GENETICS OF SCMR AND SLA, THE TRAITS RELATED TO DROUGHT TOLERANCE IN GROUNDNUT (*Arachis hypogaea* L.)

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Affectionately dedicated to

my beloved parents

And brother

Dr. S. Ramesh

&

Dr. H.D. Upadhyaya

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CERTIFICATE

This is to certify that the thesis entitled "**Genetics of SCMR and SLA, the traits related to drought tolerance in groundnut (*Arachis hypogaea* L.)**" submitted by **Mr. GOPALA REDDY, K., ID No. PAK 6201** for the degree of **MASTER OF SCIENCE (Agriculture)** in **GENETICS AND PLANT BREEDING** to the University of Agricultural Sciences, Bangalore, is a record of research work done by him during the period of his study in this university under my guidance and supervision. This thesis has not previously formed the basis of the award of any degree, diploma, associateship, fellowship or any other similar titles.

JULY, 2008
Bangalore-560 065

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I. INTRODUCTION

Groundnut (*Arachis hypogaea*. L) is one of the most important oil seed crops of the world. Groundnut, native of South America, is presently cultivated throughout tropical and warm temperature regions of the world. The crop is grown in about 23.4 million hectares world wide with a total production of 34.9 million tonnes and productivity 1490 kg per hectare. India shares 22 percent of the world groundnut production. In India, crop is grown in about 6.70 million hectares with a production of 6.6 million tonnes with a productivity of 985 kg per hectare. In Karnataka, it is grown in an area of about 0.86 million hectares with a productivity of 732 kg per hectare during 2006-07 (FAO. 2007).

It is one of the major source of dietary protein, minerals and vitamins for vegetarians in India. The protein content of groundnut kernels ranges from 22 to 36 per cent with biological value of 65.1.Groundnut kernels contains 36-54 per cent of oil which is composed of 80% unsaturated fatty acids. It can supply about 5.6 and 5.8 calories per gram in the raw and roasted forms, respectively.

Over two third of groundnut area in India is grown under rainfed conditions where frequent dry spells is a major limiting factor (among others) for productivity. Occurrence of drought is highly dynamic over the years (temporal variation) and locations in terms of timing, duration, intensity and stage of the crop. Limited water availability, especially, during flowering and peg penetration stages appears to be one of the important constraints to harness complete genetic potential yield of improved cultivars. Genetic management is sustainable and eco-friendly option to reduce the production losses due to drought. Also farmer acceptance and adoption level of seed-based technology such as drought tolerant cultivars is higher than that of cultural management technologies for mitigating losses due to drought as the former is cheaper and does not requires special skill for adoption.

Conventional breeding for improved productivity with alternate selection for seed yield in a given drought-prone environment and drought free environments is widely practiced for genetic enhancement of drought tolerance in groundnut. Empirical selection for seed yield in a given drought environment is practical and effective for specific adoption (Sheshshayee *et al*., 2006). However, breeding for specific adoption is expensive and resource demanding. While breeding groundnut for improved productivity under a range of drought-prone environments is cheaper, such efforts have met with limited success due to large genotype × environment interaction (Branch and Hilderbrand, 1989; Cooper and Hammer, 1996; Jackson *et al*., 1996; Araus *et al*., 2002). This warrants identification of simple easily measurable surrogate traits for improved productivity under drought-prone environments. Transpiration efficiency (TE) defined as amount of dry matter produced per unit of water transpired is one such trait, which influences crop performance under drought-prone environments (Nageshwara Rao *et al*., 2001). It has been estimated that a 0.1 unit increase in WUE, at a given annual rainfall of 800 mm and about 45 per cent of it available for transpiration would result in a 0.324 tonnes per hectare increase in total biomass (Farquar *et al*., 1989).

