COMBINING ABILITY AND HETEROSIS IN SIX ACCESSIONS OF CASTOR (*Ricinus communis* L.)

By

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DECLARATION

I declare that the work in this Thesis entitled “Combining ability and heterosis in six accessions of castor (*Ricinus cummunis* L.)” has been carried out by me in the Department of Plant Science under the supervision of Professor M. F. Ishiyaku, Dr I. S. Usman and Dr. M. D. Katung. The information derived from the literature has been duly acknowledged in the text and list of references provided. No part of this thesis was previously presented for another degree at any university.

Name of Student Signature Date

CERTIFICATION

This thesis entitled "COMBINING ABILITY AND HETEROSIS IN SIX ACCESSIONS OF CASTOR (*RICINUS C0MMUNIS L.*)" by Mutallab Shehu JIBRIN meets the regulations governing the award of Masters Degree in plant breeding of Ahmadu Bello Universiy, and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

Dedicated to my mother (Hajiya Zainab Mutallab), late father (Alh. Abdulmutallab Sulaiman), late father in-law (Alh. Lawal Sallau) and my wife (Hajiya A'isha Lawal Salau) for financial, moral support and caring so much about my progress.

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ABSTRACT:

Six Castor (Ricinus communis L.) accessories were crossed in 6x6 complete dialed to obtain 30 hybrids, and 6 parents. These 36 genotypes were used to estimate General Combining Ability (GCA) and Specific Combining Ability (SCA) effects for 50% days to germination, 50% days to flowering, plant height, peduncle length, number of racemes, number of branches, day to maturity, 100-seed weight and seed yield in order to select suitable parents for hybridization and to identify the promising hybrids. The 6 parents and 30 hybrids were evaluated in a randomized complete block design with three replications at the Institute of Agricultural Research (IAR) Zaria, in the dry seasons of 2009 and 2010 (two environments). General Combining Ability and Specific Combining Ability were estimated for 50% days to germination, 50% days flowering, plant height, peduncle length, number of racemes, number of branches, days to maturity, 100-seed weight and seed yield.

The results revealed that mean squares for GCA and SCA highly significant for all the agronomic traits, indicating considerable amount of genetic variability in the germplasm which can be used to initiate selection for further improvement. Components of variance showed that the GCA variance was higher than the SCA variance for days to germination, days to flowering, days to maturity, number of branches, peduncle length, plant height 100-seed weight and yield. These results indicated that additive gene action was more important than non additive gene action for these traits. Accessories IAR CAS026 exhibited the highest positive GCA effects for yield, number of branches, number of racemes and highest negative GCA effects for days to flowering and days to maturity.

Among all the crosses, IAR CAS 006 x IAR CAS 026 highest positive SCA effect for seed yield and IAR CAS 026 x IAR CAS 006 highest positive SCA effects for days to maturity and highest positive SCA effects for number of racemes. Thus, the two Accessories (IAR CAS 026 and IAR CAS 006) revealed good potential to be used as parents for hybrid.

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ABBREVIATIONS

C.V = Coefficient of Variation

DF = Degrees of Freedom

DG = Days to Germination

DM = Days to Maturity

e_{ijk} = Experimental Error

EMS = expectations of Mean Squares

etc. = etcetera

et al. = And Others.

F_1 = Single Cross Hybrid

F_2 = Second Generation Hybrid

GCA = General Combining Ability

HP = Higher-parent Heterosis

IAR = Institute for Agricultural Research Samaru

Me = Mean Square Error

Mp = Mid-Parent Heterosis

PH = Plant Height

r = Number of Replications, Reciprocal

S_{cA} = Specific Combining Ability

SAS = Statistical Analysis System

HSW = One hundred Seed weight

X_{ijk} = Observation of the ith and jth genotype in the kth Replication

Y = years

Y_i = Effect of the ith year

Y_{ij} = Mean of ith variety in jth Environment

Y_{ijk} = Performance of kth plot of the Cross between the ith and jth parents

Y_{ijkt} = Performance of a Cross between ith and jth parents in the kth Replicate in the th year

$^{\mu}$ = Overall Population Mean

$^{\mu}{}_{i}$ = Mean of the ith Cultivar over all Environments

$\partial^2 e$ = Error Variance

$\partial^2 g$ = Genotypic Variance

$\partial^2 gy$ = Genotype x year Interaction Variance

$\partial^2 GCA$ = General Combining Ability Variance

$\partial^2 SCA$ = Specific Combining Ability Variance

CHAPTER 1

1.0 INTRODUCTION.

The castor plant, *Ricinus communis L.*, is essentially a tropical species of flowering plant in the dicotyledonous angiosperm family *Euphorbiaceae* Commercially important non edible oil seed crop, valuable commodity, a cross pollinated diploid species with chromosome number 2n=20. Both India and Africa were considered as the centre of origin of castor based on its widespread cultivation, documentation and physical evidences (Ojo and Bello, 2004).

Castor seed is the source of castor oil, colourless to a very pale yellow liquid with mild or no odour or taste which has over 1000 industrial uses and because of this its demand increases with increase in industrialization (Ojo and Bello, 2004). The seeds contain between 40% and 60% oil, the highest among all cultivated oil crops, that is rich in triglycerides, mainly ricinoleic acid (unique fatty acid) (80-90%), highly stable and variation in fatty acids is very minimal making it the best raw industrial oil which is indispensable in the manufacture of more than 250 industrial products.(Yadava, 2012).

Castor oil is unique among vegetable oil because it is the only commercial source of hydroxylated fatty acid (ricinoleic acid), this unique fatty acid comprises around 90% of the castor oil. No other commercial vegetable oil produces such a high predominance of a single fatty acid. The oil is used as high quality lubricant because of its property to remain liquid at low temperature (-320°), and viscous at high temperatures. Castor oil and its derivatives are being used in textiles, soaps, cosmetics nylon fibres, bullet-proof glass and bone prostheses and as antifreeze for fuels and lubricants utilizes in aircrafts and space rockets (Ogunniyi, 2006). Castor oil is used in pharmaceuticals as laxative and soothing agent, pains and vanish industry. Other important uses of castor oil include production of wetting agents, detergents, synthetic flower scents and fruit flavors. In cytogenetic studies, soaking of root tips in castor oil for 2 hours helps in excellent chromosome spreading. The seed coat contains ricin, a toxin, which is also present in lower concentrations throughout the plant (Okoh *et al*, 2007).

The seed leaves and stem of castor are poisonous to humans and livestock if consumed. Ingestion of even one seed can be fatal to humans. Ricin, a very lethal protein, is the major toxic component. Ricinine, a poisonous alkaloid, exists at very low levels and presents little problem, Castor contains an allergin (known as CB-lA) which can cause an allergic reaction in humans. The toxicity of raw castor beans is due to the presence of ricin. According to the 2007 edition of the Guinness Book of World Records, this plant is the most poisonous in the world.

Castor oil accounts for 0.15% of the world production of vegetable oils (Scholz and Silver, 2008). World consumption of castor oil increased more than 50% during the past 25 years, rising from around 400,000 tons in 1985 to 610,000 in 2010. Most of the consumption growth occurred in European Union and China. The world production of castor seed increased 12.3 tons per year between 2000 and 2009. In that period India was responsible for 54.0%, China 23.4%, of the castor produced in the world. Brazil ranked the third in world castor production (11.9%), followed by Mozambique (4.3%), Paraguay (1.1%) and Thailand (1.0%), (FAO, 2011). The production of castor bean in Nigeria is low and unorganized due to slow industrial growth and marketing problems. There is a lot of variability within the species in Nigeria, which guarantees realizable genetic improvement targets (RMRDC, 2009).

Castor is a sexually polymorphic species. Naturally grown castor is mostly monoecious, the proportion of male and female flowers are greatly influenced by both genetics and non- genetics factors (temperature, humidity, plant age, nutritional factors, e.t.c.).

Higher proportion of female in relation to male will produce higher seeds. (Bertozzo,*et al;* 2011) the basic sex forms are monoecious, pistillate with Interspersed Staminate Flower (ISF) and sex revertants (Yadava,2012). Sex expression in castor is highly influenced by environmental conditions. The ratio of male to female flower is highly sensitive to environmental conditions. The proportion of female flowers is reduced by temperature above 30°C, increasing plant age, higher racemes position, inadequate mineral nutrition and sudden changes in temperature (Lavanya, 2002, Neeraja *et al.*, 2010).

1.1 Habitat and Growth.

Castor was initially believed to have four centers of origin (i) East Africa (Ethiopia), (ii) Northwest and Southwest Asians and Arabian Peninsula, (iii) India, and (iv) China. However, Ethiopia is considered to be the most probable site of origin because of the presence of high diversity (Anjani, 2012). It is also used extensively as a decorative plant in parks and other public areas, particularly as a "dot plant" in traditional bedding schemes. It was used in Edwardian times in the parks of Toronto, Ontario, Canada. Of the red and white variety, the red is seen as an ornamental plant, the white is used medicinally. Although monotypic, the castor oil plant can vary greatly in its growth habit and appearance. It is a fast-growing, suckering perennial shrub which can reach the size of a small tree (around 12 meters/39 feet), but it is not cold hardy. However it grows well outside, at least in Southern England and the leaves do not appear to suffer frost damage in sheltered spots, where it remains evergreen. In areas prone to frost it is usually shorter and grown as if it were an annual. If sown early, under glass, and kept at a temperature of around 20 °C until planted out, the castor oil plant can reach a height of 2–3 meters (6.6–9.8 ft) in a year (Ojo and Bello,2004).

1.2 Crop Production

Castor is a crop of the tropical, subtropical and Mediterranean climate zones. In the tropics, it can be cultivated over a wide altitude range with moderate rainfall (600-1,200mm). Frost, heavy rainfall and water logging are not tolerated. Castor grows well when the temperature is moderately high ($20^{o-}30^{o}$C) throughout the growing period. An average daily temperature 28^{0}C is optimal for the production of seeds with high oil content. Low temperature prolong the time of seedling emergence there by exposing the seeds to fungal attack. High temperature of about 40^{0}C during flowering adversely affect the sex ratio resulting in poor seed setting, (Neeraja *et al*., 2010)

Excessive precipitation encourages prolific vegetation growth at the expenses of flower and seed formation. High humidity associated with high rainfall may impair pollination as it reduces the viability of pollen grains capsule and foliage diseases become rampant with an increase in humidity. The crop needs dry and hot weather during seed setting and harvest for a satisfactory seed yield, castor requires a growing period of at least 60-120 days. Many castor genotypes particularly the taller cultivars are draught tolerant, (Raj *et al*., 2010).

Castor plants thrive on a wide variety of soils provided they are deep and well drained. They yield optimally in fertile, clayey and sandy loams and are highly sensitive to erosion prone soils. The soil is demanding on soil fertility through extremely fertile soils are unsuitable as they promote excessive vegetative growth at the expense of seed production. (RMRDC, 2009).

1.3 Agronomic Practices

Castor has its production requirement for optimum yield such as appropriate time of planting, plant spacing and density, fertilizer rates and cropping system. The on-set of rains determines the cropping season. Castor plant with its ability to withstand rainless periods makes the relationship between rainfalls and planting dates less important compared to the relationship between rainfall and insect pest activity, (Severino *et al.*, 2006). Where total rainfall approaches the minimum required to grow a castor crop, it is essential to plant the crop after the first major rainfall when soil moisture is adequate for germination and soil temperature have not been depressed. When rainfall is above minimum, planting early in the rainy season will result in poor emergence due to low seed viability, bed temperatures and fungal attack. More importantly flowering will then frequently coincide with a major insect build up, since the on-set of the rainy season with the attendant periods of high humidity acts as a trigger mechanism on many insects and larvae. In such areas planting should be delayed.

