
GCH-7	14.20	31.52	19.13	30.56	26.93	28.25	50.09	48.08	49.87
DCH-177	18.00	23.42	21.26	28.07	27.39	25.66	49.28	47.46	49.23
DCH-519	14.39	18.05	15.78	29.50	27.30	28.75	51.38	48.87	50.67
RHC-1	15.23	13.70	12.91	26.55	27.38	25.00	49.23	48.10	49.88
PCH-111	13.34	27.06	18.26	29.39	28.29	26.32	49.57	46.97	48.70
DCS-107	13.15	17.67	15.50	25.71	26.42	26.77	48.66	45.95	47.32
PCS-4	14.89	21.27	13.70	29.19	26.89	26.18	51.17	49.12	51.05
PCS-136	18.47	18.59	17.96	28.83	27.44	23.35	51.66	50.11	51.32
PCS-262	16.78	15.49	17.02	26.76	28.44	26.94	51.22	49.13	50.95
GC-3	13.54	20.26	14.80	26.31	27.68	25.45	50.59	48.28	49.75
Checks									
GCH-4	18.34	22.78	16.98	26.83	26.16	26.01	49.59	47.19	48.62
48-1	15.15	17.62	16.05	23.46	26.10	24.70	50.76	49.99	51.83
Mean	**15.86**	**20.50**	**16.92**	**27.93**	**27.64**	**26.29**	**50.17**	**48.27**	**49.94**
S.Em. ±	0.86	1.41	0.96	0.54	0.77	0.65	0.44	0.54	0.59
C.D. (5 %)	2.50	4.09	2.80	1.64	2.23	1.88	1.29	1.56	1.70
C.V. (%)	9.37	11.90	9.85	3.49	4.81	4.26	1.53	1.92	2.03

Appendix VIII. *Per se* performance of twelve genotypes and two checks of castor (*Ricinus communis* L.) at three environments during *kharif*-2015

Genotypes	Plant height (cm)			Days to flower initiation			Number of nodes upto primary spike		
	E1	**E2**	**E3**	**E1**	**E2**	**E3**	**E1**	**E2**	**E3**
GCH-5	202.72	181.06	113.13	41.00	43.33	37.67	13.73	13.80	13.87
GCH-6	182.79	172.00	119.00	37.67	36.00	37.67	12.33	13.67	12.13
GCH-7	193.60	164.07	123.00	40.67	38.67	34.00	14.93	13.00	13.80
DCH-177	162.56	173.73	125.56	38.00	35.67	38.67	15.33	15.00	12.87
DCH-519	212.48	181.41	129.25	40.67	42.00	39.67	16.80	15.20	14.87
RHC-1	130.89	176.92	133.67	38.33	41.00	41.67	12.87	12.80	14.13
PCH-111	164.67	169.76	137.67	35.67	34.67	33.33	13.73	11.60	13.67
DCS-107	152.02	169.65	140.28	46.33	40.00	43.33	13.73	14.33	12.60
PCS-4	144.60	157.11	141.67	38.67	36.00	34.00	12.73	13.53	12.40
PCS-136	143.47	159.72	145.67	38.67	40.67	41.67	12.40	12.33	13.53
PCS-262	148.75	170.59	148.33	38.00	37.33	35.33	12.27	12.60	13.13
GC-3	195.18	157.31	157.33	42.33	39.33	40.33	13.73	12.60	14.00
Checks									
GCH-4	147.33	144.89	109.67	37.67	35.67	37.67	12.80	12.60	14.13
48-1	171.00	183.81	151.33	45.67	36.33	34.33	13.67	13.47	12.80
Mean	**168.00**	**168.72**	**133.97**	**39.95**	**38.33**	**37.81**	**13.65**	**13.32**	**13.42**
S.Em. ±	6.35	3.56	3.89	1.41	1.16	1.40	0.50	0.49	0.49
C.D. (5 %)	18.46	10.36	11.31	4.11	3.38	4.08	1.45	1.43	1.41
C.V. (%)	6.55	3.66	5.03	6.13	5.25	6.43	6.34	6.39	6.26

Contd...

Appendix VIII contd….