Genetic variation in TE has been demonstrated in groundnut (Wright *et al*., 1994). It is difficult to use TE as a selection trait in routine breeding of groundnut for drought tolerance because of difficulties associated with its measurements under field conditions (Nageshwara Rao *et al.,* 2001). Significant negative association of TE with carbon isotope discrimination ($\Delta^{13}C$) in a number of studies (Farquar *et al*., 1982; Wright *et al*., 1994), indicate potential utility of $\Delta^{13}C$ as a surrogate trait of TE while breeding groundnut for drought tolerance. Being highly expensive to measure (although rapid) $\Delta^{13}C$, it cannot be used as a surrogate trait for TE in large scale screening of segregating populations and germplasm accessions. Demonstration of significant positive correlation of specific leaf area

(SLA: defined as ratio of leaf area to leaf dry weight) with $\Delta^{13}C$ (Wright *et al*., 1994; Nageshwara Rao and Wright, 1994) and negative significant relationship between SLA and TE and strong positive correlation of TE with Soil Plant Analytical Development (SPAD) Chlorophyll meter reading (measures leaf nitrogen status), provides sufficient justification for the use of SLA and SCMR as potential surrogate traits for TE (Nageshwara Rao *et al*.,2001).SCMR is a low cost, rapid and non destructive criteria for selecting groundnut genotypes for improved productivity under drought prone environments(Nageshwara Rao *et al*., 2001; Bindu Madhava *et al*., 2003; Sheshshayee *et al*., 2006).

Tailoring groundnut genotypes for SLA and SCMR well matched for water limited conditions needs a good knowledge of their inheritance pattern. However, studies on inheritance pattern of these traits in groundnut are limited. Also, assessment of inter-relationship of surrogate traits with seed yield and its components is essential for formulating selection strategy to combine drought tolerance conferring traits with higher seed yield.

Keeping these points in view, an attempt has been made to study the inheritance pattern of SCMR, SLA, yield and its attributing characters and their interrelations in groundnut with the following objectives.

1. To unravel the inheritance pattern of Specific Leaf Area (SLA) and Soil Plant Analytical Development (SPAD) Chlorophyll Meter Reading (SCMR) in groundnut.

2. To detect and estimate reciprocal differences for SLA and SCMR in groundnut.

3. To assess the carbon isotope discrimination ability of selected parents and their F_1's.

II. REVIEW OF LITERATURE

Groundnut genetic improvement of economically important traits requires availability of genetic variability, adequate knowledge of their inheritance pattern, relative contribution of genetic and non-genetic components in their expression and their inter-relationships.

The literature pertaining to genetic variability, gene action and interrelationship of surrogate traits for WUE (SCMR and SLA), and yield and its attributing characters in groundnut has been reviewed and presented in this chapter.

2.1 Genetic Variability

2.1.1 Water use efficiency

Hubick *et al*. (1986) reported substantial genotypic variation for WUE in groundnut. Wright *et al*. (1988) showed that the genotypic variability for WUE in groundnut ranges from 2.15 to 3.71 gm of dry matter per kg of water used. Genetic variability for WUE is in some of the crop species was first documented by Briggs and Shantz (1913). Hebbar (1990) reported a variation from 1.57 to 2.66g dry matter per kg of water intake.

2.1.2 SPAD Chlorophyll Meter Reading (SCMR)

Upadhyaya (2005) showed large variation and significant genotype × season interactions for SCMR and SLA in groundnut. He also observed higher mean SCMR and SLA values in post rainy season than in rainy season.

2.1.3 Specific Leaf Area (SLA)

The genotypic differences for SLA were consistent across two locations and two drought regimes indicating a low G × E interaction for SLA in groundnut (Nageshwara Rao and wright, 1994).

Shashidhar (2002) reported significant genetic variability for SLA ranging from 113.45 $cm^2 gm^{-1}$ to 231.00 $cm^2 gm^{-1}$ at 60 days after sowing in groundnut.