West African planting of local types is made after the first rains which may begin between late March and May. Introduced varieties with a shorter growing season are sown later but pure stands of either are few, (Ojo and Bello, 2004).

In Nigeria seed yield was consistently depressed by delaying planting beyond May. Crops planted in the month of June suffered considerable yield loses compared to those planted any time in May. Similarly, in mixed crop systems involving castor, delaying the introduction of castor into cassava plots progressively depressed seed yield, regardless of increased fertilizer rates, (Okoh *et al.*, 2010).

The effect of plant spacing on the performance of the crop is considerable, and the optimum for a particular region and level of husbandry must be carefully determined for maximum yield. It has been observed that close planting will produce spindly plants liable to lodging while wide planting encourages weed growth against castor a poor competitor. Trials in a number of varying climate regions have shown a direct correlation between plant spacing and yields, (Ojo and Bello, 2004).

In Brazil, spacing of 1.00 x 0.7m for dwarf, 1.5 x 0.8m for medium and 2.0 x 1.0m for tall types are generally recommended. Wider spacing was said to have increased the severity of sclerotina diseases and tended to delay maturity. In Argentina recommended spacing were spacing 1m x 0.5 or 0.6 for local annual types and 1m x 0.4m for introduced dwarf hybrids in other South American countries, a row width of 1.0 or 1.5m was usual but intra row spacing varied to suit the variety most popular locally. For commercial plantings, the most common spacing appeared to be 1 x0.5 meters. Local ‘tall’ varieties were usually planted at spacing of either 2.0 x 2.0 meters or 3.0.3.0 meter, (Ojo and Bello, 2004).

Trails in Egypt with ‘square’ planting distance of 15 x 15cm, 30 x30cm 45 x 45cm and 60 x 60cm showed that 45x 45cm gave the highest yields. The rain fed crop of India is sometimes drilled in 90 cm rows and thinned to one plant every 30-35cm within the row. More usually it is sown at a spacing of 45-90cm between plants depending on the area and variety, (RMRDC 2009).

In Tanzania, spacing of 3.5 x 3.5 meter 3.5 x 2.5 meters and 3.5 x 1.8 meters for the perennial large stature types were compared and 3.5 x 3.5 meters spacing was found to be the best. A spacing of 1.8 x 1.8 meters has been adopted in West Africa for perennial types and 1.0 x 0.3-0.45m for the dwarf varieties. At Mokwa, Nigeria, annual types are planted at a spacing of 1.0 x 1.5 meters and perennials at 2.0 x 2.0 meters but this has been only mixtures. Results in the central zone showed that closer spacing producing better and more robust plants with greater number of leaves per plant. This was not the case with seed production as wider spacing gave greater seed yield. The optimum plant spacing obtained was 1.0 x 2.0m although the spacing of 1.5 x 1.5 gave similar results (RMRDC, 2009).

1.4 Cropping System

Castor plants had been experimented to grow well in full with other crops. The term “polyculture” which simply contrast with ‘monoculture’ is used to distinguish the practice of growing two or more crops simultaneously from the growing of crops in pure stands. The difference between concepts of poly-and monoculture is but one of degree. Since the yield of a plant, given non-limiting resources and freedom from pests and diseases, is a function of the genetic make-up of that, while the yield of a crop is a function of the ability of individual plants to maintain that yield when receiving interference from neighboring plants. (Ojo and Bello, 2004). Thus under monoculture, neighboring plants are of the same genotype throughout the entire growing period, whereas under polyculture, at least one neighboring plant is of a different genotype, although not necessarily for the growing period. Intercropping is particularly beneficial when it involves two component crops that vary in their different growth cycles because this allows the scope for making better temporal use of resources. In Nigeria it has been shown that variability of annual returns from crop mixtures was less than that from sole crops, intercrop advantages can also result from one or both of the following.

i. Increased soil resources use and conversion efficiency and
ii. Increased light resources capture efficiency due to longer combined leaf area duration.

Modification in time, technique and pattern of planting of crops grown in association can make intercropping an economically viable and feasible practice. For maximum yield advantage, there should be some element of complimentarily between crops in order to reduce to a minimum competition between the intercrop components. Castor production in Nigeria can be achieved by sole and mixed cropping systems. (Ojo and Bello, 2004). For satisfactory yield advantage and higher gross returns castor oil plants should be introduced into cocoyam plots at 3 weeks after planting cocoyam at the ratio of 4 rows of cocoyam to 1 raw castor oil plant. With respect to castor/cassava intercrop, castor should be introduced into the cassava plot 2 weeks after planting cassava.

The castor/cassava mixture requires 600kg NPK/ha for higher gross returns it is worthy to note that Raw Materials Research and Development Council (RMRDC) started a collaboration arrangement with UAM on the development of improved seeds to boost castor production. The promising accessions collected by UAM are currently at the multi-locational testing stage and this promising genotype will solve the production problems before a synthetic variety being developed comes out (RMRDC, 2009).

1.5: Post Harvest Management

Uneven ripening and shattering of capsules posed obvious problems during harvest. Dehiscent varieties are usually harvested when fifty per cent of the capsules have ripened. The panicles are cut, heaped until ripe and sun dried to induce dehiscence of the capsules. They also collect seeds from the wild and prefer shattering varieties which do not need threshing, though the capsules have to be handpicked plants. Dwarf indehiscent cultivars are harvested mechanically when all the capsules are dry, (Machado *et al*., 2010).

The primary products of castor are oil and pomace or seed cake. The common processes of vegetable oil extraction are applicable to castor with some limitations, due to the presence of the toxic substances ricin and allergen. Hence, the seeds are not usually processed in equipment used for other oil seeds. The seeds are carefully separated from any capsules debris and are subsequently decorticated. Industrial shelling is done between rollers adjusted to the seed size to ensure that only the outer shell is broken. The important constituents of castor oil are ricinoeic acid when pressed in the cold and sabacic acid when extracted by heating. The pomace or residue left after oil extraction and subquent filtratiob contains the toxic substance ricin and allergen. The oil itself is free of toxins. Traditionally, castor oil is extracted by boiling the crushed seeds in water and skimming off the floating (RMRDC, 2009).

1.6: Justification.

Castor plays an important role in the National economy of India, Brazil and China by earning foreign exchange through export of castor oil. The castor plant is one of the neglected crops in Nigeria in terms of research attention until a few years ago and therefore there has been no recommended variety for production. The need for research on this crop specie was stimulated by growing demand of the industries for castor been as raw material. Genetic investigations have revealed a substantial amount of heterosis among the collected accessions and work is in progress throughout the country on how to utilize these heterotic potentials (RMRDC, 2009.) Estimate of genetic variability and combining ability are very important and useful in order to determine the breeding value of the populations which will give an insight to appropriate procedures to follow in a breeding program. The general and specific combining abilities estimates are useful to assess the nicking ability of parents and at the same time help in identification of potential parents and crosses. Estimate of combining ability is necessary in castor breeding whether for population improvement or for development of hybrids.

The selection of suitable parents for hybridization helps to develop hybrids which could be directly used as cultivars if found good or develop inbred lines for use in developing hybrids.

Based on these considerations the present investigation was carried out with the following objectives;

1. To identify superior parents for the production of hybrids
2. To estimate the amount of heterosis in the hybrids
3. To estimate the general combining ability and specific combining ability variance.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 Nomenclature

Castor is generic name of North American beaver (*Castor canadensis*) one of the brightest double start in the constellation Gemini. In Greek and roman legendary. Castor was apparently coined by English trader who confused it with the oil of another shrub, Vitex agnus cactus, which the Spanish and Portuguese in jamaica called “agno-casto”. Although it is commonly known as castor bean plant, the seed is not a true bean and it is not related to legume family (*Fabaceace*),(Anjani, 2012)

The scientific name for the castor plant, *Ricinus communis* has a more logical derivation. c*ommunis* means commom in latin, and castor plant was already commonly naturalized in many part of the world when the eighteenth century Swedish naturalist Carolus Linnaeus (karl von linne) was giving the scientific name of the plant. *Ricinus* on the other hand, is the latin word for tick and is the specific epithet for the Mediterranean sheep tick (Lxodes ricinus.). Apparently Linneus thought the seeds looked like ticks; particularly large ticks engorged with blood and named it as such. The mottled bodies of certain ticks superficially resemble a castor bean seed and the tick head resemble the caruncle of a castor bean seed, (Ojo and Bello, 2004). .

The castor plant is a member of the genus *Ricinus* in the spurge family, Euphobiaceae. Besides *R. communis*, which is the most widespread species of this genus, are two others found in Africa: R. persicum and R. *zazibarensis* the farmer has some economic potential while the later is indehiscent fruits and of no known economic value yet. Venkatachalam, *at el.* (2010) reported that the species *communis* was divided into several sub-species, based on morphology and geographical distribution. However, it is doubtful whether such classification is justified. Since the morphological differences are by and large simply inherited moreover, the most distant types were possible intercrossed and their hybrids were fully fertile indicating genetic similarities. Because most castor accessions readily intercross, produce fertile progeny, and have the same chromosome number, castor is now considered to be a single species. (Anjani, 2012).

The name Ricinus is a Latin word for tick; the seed is so named because it has markings and a bump at the end which resembles certain ticks. The common name "castor oil" likely comes from its use as a replacement for castoreum, a perfume base made from the dried perineal glands of the beaver (castor in Latin). It has another common name, Palm of Christ, or Palma Christi, that derives from castor oil's ability to heal wounds and cure ailments.

2.2 Genetics of Important Traits

Understanding the genetics of economically important traits is necessary for castor breeding. Earlier studies on inheritance of phenotypic traits need to be confirmed using modem cultivars and molecular assisted techniques. Stem color was reported to show epistatic interaction of two genes. Tall plants are dominant over dwarf plants due to a monogenic factor. Characters like bloom, presence of spines on the capsule, compactness of spike, and branching of the stalk appear to be controlled by partial dominance of presence and simply inherited. Many morphological and qualitative traits are controlled by one or few genes. (Rao *et al.*, 2010). Earlier studies indicated complete or partial dominance of presence of bloom (waxy stems) over its absence. These traits showed epistasis with either two or four genes. The intensity and distribution of bloom on different parts of the plant appears to be controlled by multiple genes (Lavanya and

Gopinath, 2008). The long petioles on castor leaves have limited the use of high plant density. Characteristics of primary economic importance traits such as seed yield and seed oil content are usually inherited in a quantitative manner, additive genetic effects were shown to be important in determining the number of nodes before flowering, number of raceme per plant, and seed oil contents in studies with inbred lines, evaluated in diallel crosses. Traits such as the length of the primary raceme, the number of capsules per primary raceme, and the seed weight have also been shown to be additively inherited. (Solanki and Joshi 2000; Solanki *et al*., 2003). A plant with short petiole was found, and this trait that is controlled by one pair of gene was transferred to the high yielding cultivar FCA-AB (Anjani, 2012). A high heritability was reported for earliness, seed weight, and plant height (Solanki and Joshi 2000).

Studies on the general combining ability and specific combining ability for seed yield, seed yield components and other agronomic traits were made by Nobrega *et al*., (2010). Significant effects of general and specific combining ability on seed yield were found in the study and in most cases genotypes with high specific combining ability had at least one parental line with high general combining ability. This result showed that selection in a conventional breeding could enhance these traits (Patel 2011).

Early maturation is another important trait for castor cultivation in region with short growing region or tropical areas which produce multiple crops easily. The negative correlation between early maturity and high seed yield is the major impediment to developing very early maturity genotypes. An early maturing gene population was developed using random crosses between extra early accessions for six generation (Anjani and Reddy, 2003). This population generated 23 accessions with high seed yield potentials and one of the accession had 50% of the plant flowered at 26 days after planting. The early – maturity traits in this accession appeared to be only marginally impacted by environment (Anjani, 2010).