Genotypes	**Length of primary spike (cm)**			**Effective length of primary spike (cm)**			**Number of spikes per plant**		
	E1	**E2**	**E3**	**E1**	**E2**	**E3**	**E1**	**E2**	**E3**
GCH-5	50.12	58.25	45.86	46.10	47.18	42.46	10.43	7.61	8.67
GCH-6	54.18	47.62	46.58	45.78	43.15	40.79	11.60	8.05	8.33
GCH-7	70.42	51.28	50.07	62.62	45.08	46.04	8.98	8.35	9.36
DCH-177	57.06	51.80	50.89	48.87	46.87	44.24	7.84	8.80	8.66
DCH-519	52.71	45.88	50.23	51.65	47.78	45.41	8.51	7.66	8.81
RHC-1	48.50	46.88	48.36	44.02	44.49	42.59	6.47	6.21	8.89
PCH-111	39.47	45.40	42.85	36.55	41.03	36.83	9.77	7.82	8.61
DCS-107	59.11	43.82	45.17	53.32	41.00	39.76	9.13	7.57	8.26
PCS-4	52.34	41.63	46.02	48.16	38.48	41.40	7.53	7.46	9.08
PCS-136	52.09	47.12	50.78	48.06	42.21	43.31	10.06	7.02	10.51
PCS-262	57.31	51.76	53.89	51.04	42.49	48.23	8.85	8.60	10.37
GC-3	51.79	47.96	49.04	47.89	45.16	40.96	9.19	7.94	9.55
Checks									
GCH-4	68.04	54.05	51.08	57.56	41.98	41.29	9.63	8.74	9.89
48-1	58.21	48.88	46.96	54.42	46.19	42.70	10.90	8.24	8.81
Mean	**55.09**	**48.74**	**48.41**	**49.72**	**43.79**	**42.57**	**9.21**	**7.86**	**9.13**
S.Em. ±	2.72	2.37	2.03	2.57	1.81	1.94	0.49	0.33	0.25
C.D. (5 %)	7.91	6.90	5.91	7.47	5.27	5.65	1.43	0.95	0.73
C.V. (%)	8.56	8.43	7.28	8.96	7.17	7.91	9.27	7.21	4.79

Contd...

Appendix VIII contd….

Genotypes	Average number of capsules per spike			Yield per plant (g)			Net plot yield (kg)		
	E1	**E2**	**E3**	**E1**	**E2**	**E3**	**E1**	**E2**	**E3**
GCH-5	39.89	35.14	34.61	97.55	110.21	98.62	3.02	3.26	2.93
GCH-6	39.49	35.27	32.81	99.52	122.99	122.89	3.08	3.90	3.33
GCH-7	46.95	39.38	35.61	76.56	153.15	99.38	2.37	5.26	3.19
DCH-177	42.89	44.58	35.38	98.03	103.20	113.85	3.00	3.26	3.55
DCH-519	38.02	34.72	34.88	79.17	91.53	83.56	2.40	3.01	2.63
RHC-1	41.98	39.58	33.91	83.97	86.30	67.51	2.54	2.28	2.15
PCH-111	40.14	36.43	30.86	73.21	165.70	96.61	2.22	4.51	3.05
DCS-107	40.45	39.32	32.93	72.39	93.71	83.25	2.19	2.95	2.58
PCS-4	42.72	34.56	36.21	80.20	119.38	71.82	2.48	3.55	2.29
PCS-136	37.54	35.30	43.90	100.11	97.59	94.87	3.08	3.10	3.00
PCS-262	42.37	40.67	45.14	92.40	80.37	88.09	2.80	2.58	2.84
GC-3	37.68	33.71	33.35	74.53	103.78	81.00	2.26	3.38	2.47
Checks									
GCH-4	41.10	44.72	36.74	98.79	120.50	90.81	3.06	3.80	2.83
48-1	41.94	40.66	36.40	81.59	100.80	91.24	2.53	2.94	2.68
Mean	**40.94**	**38.15**	**35.91**	**86.29**	**110.66**	**91.68**	**2.64**	**3.41**	**2.82**
S.Em. ±	1.08	1.88	0.25	4.52	9.86	5.59	0.14	0.19	0.16
C.D. (5 %)	3.13	5.45	0.73	13.13	28.56	16.26	0.42	0.57	0.47
C.V. (%)	4.89	9.05	4.79	9.07	15.43	10.57	9.36	9.86	9.86

Contd...

Appendix VIII contd….

Genotypes	**Total yield (q ha^{-1})**			**100 seed weight (g)**			**Oil content (%)**		
	E1	**E2**	**E3**	**E1**	**E2**	**E3**	**E1**	**E2**	**E3**
GCH-5	17.15	18.53	16.64	28.51	29.23	24.99	47.56	49.97	47.85
GCH-6	17.48	22.17	18.92	28.21	29.26	26.74	46.62	48.54	46.79
GCH-7	13.44	29.85	18.12	28.93	25.70	26.74	47.58	49.63	47.52
DCH-177	17.04	18.49	20.13	26.58	25.73	24.29	46.80	48.35	46.59
DCH-519	13.62	17.10	14.93	27.93	26.39	27.21	48.79	49.43	47.97
RHC-1	14.42	12.95	12.21	25.14	26.19	23.67	46.75	49.31	47.21
PCH-111	12.62	25.62	17.29	27.82	27.42	24.92	47.09	48.15	46.43
DCS-107	12.46	16.72	14.67	24.34	26.21	25.35	46.88	46.77	45.10
PCS-4	14.10	20.14	12.98	27.63	25.37	24.79	48.61	50.67	48.85
PCS-136	17.48	17.60	17.01	27.30	26.54	22.11	49.06	50.74	49.49
PCS-262	15.89	14.67	16.11	25.34	27.53	25.51	48.65	50.04	48.23
GC-3	12.82	19.20	14.01	24.91	27.44	24.09	48.06	49.18	47.72
Checks									
GCH-4	17.36	21.56	16.08	25.40	25.97	24.62	47.10	48.73	46.65
48-1	14.34	16.67	15.19	22.21	25.25	23.37	48.21	51.24	49.73
Mean	**15.02**	**19.38**	**16.02**	**26.45**	**26.73**	**24.88**	**47.70**	**49.34**	**47.58**
S.Em. ±	0.81	1.10	0.91	0.53	0.80	0.61	0.44	0.55	0.56
C.D. (5 %)	2.36	3.21	2.65	1.55	2.32	1.78	1.27	1.61	1.63
C.V. (%)	9.36	9.86	9.86	3.49	5.18	4.25	1.58	1.95	2.05