2.1.4 Carbon isotope discrimination

Nageshwara Rao and Wright (1994) reported significance of variance due to genotype × leaf position and $\Delta^{13}C$ under two drought regimes suggesting that the upper leaves in the canopy should be used for selecting genotypes for WUE based on $\Delta^{13}C$. The observed variation in WUE is mainly attributed to two physiological parameters namely transpiration and photosynthetic capacity among several factors that determine variation in WUE. The carboxylation efficiency regulated by the $\Delta^{13}C$ and Rubisco content are related in groundnut (Nageshwara Rao *et al*., 1995).

2.2 Gene action

2.2.1 SCMR, SLA and $\Delta^{13}C$

Jayalakshmi *et al*. (1999) documented higher narrow sense heritability for $\Delta^{13}C$. They also reported predominance of additive gene action in the expression of Kernel yield and $\Delta^{13}C$.

Nigam *et al*. (2001) reported predominance of additive and non -additive based epistatic gene action in the expression of SLA and harvest index. Babitha *et al*. (2006) reported possible involvement of large number of genes with minor effects and non- additive effects in the inheritance of SCMR.

Chuni lal *et al*. (2006) revealed both additive and non additive gene action with the predominance of additive gene action for the expression of SCMR and $\Delta^{13}C$. Whereas, SLA and HI was controlled by genes that have additive effects on their expression. They also observed maternal effects for SLA and $\Delta^{13}C$ suggesting importance of female parent in the expression of these traits.

Venkateswaralu *et al*. (2007) reported both additive and non additive gene action in the expression of SCMR and SLA, and yield traits viz., shelling per cent, pod yield and kernel yield per plant.

2.2.2 Seed yield and its component traits.

Sandhu and Khehra (1976) showed importance of non-additive gene action for the expression of pod yield per plant. Layrisse *et al.* (1980) reported additive gene action for oil per cent, pod yield and protein content. Sangha and Labana (1982) revealed that both additive and non additive gene action in the inheritance of number of pods and pod yield in groundnut.

Basu *et al.* (1986) also reported additive gene action for the expression of pod yield per plant. Basu *et al*. (1987) documented higher variance due to general combining ability (gca) effects than that due to specific combining ability (sca) effect for number of mature pods per plant, pod yield per plant and shelling percentage, indicating the prominent role of additive gene action in their expression in groundnut. Jagannadha Reddy and Raja Reddy (1987) reported predominance of both additive and non-additive gene actions for the expression of shelling per cent, Kernel yield per plant, number of mature pods per plant and pod yield per plant. Nava and Layrisse (1987) observed predominance of additive gene action for pod yield per plant, Kernel yield per plant and shelling per cent.

Dwivedi *et al.* (1989) in a study of 8×8 full diallel cross reported that seed yield and HI were controlled largely by additive gene effects, whereas number of pods per plant and pod weight per plant are governed by non additive genetic effects in groundnut.

Makne and Bhale (1989) observed importance of additive and non -additive gene action in the inheritance of pod yield per plant in ground nut. Reddi *et al.* (1989) reported predominance of non-additive gene action in the expression of pod yield per plant while predominance of additive gene action on the expression of shelling percentage.

Seshadri (1990) documented the importance of both additive and non additive gene action in the inheritance of number of pods per plant in groundnut. Halward and Wynne (1991) reported significant dominance gene effects for pod length, pod width and pod weight in a few groundnut crosses, while additive × dominance di-genic effects in a few other crosses.

Sateera Banu (1992) observed the predominance of non-additive gene action for kernel yield per plant, number of mature pods per plant, while additive gene action for number of mature pods per plant. Upadhyaya *et al. (*1992) reported the predominance of non–additive gene action for kernel yield per plant.

Vindhiya varman and Paramasivam (1992) recorded predominance of additive gene effects for 100-pod weight, sound mature kernel percentage and pod yield and dominance and dominance based epistatic gene effects for shelling percent in 6 crosses of groundnut.

Vindhiya Varman and Raveendran (1994) showed the predominance of non additive gene action in the inheritance of number of pods and pod yield per plant. Both additive and non-additive gene action were found important in the inheritance of HI and shelling out turn in groundnut.