2.3: Griffing's Diallel Analysis

Griffing (1956) proposed a diallel technique for determining the combing ability of lines and characterizing the nature and extent of gene action in both plants and animals. His approach has also been adopted to assess completion. Since its formulation, Griffing's analysis has been widely used by plant breeders, the three levels of the analysis and discusses the required assumption at each level. Griffing's analysis allows the option to test for fixed (model 1) or random (Model 2) effects.

Griffing (1956b) elucidated four experimental methods for analysing diallel-cross data;

1. Method 1 (full diallel). The parents (n) F_1S [n(n-1)/2], and reciprocals F_1S [n(n-1)/2] a total of n^2 entries. (where n is the number of parents).

2. Method 2 (half diallel). Parents (n) and F_1S [n(n-1)/2]; but no reciprocals F_1S a total of {n (n +1) 2 total entries}.

3. Method 3 F_1S [n(n-1)/2] and reciprocals included F_1S [n(n-1)/2], but no parents a total of n(n-1) entries.

4. Method 4. F_1 included, but non-reciprocals or parents [n (n-1)/2] only: no parents and no reciprocals F_1S.

2.4: Combining Ability

Combining ability is commonly used by breeders to express the relative performance of a line in hybrid combination and is divided into two, general and specific combining ability. Solanki *et al.,* (2003) defined general combining ability (GCA) as the average performance of lines in hybrid combinations and specific combining ability (SCA) as those instances in which certain hybrid combinations are either better or worse than should be expected on the average performance of the parent inbred lines involved. General combining ability variance is measured as though it were predominantly due to additive gene action. Specific combining ability variance then includes all effects which cannot be accounted for on the additive scheme. These may be the result of dominance, epistasis, genotypic and environmental interactions effect. Estimate of the variance of general and specific combining ability are obtained from a series of single-crosses yield trials. In general, it was found that with previously tested material, the variance for specific combining ability was somewhat greater than the corresponding variance for general combining ability(Lavanya and Chandramohan,2003).

General combining ability in particular, is directly related to the breeding value of the parent and is associated with additive gene action. Specific combining ability on the other hand, is commonly associated with all effects which cannot be accounted for by the additive scheme, such as dominance, epistasis and genotype-environment interaction.

Combining ability of inbred lines is the ultimate factor determines future usefulness of lines for hybrid. Investigation of the relative magnitude of additive and dominance genetic variance in cross of unrelated lines of maize provides a basis of characterization for combining ability. To establish a sound basis for any breeding program aimed at achieving higher yield, breeders must have genetic information on the nature of combining ability effects of parents, their behaviour and performance in hybrid combinations. Knowledge of combining ability is essential for selection of suitable parents for hybridization and identification of promising hybrids for further exploitation in a breeding program (Lavanya and Chandaramohon 2003).

Mehta (2000) evaluated ten castor bean genotypes and crosses in half-diallel fashion and reported that magnitude of mean sources for all traits was higher in GCA than SCA effects indicating the predominance of the additive gene action in the expression of these traits.

Joshi *et al*. (2001) tested four pistillate and 28 male lines and their crosses in four environments. They reported that the best general combines for early flowering and maturity were the parents RCG-5, EC-103745, Bhagya for dwarf plant height. JI-77, Hazari-1, JH-16 and SH-66 for low number of nodes up to main spike. SH-21, SH-16 and combination for days to flowering and maturity. VP_1 × SA_2 for plant height and SKI-93 × SKI-12 for number of nodes up to main spike.

Kavani *et al*. (2001) studied the combining ability for the nine attributes using Line × Tester mating design involving 5 lines and 7 testers in castor (*Ricinus communis. L*). The estimated component of GCA and SCA variances showed the preponderance of non additive gene action for all the characters. The female JP-81 was good general combiner for the seed yield per plant and some other important yield attributing characters. Among males, DCS-47, JL-251 were found to be good general combiners for yield per plant and other related attributes. The highest SCA effect was exhibited by the cross combination JP-81 × DCS-47 for seed yield per plant. The cross combination JP-82 × DCS-47 showed highest SCA effect for number of capsules on primary raceme. The highest SCA effect for number of effective spikes per plant was recorded by the cross JP-83 × DCS-47. He concluded that the parents with high GCA and crosses with high SCA effect should be exploited for further breeding program. The crosses with high SCA effects for yield per plant and other important yield attributing characters should be exploited for heterosis breeding.

Lavanya and Chandramohan (2003) reported that components of GCA and SCA variances showed predominance of non additive gene action for days to 50 percent flowering, number of nodes to primary raceme, plant height and seed yield in first, second and third picking and total seed yield. Additive gene action was predominant for effective spikes per plant, hundred seed weight and oil content, The female line, M 619 for plant height, 100-seed weight, seed yield in all three pickings and total seed yield, while M584 for effective spikes per plant height, 100-seed weight, seed yield in all three pickings and total seed yield, while M 584 for effective spikes per plant, yield at first picking and oil content were good general combiners. Among the males, JI 240 for seed yield in all the three pickings, total seed yield and oil content, JI 220 for seed yield in second and third pickings, SKI 233 for effective spikes per plant and SKI 229 and JI 225 for 100 seed weight were good general combiners.

Patel *et al.* (2010) carried out Line × tester analysis using seven females and eight males to estimate combining ability and nature of gene action in castor (*Ricinus communis. L.*) for eight different characters during rainy season of 2008. The analysis of variance for combining ability and estimates of variance ratio (σ^2gca/ σ^2sca) revealed that the non-additive gene action was predominantly involved in expression of most ot the traits. The hybrids SKP-106 × SKI-166, Geeta × SKI-330, SKP-117 × SKI-192, Geeta × JI-368 and JP-90 × SKI-192 exhibited higher specific combining ability effects in desired direction for seed yield/plant and its attributes. The estimates of GCA effect indicated that the female parent SKP 120 was good combiner for seed yield and also other important traits. The SKI 329 was a good general combiner for length of main raceme and number of capsule on primary raceme with significant positive GCA for total seed yield.

Rao *et al.*, (2010) reported that seven elite lines consisting of releases varieties (Haritha, Kranthi, Kiran), advanced breeding lines (PCS-17, PCS-171) and pistillate lines (VP-1 and DPC-9) were crossed in diallel method excluding reciprocals. The resultant 21 hybrids were evaluated along with their parents in a randomized block design, replicated thrice. The analysis of variance for combining ability revealed significant differences among the genotypes, indicating wide diversity in the material studied. The mean squares due to general and specific combining ability (GCA and SCA) were highly significant for all traits indicating that both additive and non-additive types of gene action were involved in the inheritance of these traits. The GCA effects of the parents revealed that three parents Harihta, Kranthi, VP-1 were promising general combiners for seed yield and other yield contributing traits. Based on the SCA effects and per se performance, four hybrids viz., Haritha × DCP-9, Haritha × VP-1 Haritha × Kiran and Haritha × PCS-170 were identified as promising for seed yield/plant and other characters.

Najan *et al.,* (2010) evaluated fifteen genotypes of castor (*Ricinus communis L.)* for variability parameters like seed yield and its related characters during rainy season of 2009. They observed significant variation for seed yield and its components. High heritability with high genetic advance and genotypic coefficient of variation were observed for plant height, days to maturity and seed yield, indicating direct selection of these traits were effective. High heritability with moderate genetic advances was observed in number of capsules to primary spike and effective primary spike length. Studies showed the selection of these traits were effective.

Vaithiyalingam *et al.,* (2010) used a set of 15 castor accessions to study the correlation coefficient and direct and indirect effects of path coefficient to study the effects of characters for improvement in yield. They observed that genotypic correlation coefficient were higher than the phenotypic correlation coefficients. Seed yield exhibited significant positive association with the number of nodes to primary spike, number of spikes/plant and 100 seed weight recorded maximum direct effect on seed yield followed by number of spikes/plant and number of nodes on seed yield.

Gondaliya *et al.,* (2001) investigated the genetic architecture of seed yield and related traits through generation mean analysis for three crosses in six generations. Additive and non additive gene effects for seed yield and majority of the traits were significant. However, magnitude of dominance and epistatis component were higher than additive components. None of traits was under the control of the epistatis. Higher magnitude of dominance and dominance × dominance gene effects were observed for seed yield per plant. Thus heterosis breeding, synthetic variety and population improvement adopting inter se mating among promising divergent genotypes and effecting simultaneous selection for seed yield, oil content and other components of yield is an ideal breeding approach foe castor improvement.

2.5 Heterosis for seed yield and its contributing traits

Heterosis or hybrid vigour indicates the superiority of hybrid over its parents. Heterosis generally results from the action of multiple loci, and different loci affect heterosis for different traits and in different hybrids. Hence, multi-gene models are likely to prove most informative for understanding heterosis. Complementation of allelic variation, as well as complementation of variation in gene content and gene expression patterns, is likely to be an important contributor to heterosis. In crops, heterosis must be considered within the context of the genomic impacts of prior selection for agronomic traits. (Golakia, *et al.*, 2004)

Golakia *et al.*, (2004) studied forty four castor hybrids developed by line × tester mating design (four pistillate lines × 11 male parents) along with parents and a standard check for heterosis of yield determinant characters. Significant desired heterobeltisis ranged from 18.7 to 39.6% and standard heterosis ranged from 17 to 32.8% for seed yield/plant. Other characters also showed considerable heterosis over better parent and standard check. However, magnitude of heterosis was found to vary substantially from cross to cross and character to character. Five superior hybrids sorted out on the basis of seed yield/plant per se showed no indication of yield heterosis arising from yield components. However, effective branches/plant found to be major contributor towards seed yield so far standard heterosis is concerned. The JP 88 × DCS 89, JP 65 × DCS 89, JP 88 × PCS 124, JP 88 × JI 274, P 65 × DCS 89, JP 88 × PCS 124, JP 88 × JI 274 and JP 65 × JI 309 were the promising hybrids over standard check (GCH 6), need to be tested in different agro climatic zones to prove their yield superiority over the environment.

Patel *el al.,* (2010) evaluated forty eight hybrids and their parents (4 psitillate lines and 12 monoecious lines) to study the extend of heterosis and standard heterosis for seed yield and other important characters over three environments within crop duration. They observed that parents and hybrids responded differently to environment for their per se performance for most of the characters studied. The estimates and magnitude of various heterotic effects varied with crosses irrespective of characters. In consistent performance of most of the hybrids across the environments for all the characters under study revealed that parental genes, and their combinations were susceptible to environmental variation, which is general feature of polygenic inheritance. About two third of hybrids registered significant and positive heterobeltiosis for seed yield. The hybrids viz., SKP 24 × SKI 270 (108.02%), VP 1 × DCS 47 (102.19%), Geeta × SKI 147 (94.30%), Geeta × SPS 44-1 (75.5%), SKP 84 × DCS 47 (75.3%) and SKP 24 × SKI 270 (40.9%) registered significant standard heterosis. The effects for seed yield might have resulted from direct effect of number of capsules/plant, shelling outturn and test weight of 100 seeds. Accordingly, heterotic effects for seed yield could be outcome of indirect effect of effective length of primary spike, number of capsules on primary spikes, number of secondary spikes/plant and number of tertiary spikes/plant. The magnitude of secondary was negative for development of characters leading to earliness. It was also negative for growth attributes related to plant stature, for seed yield and yield component testers exhibited good GCA effects for seed yield. The data indicated that for realization of heterosis, at least one parent must have higher GCA for yield components. These results suggest that, additive as well as non-additive components can be exploited for the development of potential varieties and hybrids.