Contd...

Appendix VIII contd….

Genotypes	SPAD @ 75 DAS			SPAD @ 90 DAS			SPAD @ 120 DAS		
	E1	**E2**	**E3**	**E1**	**E2**	**E3**	**E1**	**E2**	**E3**
GCH-5	38.07	39.7	36.7	49.3	43.93	47.83	51.7	46.7	50.2
GCH-6	39	34.17	37.37	43.7	36.9	43.57	49.07	42.43	48.77
GCH-7	40.83	37.3	39.93	49.6	41.13	49.4	53.73	38.87	54.67
DCH-177	37.6	40.53	38.7	45.1	42.17	36.93	50.4	44.53	53.93
DCH-519	36.07	39.17	34.43	58.13	40.1	44.27	60.3	45.83	59.43
RHC-1	33.2	35.63	32.7	50.3	38.57	42.57	55.8	44.83	50.7
PCH-111	34.5	38.43	33.67	53.4	40.4	44.8	57.33	47.87	55.93
DCS-107	36.33	34.23	36.07	54.17	40.2	48.37	58.13	48.43	54.93
PCS-4	36.8	47.13	36.77	48.17	36.3	45.5	56.43	44.13	55.87
PCS-136	33.27	45.1	33.47	47.27	39.33	51.03	55.1	45.87	51.77
PCS-262	34.9	35.07	32.33	46.37	41.23	46.53	51.9	47.7	55.77
GC-3	37.57	38.8	36.7	49.47	43.77	40.87	53.6	50.6	54.43
Checks									
GCH-4	35.9	33.6	34.73	45.1	43.93	46.43	50.43	52.73	50.27
48-1	33.47	38.4	34.73	55.37	46.97	45.1	61.07	54.8	53.5
Mean	**36.25**	**38.33**	**35.62**	**49.67**	**41.04**	**45.23**	**54.64**	**47.57**	**53.58**
S.Em. ±	1.51	1.25	0.90	2.78	1.21	1.39	1.98	1.36	1.22
C.D. (5 %)	4.38	3.63	2.63	8.098	3.51	4.03	5.77	3.95	3.54
C.V. (%)	7.20	5.64	4.40	9.70	5.10	5.31	6.29	4.95	3.94

STABILITY ANALYSIS OF VARIETIES AND HYBRIDS IN CASTOR (*Ricinus communis* L.)

MANJESH CHANDRA S. **2016** **DR. P.V. KENCHANAGOUDAR**
MAJOR ADVISOR

ABSTRACT

An experiment was carried out to assess the stability of yield and yield parameters of 8 hybrids and 6 varieties of castor including two checks *viz.,* GCH-4 and 48-1 during *kharif*-2014 and *kharif*-2015 at three locations *viz.,* NSP/BSP, Seed Unit, MARS, University of Agricultural Science, Dharwad, Agricultural Research Station, Hanumanamatti and Horticultural Research and Extension Station, Devihosur.

According to Eberhart and Russel stability model (1966) the stable genotypes identified for total yield (q ha^{-1}) were GCH-5, GCH-6 and GCH-4(c). The promising genotypes identified for yield *per se* were GCH-7, DCH-177, PCH-111 and PCS-136. The association analysis revealed that seed yield per plant exhibited significant positive association with length of primary spike, effective length of primary spike, number of spikes per plant and average number of capsules per spike at three environments and path analysis indicated that number of spikes per plant and average number of capsules per spike have high direct effect on seed yield in all the locations under study.

Genetic variability analysis of various traits for *kharif*-2015 across three environments revealed that, GCV and PCV values ranged from high to moderate for seed yield per plant, net plot yield and total yield. Heritability in broad sense was high for the characters *viz.,* plant height, seed yield per plant, net plot yield, total yield and SPAD @ 75 DAS at all three environments. Plant height, number of spikes per plant, average number of capsules per spike, yield per plant, yield per plot, yield per hectare and SPAD @ 75 DAS exerted high heritability, wide variability and moderate to high genetic advance. High heritability coupled with high genetic advance indicated that these traits were controlled by additive gene action; hence, phenotypic selection could be effective in improvement of such traits.