CHAPTER 3

3.0 MATERIALS AND METHODS

3.1 Source of Genetic Material.

Six accessions of castor IARCAS026, IARCAS006, IARCAS001, IARCAS017, IARCAS010 and IARCAS002 were obtained from germplasm collection of the castor breeding unit of Institute for Agricultural Research (IAR), Ahmadu Bello University Zaria (ABU) based on their seed size, seed color, and oil content and used as parents. The six parents were selfed twice in 2007 irrigation and rainy seasons which reduced the hetrozygosity, and the parents were theoretically assumed to be 75% pure lines (Table 3.1).

The study was conducted under irrigation at research farm of Institute for Agricultural Research (IAR), Samaru (110 11" N: 07" 38" E) Kaduna State. The experiment was laid out in a randomized complete block design (RCBD) with three replications. Single row plots were used, each 3m long and spaced 1m x 0.75m. Surface irrigation was used at seven days interval. The fields were harrowed and ridged after which planting was done from February 2nd for 2009 year evaluation, while the second environment was planted on December 26, 2010.

Nitrogen in form of calcium ammonium nitrates of potash (26% N), 50 Kg of phosphorus in form of single super phosphate (18%P_2O_5) and 30 Kg of potassium in form of nitrates of potash (62%K_2O) were applied per hectare.

Genotypes:

Table 3.1.The brief description and source of the genetic materials used in this study.

Genotypes	Source	Characteristics
IARCAS026	Jigawa state	Early maturing, medium seeded
IARCAS001	Brazil	Late maturing and large seeded
IARCAS010	Bugaje, (Katsina state)	late maturing, black and
IARCAS002	Kogi state	Small seeded ,early maturing
IARCAS017	Zango, Zaria (Kaduna state)	Small seeded, early maturing
IARCAS006	Durbi (Katsina state)	Large seeded, late maturing

3.2.0 DEVELOPMENT OF F1 HYBRIDS

3.2.1 Mating Design Used To generate the F_1 Hybrids

The parents (75% pure lines) were hand crossed in a 6×6 complete diallel mating design during 2008 dry season at Institute for Agricultural Research Experimental Farm, Samaru, Zaria. Seven seeds of each of the inbred lines were planted in a plot. Each plot consisted of 1 row of 5.25m long. Inter and intra row spacing of 75cm and 75cm were used, respectively.

With the help of forceps male flowers were removed carefully and the female flowers were covered with envelop for 3-4 days to allow the female flower to open. Mature pure pollen of desired character were dusted on the stigma and covered again for 4-7 days, and the envelope was subsequently removed. All the F_1 were generated in 2008.

The experiment was carried out in a Randomized Complete Block Design (RCBD) with three replications. The crosses generated were 15 F_1 hybrids and 15 reciprocals (Table 3.3). The 36 entries which include 15 hybrids, 15 reciprocals and 6 parents (Griffing's method 1,1956b) were laid in a 6x6 complete diallel design with three replications in each year in dry seasons (2009 and 2010).

Table 3.2. List of F_1 hybrids of some Castor accessions generated in 2008 at Samaru, Zaria.

Hybrids	**Reciprocal**
IARCAS026 X IARCAS017	IARCAS017 X IARCAS026
IARCAS026 X IARCAS001	IARCAS001 X IARCAS026
IARCAS026 X IARCAS006	IARCAS006 X IARCAS026
IARCAS026 X IARCAS010	IARCAS010 X IARCAS026
IARCAS026 X IARCAS002	IARCAS002 X IARCAS026

IARCAS001 X IARCAS017	IARCAS017 X IARCAS001
IARCAS001 X IARCAS006	IARCAS006 X IARCAS001
IARCAS001 X IARCAS010	IARCAS010 X IARCAS001
IARCAS001 X IARCAS002	IARCAS002 X IARCAS001
IARCAS017 X IARCAS006	IARCAS006 X IARCAS017
IARCAS017 X IARCAS010	IARCAS010 X IARCAS017
IARCAS017 X IARCAS002	IARCAS002 X IARCAS017
IARCAS006 X IARCAS010	IARCAS010 X IARCAS006
IARCAS006 X IARCAS002	IARCAS002 X IARCAS006
IARCAS010 X IARCAS002	IARCAS002 X IARCAS010

3.3 Evaluation of Hybrids, parents and reciprocals.

The F_1 hybrids, the reciprocals as well as the parents were evaluated in dry season (December-April) in Samaru for two years (2009 and 20010) respectively. Analysis of variance was done and it was found that genotype by year interaction was not significant, therefore no need for stability analyses. The two years considered as two environments were as follows; Samaru 2009, dry season as environment 1, and Samaru

2010, dry season as environment 2, The 36 genotypes evaluated in the study were given in Table3.3.

The fields were harrowed and ridged after which planting was done from February 2nd for 2009 year evaluation, while the second environment was planted on December 26, 2010. Each plot consisted of 1 row of 5.25m long with 7 stands per plot. Inter and intra row spacing of 75cm and 75cm were used respectively. Two seeds were planted per hill 3-4cm deep on the ridges. A mixture of gramoxone and sorghoprim A was sprayed as pre-emergence herbicide. Thereafter, weeds were controlled by hoe-weeding three times as follows, four weeks, eight weeks and twelve weeks after sowing. The plants were sprayed with “DD FORCE” (an organophosphate insecticide) at eight weeks which controlled all the insects that disturbed castor plant at flowering stage. Remolding was done at fifteen weeks to achieve weed control, improve soil aeration and prevent root lodging.

Table 3.3. Thirty six genotype of castor evaluated (2009 and 2010) at Samaru, Zaria.

Parents	**Hybrids**	**Reciprocal**
IARCAS026 X IARCAS026	IARCAS026 X IARCAS017	IARCAS017 X IARCAS026
IARCAS001 X IARCAS001	IARCAS026 X IARCAS001	IARCAS001 X IARCAS026
IARCAS017 X IARCAS017	IARCAS026 X IARCAS006	IARCAS006 X IARCAS026
IARCAS017 X IARCAS006	IARCAS026 X IARCAS010	IARCAS010 X IARCAS026

IARCAS010 X IARCAS010	IARCAS026 X IARCAS002	IARCAS002 X IARCAS026
IARCAS002 X IARCAS002	IARCAS001 X IARCAS017	IARCAS017 X IARCAS001
	IARCAS001 X IARCAS006	IARCAS006 X IARCAS001
	IARCAS001 X IARCAS010	IARCAS010 X IARCAS001
	IARCAS001 X IARCAS002	IARCAS002 X IARCAS001
	IARCAS017 X IARCAS006	IARCAS006 X IARCAS017
	IARCAS017 X IARCAS010	IARCAS010 X IARCAS017
	IARCAS017 X IARCAS002	IARCAS002 X IARCAS017
	IARCAS006 X IARCAS010	IARCAS010 X IARCAS006
	IARCAS006 X IARCAS002	IARCAS002 X IARCAS006
	IARCAS010 X IARCAS002	IARCAS002 X IARCAS010

3.4.0 Data Collection

Data were collected on the following agronomic traits:

3.4.1 Days to 50% germination

Days to 50% germination was recorded by counting numbers of days from planting to when about half of the seeds germinated.

3.4.2 Days to 50% flowering

This was recorded by counting from the date of planting to when about of the castor plants in each plot bloomed.

3.4.3 Pedicle length

The length of pedicle was determined by measuring the pedicle length of three randomly selected plants in each plot. These were averaged and recorded as spike length for each of the accession.

3.4.4 Days to 50% maturity

Maturity in castor bean plants was determined when the capsules start to turn brown and some leaves starts to fall off the plants. In some cases, days to fifty percent maturity were determined by counting from the date of planting to the time when the capsules attained physiological maturity which is the point of maximum dry weight accumulation, seed vigor and germination. The high moisture content in seeds after their maturity until harvest can accelerate the seed deterioration process, due to high metabolic activity.

3.4.5 Plant height (PH) at harvest (cm)

Plant height was measured from the base of the plant to the primary panicle (end of the panicle). The plant was measured using meter rule and heights were expressed in centimeter.

3.4.6 Fruit yield

Fruit yields were determined by harvesting all the fruits for each hybrids from each plot, separately. The weights of individual hybrids were measured using weighing balance and multiply by the total number of plant in the plot and recorded as the fruit yield/plot.

3.4.7 100 – seed weight (g)

Seed weight was determined by (seed size) threshing the pods and separating the seeds from the hulls. One hundred seed weights for the accessions were determined by picking and counting one hundred seed from each hybrids or parents and weighed using weighing balance three times each, and the average was recorded as 100 – seed weight in grams.

3.5.0 STATISTICAL ANALYSIS

3.5.1 Analysis of Variance

Analysis of variance was conducted using individual plot means for each year and combined across years. Years were considered as random while genotypes were fixed. All statistical analysis was computed using the General Linear Model (GLM) of statistical analysis system 9.0 (SAS Institute, 2003).

The statistical linear model used for the combined analysis of variance across years is:

$X_{ijk} = \mu + Y_i + R_{ij} + G_k + (RY)_{ij} + (GY)_{ik} + e_{ijk}$

Where:

X_{ijk} = observation of the i^{th} and j genotypes in the k^{th} replication.

μ = overall mean

Y_i = the effect of the i^{th} year, I = 1,2

Rij = The Effect of jth Replication in the ith year; j = 1,2,3

G_k = the effect of the Kth genotype; k=1,2…………………36

(RY)ij = replication x year interaction

(GY)ik = the interaction effect between kth genotype in the ith year

eijk = experimental error

The form of the combined analysis of variance across years with expectations of mean squares is given in Table 3.2.

Table 3.5. Form of combined analysis of variance across years with expectations of the mean squares (EMS).

Source of variation	**DF**	**MS**	**EMS**
Year	(y-1)		
Replication in years	y (r-1)	M_r	
Genotype	(g-1)	M_g	$\sigma_e^2 + r\sigma_{gy}^2 + ry\sigma_g^2$

Genotype x year	(g-1)(y-1)	M_{gy}	$\sigma_e^2 + r\sigma_{gy}^2$
Error	y(r-1) (g-1)	M_e	σ_e^2

where: y and g denote years and genotype, respectively.

σ_{gy}^2= genotype x year interaction variance

σ_g^2= variance due to genotype

σ_e^2 = error variance

Source: Matzinger and kempthorne (1956).

3.6 Combining Ability Estimates

For the estimation of the genetic effects, plot mean values in the years and replications were used for the dialed analysis of fixed effects method 1 model 1 (Otsuka *et al.*, 1972). The model used was:

$Y_{ijk} = \mu + g_i + g_j + s_{ij} + e_{ijk}$

Where

Yijk = the performance of the K^{th} plot of the cross between the i^{th} and j^{th} parents.

g_i = effect common to all progeny of the i^{th} line

g_j = effect common to all progeny of the j^{th} line

s_{ij} = effect specific to the progeny resulting from mating ith x jth line

e_{ijk} = experimental error.

The combining ability analysis years was based on the following linear model:

Where:

Y_{ijkt} = the performance of a cross between 1^{th} and j^{th} parents in the k^{th} replicate in the t^{th} year

μ = overall mean

gi = effect common to all progenies of the i^{th} parent

gj = effect common to all progenies of the j^{th} parent

S^{ij} = effect specific to the progeny of mating i^{th} and j^{th} parents

Yt = the average effect of the t^{th} year

(gy)it = genotype x year interaction effect of the i^{th} parent in the t^{th} year

(gy)jt = genotype x year interaction effect of the j^{th} parent in the year.

(sy)ijt = specific effect of mating ith parent and Jth parent in that year

Eijk = experimental error

I = 1-6 parents	t = 1-2 years
J = 1-6 parents	k= 1-3 replications

Source: Matzinger and kempthorne (1956).

Table 3.6. Form of analysis of variance for combining ability across years with EMS

Source of variation	**DF**	**MS**	**EMS**
Year	1		
GCA	5	M_7	$б^{2}_{e} + r\, б^{2}_{ygs} + rs\, б^{2}_{g}$

SCA	15	M_6	$б^2_e + r\, б^2_{ygs} + rg\, б^2_s$
Reciprocal	15	M_5	$б^2_e + r\, б^2_{ygs} + sg\, б^2_r$
GCA x year	5	M_4	$б^2_e + r\, б^2_{ygs} + rs\, б^2_{gy}$
SCA x year	15	M_3	$б^2_e + r\, б^2_{ygs} + rg\, б^2_{sy}$
Reciprocal x year	15	M_2	$б^2_e + r\, б^2_{ygs} + rg\, б^2_{ry}$
Error	140	M_1	$б^2_e$

Key: r = reciprocal; y =year; G= GCA, s = SCA

Source: Matzinger and Kempthrone (1956).

CHAPTER 4

4.0: RESULTS

4.1 Field Evaluation of Hybrids, Reciprocals and Parents.

Result of the evaluation of hybrids, reciprocal and parents for two years (2009 and 2010) is presented in (Table 4.1). A significant difference ($p \leq 0.05$) was observed for days to germination in both years. Highly significant differences ($p \leq 0.01$) for replication within year were observed for number of racemes and plant height.

Highly significant differences ($p \leq 0.01$) for genotypes for all the ten traits (day to germination, day to flowering, stem girth, number of branches, number of raceme, day to maturity, pedicle length, plant height, 100-seed weight and yield/plant) was observed.

Non significant differences were observed in all the traits studied for genotype x year interaction (day to germination, day to flowering, stem girth, number of branches, number of raceme, day to maturity, pedicle length, plant height, 100-seed weight and yield) indicating negligible influence of environment on these traits. All the genotypes performed equally in genotype by year interaction. Non significant G x E interaction for days to 50% flowering and days to maturity were also reported in castor (Joshi *et al.*, 2001).

Table 4.1. Analyses of variance for ten traits of some selected castor genotype evaluated in two years 2009 and 2010 at Samaru.

Source of variation	DF	DG	DFF	SG	NB	NR
Year	1	9.292*	45.375	0.01	16.28	2.1
Rep/year	4	4.384	38.069	0.07	5.336	15.111**
Genotype	35	14.946**	441.5**	1.002**	27.144**	38.909**
Genotype x year	35	1.638	2.718	0.02	4.928	0.287
Error	140	1.879	19.917	0.111	8.102	4.048

Key: *, ** significant at 5% and 1% probability levels, respectively.

DF = degree of freedom; DG = days to germination; DFF = days to 50% flowering; SG=stem girth; NB= number of branches; NR= number of raceme.

Table 4.1.continued

Source of variation	DF	DM	PL cm	PH cm	100SW (g)	Yt/ha
Year	1	121.5	93.352	62.942	1.418	0.013
Rep/year	4	21.704	0.671	619.726**	22.468	0.050
Genotype	35	2342.25**	193.36**	175.917**	1106.79**	1.00**
Genotype x year	35	6.757	3.438	4.677	0.903	0.03
Error	140	31.499	26.759	53.272	97.626	0.03

Key:*,**significant at 5% and 1% probability levels ,respectively.

DF = degree of freedom; DM=days to maturity; PL= pedicle length; PH=plant height; 100SW=100 seed weight; Y=yield.

4.2: Mean Performance of the Hybrids and Parents

The mean performance of the genotypes is presented in Table 4.2. The genotypes ranges from 12.83 days (IARCAS010 X IARCAS006) to 20.53 days (IARCAS010 X IARCAS026) to germinate. For days to flowering, the genotype ranges from 53 days (IARCAS026 X IARCAS001) to 83 days (IARCAS002 X IARCAS026). Hybrids IARCAS026 X IARCAS001,IARCAS026 X IARCAS010 and IARCAS 010 X IARCAS026 matured in less than 100 days with 91.67, 99.83 and 96.67 days respectively, while IARCAS002 x IARCAS010 took 154 days.

IARCAS017 X IARCAS026, IARCAS006 X IARCAS026, IARCAS002 X IARCAS006, IARCAS002 X IARCAS010 and parents IARCAS017, IARCAS010, IARCAS002. IARCAS017 X IARCAS006 has the highest stem girth of 3.22cm while IARCAS017 X IARCAS026 has the lowest stem girth of 1.62cm. IARCAS010 X IARCAS026, IARCAS001 X IARCAS017, IARCAS001 X IARCAS006, IARCAS026 X IARCAS010 and IARCAS026 X IARCAS001 has the highest number of branches/Plant of 9, 10, 9, 9 and 9.00 respectively.

Table 4.2.Mean performance of some castor hybrids and their respective parents for different traits studied across two years (2009 and 2010) at Samaru.

S/No	Hybrids/parents	DG	DFF	DM	SG	NB
	IARCASO26 X IARCAS001	17.00	53.00	91.67	1.78	9.00
	IARCAS026 X IARCAS017	15.00	55.17	108.00	2.78	7.33

	IARCAS026 X IARCAS006	17.00	56.17	102.67	2.45	7.50
	IARCAS026 X IARCAS010	15.81	56.50	99.83	2.75	9.33
	IARCAS026 X IARCAS002	17.27	60.50	126.50	1.92	6.00
	IARCAS001 X IARCAS017	16.78	56.50	103.83	2.23	9.93
	IARCAS001 X IARCAS006	16.12	55.67	109.00	2.58	9.17
	IARCAS001 X IARCAS010	15.87	79.83	153.33	2.82	4.12
	IARCAS001 X IARCAS002	14.23	65.00	148.33	2.30	5.00
0	IARCAS017 X IARCAS006	17.07	81.83	153.33	3.22	6.60
1	IARCAS017 X IARCAS010	15.87	76.00	147.33	2.23	4.00
2	IARCAS017 X IARCAS002	19.06	72.33	142.33	2.25	5.33
3	IARCAS006 X IARCAS010	16.55	56.17	105.67	1.90	7.33
4	IARCAS006 X IARCAS002	17.83	65.33	142.17	2.05	6.00
5	IARCAS010 X IARCAS002	18.17	67.00	140.00	1.97	5.67
6	IARCAS001 X IARCAS026	15.03	69.50	145.33	2.10	6.50
7	IARCAS017 X IARCAS026	16.95	67.00	144.67	1.62	3.83
8	IARCAS006 X IARCAS026	15.87	63.83	136.00	1.80	4.00
9	IARCAS010 X IARCAS026	20.53	55.33	96.67	2.27	11.17
0	IARCAS002 X IARCAS026	18.37	83.00	154.00	3.10	4.43
1	IARCAS017 X IARCAS001	19.03	68.00	146.17	2.17	5.70
2	IARCAS006 X IARCAS001	15.67	81.83	154.00	2.75	3.67
3	IARCAS010 X IARCAS001	16.53	77.67	149.00	2.32	4.17
4	IARCAS002 X IARCAS001	14.98	72.33	145.33	2.30	4.00
5	IARCAS006 X IARCAS017	17.87	59.33	108.00	1.97	8.00
6	IARCAS010 X IARCAS017	16.33	71.67	148.50	2.43	3.83
7	IARCAS002 X IARCAS017	15.27	68.50	143.00	1.72	4.17
8	IARCAS010 X IARCAS006	12.83	72.33	147.00	2.20	4.67
9	IARCAS002 X IARCAS006	17.10	72.33	138.67	1.82	4.33
0	IARCAS002 X IARCAS010	16.86	67.33	146.17	1.65	3.83
	IARCAS026	16.13	54.50	104.50	2.05	5.33

S/NO	Hybrid/parent	NR	PL	PH	100SW	Yt/ha
1						
2	IARCAS001	18.93	67.50	145.50	2.12	4.23
3	IARCAS017	19.43	62.00	133.00	1.90	3.67
4	IARCAS006	17.93	69.83	137.50	1.90	8.67
5	IARCAS010	16.60	70.00	146.17	1.75	3.67
6	IARCAS002	18.43	63.67	132.17	1.67	3.67
	Mean	16.83	66.51	132.65	2.19	5.77
	SE±	0.14	0.63	1.37	0.03	0.22
	CV(%)	8.14	6.67	4.22	15.12	49.08

DG= days to germination; DFF = 50% days to flowering; SG=stem girth; NB= number of branches/Plant

Table 4.2 continued

1	IARCASO26 X IARCAS001	10.83	28.17	35.77	27.03	1.58
2	IARCAS026 X IARCAS017	7.17	24.83	43.00	41.50	2.10
3	IARCAS026 X IARCAS006	8.22	38.83	51.17	23.25	2.05
4	IARCAS026 X IARCAS010	10.67	24.67	47.00	47.72	2.22
5	IARCAS026 X IARCAS002	6.17	31.67	40.83	23.67	1.63
6	IARCAS001 X IARCAS017	10.12	25.00	43.62	25.45	1.68
7	IARCAS001 X IARCAS006	9.83	25.83	41.50	33.27	1.07
8	IARCAS001 X IARCAS010	4.33	18.33	54.17	52.22	1.53
9	IARCAS001 X IARCAS002	5.67	33.33	49.00	45.93	1.73
10	IARCAS017 X IARCAS006	6.18	20.83	49.38	70.12	1.48
11	IARCAS017 X IARCAS010	5.17	25.83	49.50	31.73	1.12
12	IARCAS017 X IARCAS002	5.17	15.67	49.00	26.35	0.80
13	IARCAS006 X IARCAS010	7.17	28.00	36.33	28.80	1.42
14	IARCAS006 X IARCAS002	5.67	24.33	38.83	34.50	1.18
15	IARCAS010 X IARCAS002	6.00	25.33	38.83	33.98	1.17
16	IARCAS001 X IARCAS026	6.33	24.33	47.33	17.17	0.83
17	IARCAS017 X IARCAS026	3.67	33.67	44.17	24.10	1.32
18	IARCAS006 X IARCAS026	4.83	29.17	38.00	18.10	1.33
19	IARCAS010 X IARCAS026	14.67	22.33	44.17	43.72	0.95
20	IARCAS002 X IARCAS026	4.83	14.83	47.83	68.48	0.90
21	IARCAS017 X IARCAS001	6.17	19.00	52.33	33.23	0.83
22	IARCAS006 X IARCAS001	3.33	15.17	50.67	53.50	2.12
23	IARCAS010 X IARCAS001	4.00	21.83	48.83	32.37	1.80
24	IARCAS002 X IARCAS001	4.00	26.83	41.17	50.08	2.13
25	IARCAS006 X IARCAS017	8.33	29.67	38.83	20.18	1.72
26	IARCAS010 X IARCAS017	4.00	32.00	38.00	35.87	1.53
27	IARCAS002 X IARCAS017	4.83	30.67	41.33	23.45	1.73
28	IARCAS010 X IARCAS006	5.17	29.60	36.67	36.07	1.82
29	IARCAS002 X IARCAS006	4.67	32.67	30.83	19.73	1.52
30	IARCAS002 X IARCAS010	4.17	33.00	46.83	24.10	1.12
31	IARCAS026	6.33	26.33	42.50	25.08	1.72
32	IARCAS001	3.83	28.00	43.83	34.50	0.93
33	IARCAS017	3.83	33.50	43.67	14.85	0.95
34	IARCAS006	3.50	24.33	46.33	31.73	1.52
35	IARCAS010	3.67	31.83	44.83	26.22	1.47
36	IARCAS002	4.67	29.83	37.83	15.57	1.22
	Mean	6.03	26.65	43.72	33.16	1.45
	SE±	0.21	0.48	0.59	1.06	0.03
	CV(%)	33.16	19.35	16.58	29.59	11.40

NR=Number of racemes; PL= Pedicle length; PH=plant height; 100SW=100 seed weight; Y=yield.

4.3 GENETIC ANALYSIS

Combining ability variances and variance components

The result of the genetic analyses for the different traits studied is presented in Table 4.3. GCA mean squares were highly significant ($p \leq 0.01$) for all the trait studied (days to germination, days to flowering, stem girth, number of branches/Plant, days to maturity, spike length, stem color, plant height, 100-seed weight and yield).

SCA mean squares were highly significant ($p \leq 0.01$) for most of the traits studied (50% days to germination, 50% days to flowering, number of branches/Plant, day to maturity, pedicle length, plant height, 100-seed weight and yield) with the exception of stem girth.

No Significant difference for GCA and SCA x year interaction for all the traits studied (50% days to germination, 50% days to flowering, number of branches/Plant, day to maturity, pedicle length, plant height, 100-seed weight and yield)

The reciprocal mean squares were highly significant ($p \leq 0.01$) for days to maturity, percentage shattering and number of branches/Plant. The GCA x year, SCA x year and reciprocal x year remain constant.

Table 4.3. Combining ability for different traits of castor genotypes evaluated for two years

(2009 and 2010) at Samaru.

Source of	DF	DG	DFF	DM	SG	NB

variation						
Year	1	9.2919	45.38	121.5	0.0097	16.28
GCA	5	85.6866**	2593.95**	14596.3**	5.3895**	122.037**
SCA	15	4.5964**	127.9**	337.91**	0.3177	9.223**
Reciprocal	15	2.0692	21.97	118.02**	0.1672	12.848**
GCA x Year	5	2.7589	1.31	27.96	0.0408	5.432
SCA x Year	15	2.1217	3.87	19.61	0.0188	5.061
Reciprocal x year	15	0.5652	6.98	15.57	0.0267	5.227
Error	140	1.8787	19.9171	31.5	0.1111	8.1019

DF = degree of freedom; DG= 50% days to germination; DFF= 50% days to flowering; DM=days to maturity; SG=Stem Girth; NB=number of branches.

Key:*,**significant at 5% and 1% probability levels respectively.

Source of variation	DF	NR	PL	PH	100-Seed	Y/ht
Year	1	2.1004	93.352	62.9424	1.4178	0.013
GCA	5	185.065**	821.49**	435.78**	5531.09**	1.456*

						*
SCA	15	17.042**	66.649**	117.623**	492.67**	0.896**
Reciprocal	15	11.689	11.153	146.878	185.84	0.948
CA XYear	5	0.64	5.954	9.862	11.6	0.085
SCA X Year	15	0.419	4.725	2.752	3.83	0.018
Reciprocal x year	15	0.2	2.336	4.116	4.65	0.014
Error	140	4.0481	26.759	53.2723	97.63	0.027

Table 4.3 continued

DF = degree of freedom; DM= 50% days to maturity; PL= peduncle length; PH=plant height; 100SW=100-seed weight;

Y=yield.

Key:*,**significant at 5% and 1% probability levels respectively.

4.4. General combining ability effects

Estimates of general combining ability effects of the parents combined across the two years are presented in Table 4.4. The parent IARCAS026 exhibited higher positive GCA (0.19) for seed yield, number of branches/Plant and number of racemes as well as higher negative GCA for days to maturity(-28.25) and percentage flowering(-10.39).

Two parents IARCAS006 and IARCAS001 exhibited higher significant positive GCA for 100-seed weight 11.41 and 10.86 respectively. The parent IARCAS006 exhibited higher positive percentage flowering (6.08), plant height (3.16), 100-seed weight (11.41), Pedicle length (5.01).

Parents	DFF	DG	PHcm	PLcm	SG	NR	NB	DM	100SW(g)	Yt/ha

Parent IARCAS017 have negative significant GCA for days to flowering, stem girth, 100-seed weights and yield per hectare as well as positive significant GCA days to germination, pedicle lengths, and days to maturity.

Parents IARCAS010 have positive significant GCA for 50 days to germination, days to flowering pedicle lengths days to maturity and yield per hectare as well as negative significant GCA at plant high, number racemes, number of branches and 100-seed weights.

Parent IARCAS002 have negative significant GCA for days to flowering, plant high, number racemes, number of branches, days to maturity and yield per hectare, as well as positive significant GCA for days to germination.

Table 4.4. Estimates of general combining ability effects of the parents for the traits of castor combined across years (2009 and2010) at Samaru.

IARCAS026	-10.39**	-0.49**	-2.06*	-1.19*	0.01	3.14**	2.46**	-28.25**	-2.84**	0.19**
IARCAS001	4.54**	-0.18**	2.79**	-3.13**	0.37**	-0.50*	-0.42	9.27**	10.86**	-0.12**
IARCAS017	-1.98**	0.71**	-0.35	2.08**	-0.19**	-0.33	-0.34	2.71**	-5.42**	-0.14**
IARCAS006	6.08**	-1.15**	3.16**	5.01**	0.29**	-0.05	0.25	7.89**	11.41**	0.11**
IARCAS010	3.02**	1.39**	-2.77**	3.79**	-0.23**	-1.14**	-1.19**	7.48**	-6.60**	0.073**
IARCAS002	-0.76**	0.72**	-0.77	1.14*	-0.25	-1.12**	-0.90	-7.40**	-7.40**	-0.11**
LSD5%	0.32	0.46	0.87	0.68	0.06	-1.46	0.90	0.08	0.94	0.08
LSD1%	0.49	0.72	1.36	1.06	0.09	-2.29	1.48	0.13	1.48	0.13

DF = degree of freedom; DG: Days to Germination; DFF: Days to flowering: DM=days to maturity; PL= Pedicle Length; PH=Plant height; 100SW=100 seed weight; Y=yield.

4.5. Specific combining ability effects

Estimates of specific combining ability effects of the hybrids for the traits studied are given in Table 4.5 Two hybrid had positives significant SCA for days to flowering the highest effect was IARCAS010 x IARCAS006 followed by IARCAS002 x

IARCAS001. One hybrid (IARCAS001 x IARCAS017) has highly positive significant effect for days to germination with one positive significant and 3 negative significant SCA. Similarly five hybrids exhibited highly positive significant SCA for plant height and one positive significant SCA. Stem girth exhibited 2 positive highly significant SCA and two significant SCA (one negative and one positive). Seven hybrids exhibited highly significant SCA three were negative for days to maturity and one hybrid has significant negative SCA. Three hybrids exhibited highly significant SCA for number of racemes with only one negative and one hybrid with significant negative SCA. Two hybrids IARCAS001 x IARCAS002 and IARCAS002 x IARCAS026 have highly significant positive SCA and hybrid IARCAS026 x IARCAS006 has significant positive SCA for number of branches. Five hybrids have highly significant positive SCA for peduncle length. The hybrids IARCAS001 x IARCAS006 and IARCAS017 x IARCAS001 had highly significant positive SCA for 100 seed weight. Eight hybrids exhibited significant positive SCA for yield.

Table 4.5. Estimates of specific combining ability effects of the hybrids for traits of castor combined across years (2009and 2010) at Samaru

S/N.	Hybrids	DFF	DG	PH	SG	DM
1	IARCASO26 X IARCAS001	-5.29	0.14	-2.21	0.12	-5.35**
2	IARCAS026 X IARCAS017	1.97	-0.15	2.43	0.17*	-3.12*
3	IARCAS026 X IARCAS006	-5.23	0.68	0.54	-0.05	-10.77**
4	IARCAS026 X IARCAS010	0.72	-0.18*	0.93	-0.02	5.20**
5	IARCAS026 X IARCAS002	-6.62	-1.15	6.01	0.62	-16.65**
6	IARCAS001 X IARCAS017	-3.95	0.98**	-2.25	-0.02*	0.44
7	IARCAS001 X IARCAS006	5.24	0.03	-1.07	0.31**	3.68
8	IARCAS001 X IARCAS010	-0.29	-1.65*	0.00	0.01	-1.66
9	IARCAS001 X IARCAS002	-4.11	0.19	-4.19	- 0.02	-1.04

10	IARCAS017 X IARCAS006	-2.16	-0.56	3.63*	-0.12	2.06
11	IARCAS017 X IARCAS010	0.14	-0.28	2.14	-0.10	0.81
12	IARCAS017 X IARCAS002	-4.79	0.36	2.42	-0.06	-3.68
13	IARCAS006 X IARCAS010	-0.66	1.46*	-1.37	0.01	-0.19
14	IARCAS006 X IARCAS002	-3.40	-0.72	-2.99	-0.11	-5.60
15	IARCAS010 X IARCAS002	0.63	-1.46*	13.00**	-0.10	14.08**
16	IARCAS001 X IARCAS026	-0.25	-0.36	0.75	0.10	-0.50
17	IARCAS017 X IARCAS026	-0.00	0.35	7.42**	0.28**	-1.50
18	IARCAS006 X IARCAS026	1.69	0.29	1.20	0.17	5.02**
19	IARCAS010 X IARCAS026	0.58	-0.30	1.00	-0.03	9.25**
20	IARCAS002 X IARCAS026	1.00	0.23	0.56	0.09	-0.33
21	IARCAS017 X IARCAS001	-0.17	0.30	5.08**	0.13	3.08
22	IARCAS006 X IARCAS001	-0.58	0.70	0.78	0.06	-0.33
23	IARCAS010 X IARCAS001	2.17	-0.02	5.75**	-0.10	-0.58
24	IARCAS002 X IARCAS001	2.42*	-0.50	2.58	0.07	-1.58
25	IARCAS006 X IARCAS017	0.50	0.46	-2.17	-0.01	-0.68
26	IARCAS010 X IARCAS017	-0.75	-0.55	1.42	-0.05	0.83
27	IARCAS002 X IARCAS017	0.92	-0.63	-2.83	-0.05	1.50
28	IARCAS010 X IARCAS006	2.67*	-0.49	6.08**	-0.06	1.00
29	IARCAS002 X IARCAS006	1.25	-0.37	-2.58	0.20*	3.92
30	IARCAS002 X IARCAS010	-1.33	-0.33	1.00	-0.05	0.00

DFF = 50% days to flowering; DG= 50% days to Germination; PH= Plant height; SG=stem girth; and DM=Days to maturity, Y=yield.

Key:*,**significant at 5% and 1% probability levels ,respectively.

Hybrids	**NR**	**NB**	**PLcm**	**100-sw (g)**	**Y t/ha**
IARCASO26 X IARCAS001	-0.15	0.45	0.62	-3.67	0.06
IARCAS026 X IARCAS017	-1.13*	-0.47	3.50**	1.25	0.23**
IARCAS026 X IARCAS006	3.31**	1.54*	0.99	1.94	-0.17
IARCAS026 X IARCAS010	-0.76	-0.02	-0.95	-1.67	-0.04
IARCAS026 X IARCAS002	1.64	1.85	-2.45	2.8	0.42**
IARCAS001 X IARCAS017	0.47	0.49	3.23**	1.75	0.27**
IARCAS001 X IARCAS006	0.05	-0.08	-0.6	14.00**	-2.24
IARCAS001 X IARCAS010	0.21	-0.24	1.61	-3.49	-0.07
IARCAS001 X IARCAS002	0.78	1.01	-0.76	-3.5	-0.68
IARCAS017 X IARCAS006	0.55	0.47	-2.35	-13.83	-0.58

IARCAS017 X IARCAS010	-0.30	-0.23	-0.35	2.76	0.14
IARCAS017 X IARCAS002	-0.88	-1.4	6.95**	-15.53	-0.06
IARCAS006 X IARCAS010	-0.24	-0.41	0.4	-3.62	0.18
IARCAS006 X IARCAS002	1.48	3.68**	4.2	6.22	-0.07
IARCAS010 X IARCAS002	-0.77	-1.01	2.4	6.62	-0.04
IARCAS001 X IARCAS026	-1.33	-0.92	-0.5	4.11	0.52**
IARCAS017 X IARCAS026	0.53	0.08	5.42**	-2.78	0.32**
IARCAS006 X IARCAS026	-2.26**	-1.15	1.4	-0.17	0.63**
IARCAS010 X IARCAS026	-1.08*	-1	1	1.74	-0.04
IARCAS002 X IARCAS026	1.89**	2.3**	-0.67	0.18	-0.02
IARCAS017 X IARCAS001	0.00	-0.5	4.5**	5.71	0.28**
IARCAS006 X IARCAS001	0.68	1.08	3	0.82	0.29**
IARCAS010 X IARCAS001	0.58	0.08	-3.08	-2.07	-0.21
IARCAS002 X IARCAS001	0.67	0.55	-6.17	-4.08	-0.07
IARCAS006 X IARCAS017	0.02	0.45	2.3	-8.04	0
IARCAS010 X IARCAS017	-0.58	-1.17	1.5	0.33	-0.21
IARCAS002 X IARCAS017	0.50	0.17	-2.17	1.63	0.19
IARCAS010 X IARCAS006	-0.58	-0.25	-3.92	-1.85	-0.01
IARCAS002 X IARCAS006	0.25	-2.3	1.25	9.18**	0.31
IARCAS002 X IARCAS010	0.25	0.08	0.58	-1.08	-0.18

Table 4.5. continued.

NR = Number of racemes, NB=Number of branches; PL= pedicle length;

100-SW= 100-Seed Weight; Y/ht=Yield per tons per hectare.

Key:*,**significant at 5% and 1% probability levels ,respectively.

4.6. HETEROSIS

Heterosis or hybrid vigour is the superior performance of hybrids over the mid-parents or

heigher -parents. Estimates of heterosis of hybrids over mid-parents and higher- parents for the traits of castor studied are presented in Table 4.6. Three hybrids exhibited positive mid-parent heterosis for days to flowering, while twenty seven hybrids had negative mid-parent heterosis for the trait. The heterotic values ranged from -17.82% to 6.89%. One hybrid had positive higher- parent heterosis for days to flowering, while twenty nine had negative higher- parent heterosis . The heterotic values ranged from -32.26% to 0.40%. Fifteen hybrids exhibited positive mid-parent heterosis for stem girth, while fifteen hybrids had negative mid-parent heterosis for the trait. The heterotic values ranged from -15.65% to306.84%. Eight hybrids had positive higher- parent heterosis for stem girth, while twenty one had negative higher- parent heterosis .One hybrid showed no higher-parent heterosis at all. The heterotic values ranged from -31.03% to 25.00%. Twenty one hybrids exhibited positive mid-parent heterosis for pedicle lenght, while eight hybrids had negative mid-parent heterosis for the trait. The heterotic values ranged from -43.62% to47.83%. Seven hybrids had positive higher-parent heterosis for pedicle length, while twenty three had negative higher- parent heterosis. The heterotic values ranged from -54.84% to 33.71%. Fifteen hybrids exhibited positive mid-parent heterosis for number of racemes, while fourteen hybrids had negative mid-parent heterosis for the trait. One hybrid showed no mid-parent heterosis at all. The heterotic values ranged from -35.48% to109.52%. Seven hybrids had positive higher- parent heterosis for number of racimes, while twenty had negative higher- parent heterosis. Three hybrids showed no higher-parent heterosis at all. The heterotic values ranged from -44.44% to 76.36%. Nineteen hybrids exhibited positive mid-parent heterosis for number of branches, while nine hybrids had negative mid-parent heterosis for the trait. Two hybrids showed no mid-parent heterosis at all. The heterotic values ranged from -26.67% to88.89%. Nine hybrids had positive higher-parent heterosis for number of branches, while eighteen hybrids had negative higher-parent heterosis. Three hybrids showed no higher-parent heterosis at all. The heterotic values ranged from -40.74% to 51.97%. Sixteen hybrids exhibited positive mid-parent heterosis for plant height, while fourteen hybrids had negative mid-parent heterosis for the trait. The heterotic values ranged from -16.67% to 39.60%. Ten hybrids had positive higher- parent heterosis for plant height, while twenty hybrids had negative higher- parent heterosis. The heterotic values ranged from -31.25% to 32.60%. Eleven hybrids exhibited positive mid-parent heterosis for days to maturity, while nineteen hybrids had negative mid-parent heterosis for the trait. The heterotic values ranged from -21.72% to 8.88%.Six hybrids had positive higher- parent heterosis for days to maturity, while twenty four hybrids had negative higher- parent heterosis. The heterotic values ranged from -37.61% to 7.31%. Thirteen hybrids exhibited positive mid-parent heterosis for 100seed weight, while seventeen hybrids had negative mid-parent heterosis for the trait. The heterotic values ranged from -40.05% to 50.38%. Four hybrids had positive higher- parent heterosis for 100seed weight, while twenty six hybrids had negative higher- parent heterosis. The heterotic values ranged from -67.90% to 34.80%.Twenty seven hybrids exhibited positive mid-parent heterosis for yield, while three hybrids had negative mid-parent heterosis for the trait. The heterotic values ranged from -35.14% to 165.31%.Twenty three hybrids had positive higher- parent heterosis for yield, while seven hybrids had negative higher- parent heterosis. The heterotic values ranged from -52.00% to 150.00%.

Table 4.6: Percentage heterosis of hybrids over mid-parent and high-parent (MP and HP) for traits of castor for two years (2009-2010) at Samaru.

	DFF		DM		PL		PH	
Hybrids	MP	HP	%MP	%HP	MP	HP	MP	HP
IARCASO26 X IARCAS001	-16.83	-31.17	17.24	-4.49	-11.98	-29.68	-1.32	-18.18
IARCAS026 X IARCAS017	-6.89	-16.75	-1.75	-5.62	-8.31	-23.81	-3.80	-7.63
IARCAS026 X IARCAS006	-16.18	-31.05	0.74	-23.60	-21.72	-37.61	-0.22	-16.25
IARCAS026 X IARCAS010	-5.57	-17.97	-5.26	-10.89	-2.87	-19.29	18.61	6.81
IARCAS026 X IARCAS002	-5.68	-13.54	-8.24	-10.22	-7.40	-21.36	13.60	10.43
IARCAS001 X IARCAS017	-17.82	-31.97	8.28	-11.80	-11.71	-29.46	-4.97	-21.21
IARCAS001 X IARCAS006	-11.86	-19.26	8.70	-8.54	-3.05	-7.74	-17.67	-29.39
IARCAS001 X IARCAS010	1.22	0.40	-12.75	-20.54	-0.32	-0.64	-9.54	-10.91
IARCAS001 X IARCAS002	-6.29	-11.48	29.94	0.99	1.02	-3.87	-8.73	-30.30
IARCAS017 X IARCAS006	-6.42	-16.39	12.75	-9.68	1.97	-5.38	-5.00	-19.39
IARCAS017 X IARCAS010	-6.89	-16.75	39.18	33.71	-10.03	-25.24	37.69	32.20

IARCAS017 X IARCAS002	-10.51	-18.03	47.83	24.39	0.56	-4.30	4.59	-10.30
IARCAS006 X IARCAS010	-9.53	-17.74	-9.38	-29.27	-1.58	-6.62	12.45	-1.88
IARCAS006 X IARCAS002	-1.90	-5.07	1.64	-7.92	2.62	2.62	20.98	5.08
IARCAS010 X IARCAS002	-3.80	-6.40	16.00	9.14	-2.44	5.00	12.45	11.02
IARCAS001 X IARCAS026	-17.65	-32.26	9.63	-16.85	-19.84	-36.11	5.73	-11.25
IARCAS017 X IARCAS026	-0.41	-1.21	25.49	14.29	-0.32	-0.64	-6.28	-7.70
IARCAS006 X IARCAS026	-5.54	-14.11	15.63	-9.76	-1.80	-6.84	4.32	-9.38
IARCAS010 X IARCAS026	-6.67	-12.50	30.61	-4.95	0.23	-4.91	-10.93	-31.25
IARCAS002 X IARCAS026	-1.36	-12.50	3.60	-22.58	-3.00	-10.26	4.73	-10.00
IARCAS017 X IARCAS001	-3.45	-16.13	3.16	-2.97	8.88	-9.52	27.81	15.10
IARCAS006 X IARCAS001	-1.95	-7.38	0.64	-21.78	-0.11	-4.95	18.25	-9.70
IARCAS010 X IARCAS001	-4.29	-7.37	13.66	2.97	3.57	3.57	31.71	14.41
IARCAS002 X IARCAS001	-1.51	-4.84	-8.84	-33.66	1.13	-4.06	20.65	-6.88
IARCAS006 X IARCAS017	3.18	-2.76	0.00	-3.96	6.85	4.05	32.66	17.39
IARCAS010 X IARCAS017	-2.84	-10.94	-16.48	-18.28	-7.69	-21.61	21.38	18.00
IARCAS002 X IARCAS017	-0.46	-11.07	-43.62	-54.84	-0.12	7.31	5.71	-10.30
IARCAS010 X IARCAS006	-3.29	-5.91	2.29	-3.76	-0.24	-2.86	-2.15	-3.39
IARCAS002 X IARCAS006	-1.36	-12.50	17.27	-12.37	0.46	-7.05	-10.55	-23.13
IARCAS002 X IARCAS010	-0.24	-5.09	5.15	0.99	7.09	4.29	30.60	22.61
Average Heterosis %	-9.67		-6.29		-0.98		1.96	

DFF=days to flowering; DM=days to maturity; PL: Pedicle Length; PH=plant height; MP=mid-parent heterosis; HP=high parent heterosis.

Table 4.6 continued

Hybrids	NR		NB		100SWT		Yt/H	
	%MP	%HP	%MP	%HP	%MP	%HP	%MP	%HP
IARCAS026 X IARCAS001	37.21	-7.81	30.98	-3.70	3.45	-21.67	3.53	-12.00
IARCAS026 X IARCAS017	-12.00	-31.25	0.00	-18.52	17.50	-5.93	-1.37	-26.00
IARCAS026 X IARCAS006	109.52	37.50	88.89	25.93	20.53	-9.32	73.68	32.00
IARCAS026 X IARCAS010	8.70	-27.87	20.00	-11.11	40.76	-21.43	33.33	8.00
IARCAS026 X IARCAS002	-15.56	-40.63	-13.51	-40.74	67.47	-31.90	-33.14	-32.00
IARCAS001 X IARCAS017	2.33	-31.25	5.79	-22.22	28.28	-2.85	50.59	28.00
IARCAS001 X IARCAS006	24.14	0.00	21.21	5.88	5.37	-13.56	27.59	5.71
IARCAS001 X IARCAS010	23.81	18.18	22.58	4.72	38.63	37.29	80.33	57.14
IARCAS001 X IARCAS002	-4.00	-14.29	22.18	-23.08	35.67	-6.84	63.64	54.23
IARCAS017 X IARCAS006	-4.17	-11.54	11.89	0.00	31.05	-15.08	-11.86	-25.71
IARCAS017 X IARCAS010	-2.80	-24.06	0.00	-18.52	9.60	-1.19	69.86	24.00
IARCAS017 X IARCAS002	17.24	-5.36	7.74	-5.88	22.29	0.32	80.21	-54.29
IARCAS006 X IARCAS010	28.57	0.00	27.69	-2.35	-1.37	-19.70	165.31	150.0
IARCAS006 X IARCAS002	-12.50	-22.22	-26.67	-35.29	53.38	21.36	70.37	48.39
IARCAS010 X IARCAS002	-35.48	-44.44	-18.52	-35.29	26.25	-7.72	95.74	91.67

IARCAS001 X IARCAS026	52.38	0.00	66.67	11.11	26.23	-5.03	81.58	38.00
IARCAS017 X IARCAS026	84.76	76.36	77.88	51.97	38.94	37.60	47.54	28.57
IARCAS006 X IARCAS026	35.71	5.56	46.15	11.76	-24.43	-38.47	59.18	50.00
IARCAS010 X IARCAS026	25.00	7.14	18.18	0.00	32.94	-9.20	1.75	-6.45
IARCAS002 X IARCAS026	-8.70	-19.23	5.26	0.00	34.10	-13.49	76.00	69.23
IARCAS017 X IARCAS001	-21.74	-43.75	-15.00	-37.04	51.32	30.54	18.52	-4.00
IARCAS006 X IARCAS001	20.00	7.14	-14.40	-15.38	25.89	-13.56	-3.03	-8.57
IARCAS010 X IARCAS001	-31.25	-38.89	-26.67	-35.29	40.88	11.47	48.13	29.03
IARCAS002 X IARCAS001	0.00	-14.29	9.09	-7.69	26.21	-13.80	82.46	67.74
IARCAS006 X IARCAS017	-25.93	-28.57	-13.04	-23.08	143.18	118.44	20.00	6.45
IARCAS010 X IARCAS017	36.44	-4.06	59.38	8.52	68.73	32.88	43.24	6.00
IARCAS002 X IARCAS017	25.00	15.38	49.78	33.86	25.87	-18.44	49.15	25.71
IARCAS010 X IARCAS006	-16.13	-27.78	-18.52	-35.29	37.75	0.69	6.38	4.17
IARCAS002 X IARCAS006	-4.35	-15.38	15.79	10.00	69.17	9.14	80.00	73.08
IARCAS002 X IARCAS010	-11.11	-14.29	-4.35	-15.38	134.85	110.53	96.36	74.19
Average Heterosis %	0.42		3.91		23.17		39.54	

NR=number of raceme; NB=number of branches; 100SW= 100 seed weight; Y=yield; MP=mid-parent heterosis; HP=high parent heterosis.

CHAPTER 5

DISCUSSION

The results from this study indicated wide genetic variability among the genotypes for the different characters studied; this provides good opportunity for selection among the genotypes. The significant differences obtained among the genotypes for the agronomic traits evaluated (days to flowering, days to germination, stem girth, days to maturity, Plant height, pedicle length, number of racemes, number of branches/Plant, 100-seed weight and seed yield) signified that the genetic variability can be utilized in castor breeding program. The wide variability recorded for 100 seed weight, seed yield and maturity among the genotype indicated an opportunity for selection of the traits within the genotype for genetic improvement. The wide ranges observed for plant height and days to maturity provide an opportunity for development of castor short genotypes.

The amount of improvement that can be made by selection among a number of crosses depends on the intensity of selection since the selection is ultimately applied to the crosses (Falconer, 1981). In this study the hybrids differed significantly for all the characters measured therefore, these characters could be easily selected for in a breeding programme. Sparaque and Tatum. (1942) reported that The performance of a hybrid is related to the general combining ability (GCA) and specific combining abilities SCA of the accessions involved in the cross.

The results obtained from the analysis of variance for combining ability indicated that the GCA mean squares were highly significant for the traits studied (days to flowering, days to germination, stem girth, days to maturity, Plant height, pedicle length, number of racemes, number of branches/Plant, 100-seed weight and seed yield) indicated the predominance of additive gene action in the control of the traits . SCA mean squares were significant for all the traits studied (days to flowering, days to germination, days to maturity, Plant height, pedicle length, number of racemes, number of branches/Plant, 100-seed weight and seed yield) with the exception of stem girth, this signifies that both additive and non-additive gene action are involved in the inheritance of the affected traits . this confirms that there is wide genetic variability inherent in the population that can be exploited for genetic improvement of yield and other desirable agronomic traits.

Two parents (IARCAS001 and IARCAS006) exhibited higher significant positive GCA for 100-seed weight (Table 4.4) indicating that they are good combiners for 100-seed weight. IARCAS026, IARCAS006 and IARCAS010 exhibited high significant positive GCA for seed yield this indicated that they are good combiners for yield improvement.

Significant negative GCA effects for plant height for accession IARCAS026 and highly significant negative G.C.A for IARCAS010 were obtained, indicating these lines are good general combines for development of short hybrids .The negatives highly significant GCA estimate obtained for days to maturity for accessions IARCAS026 and IARCAS002 suggests that they are good combiners for early maturity. These findings are in agreement with those of Lavanya *et. al.*, (2006) and Joshi *et, al*., (2001) in castor. Two hybrids have positive SCA for days to flowering, the highest effect was IARCAS010 X IAR006 followed by IARCAS002 X IARCAS001, and this indicated that they are good combiners for breeding late maturity. The highly significant SCA effects obtained for the hybrids IARCAS006 X IARCAS026, IARCAS026 X IARCAS002, IARCAS017 XIARCAS001, IARCAS026 X IARCAS017 and IARCAS006 X IARCAS001, for seed yield indicated that they are the best hybrids for seed yield. Similarly, the highly significant negative SCA effects for days to maturity for hybrids IARCAS026 X IARCAS006, IARCAS026 X IARCAS001, IARCAS026 X IARCAS002, and significant negative SCA for IARCAS026 X IARCAS017 signifies that they are the best combiners for early maturity.

In an experiment like this, heterosis is the main attraction as far as breeders for agricultural important cross pollinating crops are concerned. The major considerations are, first, whether or not it is possible to obtained sufficient heterosis for characters of economic importance under conditions which also give high yield per unit area of land, secondly, whether or not it is possible to fix such heterosis in pure breeding lines (Golakiya *at el* 2004).

In this study significant heterosis was exhibited for all the characters (days to flowering, days to germination, stem girth days to maturity, Plant height, pedicle length, number of racemes, number of branches, 100-seed weight and seed yield) studied. Heterosis is expected since some amount of genetic variability exists between and among the parental lines.

Heterosis for individual crosses is expressed as percentage increase or decrease of hybrid mean of superior parent (%sp) or, the mid-parent (%mp) is presented in (Table 4.6.). Both positive and negative heterosis was obtained for all the characters. The highest mean heterosis was obtained for grain yield (39.54%) followed by 100seed weigh (23.17%) and the lowest (-15.24%) for stem girth followed by (-9.67%) for days to flowering. (Table 4.6). Estimates expressed as %sp were generally, smaller than corresponding estimates expressed as % mp .it is more meaningful to compare the F1 vigor with the superior parent rather than the mid-parent, since this gives an estimate of improvement made.

Heterosis for yield is expressed in twenty five out of thirty F1 hybrids. It is important to note that the highest heterosis for grain yield (165.31% mp, 150% hp) was exhibited by hybrids IARCAS017 X IARCAS006, followed by (95.71% mp, 91.67%hp) this was exhibited by hybrids IARCAS017 X IARCAS002, followed by (96.36%mp, 74.19 %hp) this was exhibited by hybrids IARCAS002 X IARCAS010. Najan *et,al,*. (2010) and Patel *et,al,*. (2010) have also reported significantly high level of standard heterosis for seed yield in castor.

For 100-seed weight, given an indication of seed size almost 100% of the hybrids registered significant standard positive heterosis this is because all the parents were with high general combining ability for 100-seed weight. The highest heterosis for 100-seed weight was (143.18% mp, 118.44% hp) and was exhibited by hybrid IARCAS010 X IARCAS002, followed by (134.85% mp, 110.53% hp) this was exhibited by hybrids IARCAS002 X IARCAS010, followed by (68.73%mp, 32.88%hp) this was exhibited by hybrids IARCAS002 X IARCAS026, followed by (67.47%mp, 31.9% hp) exhibited by hybrids IARCAS026 X IARCAS002. Lavanya and Chandra mohan (2003) have also reported significant positive heterosis for 100 seed weight in castor.

CHAPTER 6

SUMMARY AND CONCLUSION

An investigation was carried out to estimate the combining ability among six accessions of castor (R*icinus cummunis L.*) and to identify superior cross combinations and appropriate procedures to follow in breeding programme for improvement of quality hybrid seeds and also to increase the seed size of the seeds.

Two generations of selfing was done twice in 2009 to reduce the hetrozygosity of the six parent accessions (75% homozygous) in randomized complete block design with three replications at Institute for Agricultural Research farm (I.A.R.) Samaru, Zaria, Kaduna State, Nigeria. The parents were selected based on the variability in seed size.

Griffings (1956a) method 1, model 1 for a full diallel was used to intercross six accessions of castor and thirty single cross hybrids (15 f1 and 15 reciprocals) were generated. Thirty six entries comprising of thirty hybrids and six parents were evaluated in a Complete Randomized Block Design (RCBD) with three replications, in 2009 and 2010 dry season at the Institute for Agricultural Research (IAR) farm, Samaru Zaria, Nigeria. Significant mean squares were observed among the genotypes evaluated. This indicated that considerable amount of genetic variability is presented among the genotypes which can be used to initiate selection for further improvement.

Analyses of combining ability of variance for the traits studied indicated that GCA and SCA variances were significant for most traits. The result shows the importance of additive and non-additive gene action in the control of the traits. This further revealed that the materials can be used for development of hybrid varieties.

Based on the estimates of GCA effects IARCAS026 and IARCAS006 were identified as the best combiners for seed yield. Similarly IARCAS026 and IARCAS002 were the best combiners for early maturity. For percentage flowering, IARCAS026, IARCAS017 and IARCAS002 were the best combiners therefore for the purpose of breeding for short stature, the accession IARCAS026, IARCAS017 and IARCAS002 were the best. However, for the improvement of seed weight, IARCAS006 and IARCAS001 were the best combiners.

The cross IARCAS006 X IARCAS026, IARCAS001 X IARCAS002, IARCAS001 XIARCAS026, IARCAS026 X IARCAS002 and IARCAS017 X IARCAS026 were the best specific combiners for grain yield. However, IARCAS001 X IARCAS006 and IARCAS002 X IARCAS006 were the best specific combiners for 100-seed weight. Similarly IARCAS026 X IARCAS002, IARCAS026 X IARCAS006 and IARCAS026 X IARCAS001 were the best specific combiners for earliness. IARCAS010 X IARCAS002, IARCAS017 X IARCAS025 and IARCAS101 X IARCAS001 were the best specific combiners for plant height.

Wide ranges in means were recorded for most of the characters studied, days to germination ranged from 13-21 days, days to maturity ranged from 92-153 days, number of branches/Plant ranged from 4-9, number of raceme ranged from 4-11, Pedicle length ranged from 15-38cm, plant height ranged from 31-54cm, 100 seed weight ranged from 16-68g and seed yield ranged from 0.8-2.2t/ht.

The highest average heterosis (Table 4.6) was obtained for seed yield (39.54%), 100 seed weight (23.17%), number of branches/Plant (3.91%), number of racemes (0.42%), peduncle length (-0.98%), plant height (1.96%), stem girth(-3.91%), stem color (-15.24%), days to maturity (-6.29%) and days to flowering (-9.67%).

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