Nisar Ahmed (1995) reported the importance of non-additive gene action for seed yield and yield component traits viz., number of pods per plant, number of mature pods per plant, and kernel weight. They also reported involvement of both additive and non-additive gene action in the control of HI, and additive gene action in the expression of shelling percentage.

Kalaimani and Thangavelu (1996) revealed predominance of additive gene action in the inheritance of number of mature pods per plant, shelling percent and pod yield per plant in groundnut.

The predominance of additive and additive × additive type of gene action for expression of shelling percentage and 100-seed weight was observed in groundnut crosses by Kuchanur *et al.* (1997).

Francies and Ramalingam (1999) revealed the predominance of non-additive gene action for the expression of number of pegs, number of mature pods, pod yield and kernel yield.

Kumar and Patel (1999) reported the predominance of additive type of gene effects for the expression of pod length and pod width, while 100- kernel weight and shelling out-turn were governed by duplicate type of epistasis in Spanish bunch and Virginia bunch type groundnut crosses. In a cross between two Spanish bunch type groundnut, additive and additive × additive type of gene effects played a major role in the expression of 100-Kernel weight. They also found importance of dominance × dominance type of interaction for the expression of pod width, 100-kernel weight, pod yield and pod length.

Number of primary branches per plant appeared to be governed by additive gene action in groundnut (Vindhiya Varman, 2000). In a six generation mean analysis of 15 bunch type groundnut crosses, Manoharan (2001) reported the importance of dominance gene effects and epistatic gene effects in the expression of shelling per cent.

Parameshwarappa and Girish Kumar (2007) observed major role of non-additive gene action in the inheritance of pod yield, shelling per cent, number of pods and number of mature and immature pods in groundnut. Shelling per cent and 100-kernel weight were found to be governed by both additive as well as non-additive gene effects in different genetic backgrounds.

Hariprasanna *et al*. (2008) reported predominance of additive gene action in the expression of shelling out turn, 100-seed weight, while non additive gene action played an important role in the inheritance of seed size.

2.3 Character association

2.3.1 Drought related traits

Hubick *et al.* (1986) found a wide difference for carbon isotope discrimination ability among different groundnut species having different ploidy level. They also showed that WUE was strongly negatively correlated with $\Delta^{13}C$ (r = -0.81). A strong negative phenotypic correlation between WUE and $\Delta^{13}C$ (r = -0.78) and positive correlation between $\Delta^{13}C$ and kernel yield (r=0.68) was observed in F_2 progeny derived from parents contrasting for $\Delta^{13}C$ and WUE (Hubick *et al*., 1988).

In groundnut, plants grown in field and in mini lysimeter, Wright *et al.* (1988) observed a strong negative correlation between $\Delta^{13}C$ and WUE (r = -0.91) and between $\Delta^{13}C$ and TDM (r = -0.99).

WUE was inversely related to $\Delta^{13}C$ in groundnut (Nageshwara Rao, 1992). Nageshwar Rao *et al.* (1993) reported negative correlation of $\Delta^{13}C$ with WUE (r = -0.66) in groundnut genotypes grown under end of season drought conditions. Wright *et al*. (1994) reported a wide range of $\Delta^{13}C$ in groundnut grown under two drought environments. They further showed a strong negative relationship between $\Delta^{13}C$ and WUE (r = -0.89).

Hebbar *et al.* (1994) showed that more than 92 per cent of the variation in total dry matter (TDM) accumulation was accounted by the variation in the WUE.

WUE showed a positive correlation with TDM. At the same time, higher SLA denotes lesser leaf thickness and hence smaller photosynthetic capacity. SLA was negatively correlated with nitrogen content per unit leaf area i.e. specific leaf Nitrogen (Nageshwara Rao and Wright, 1994).

Roy Stephen (1995) evaluated 21 selected groundnut genotypes in three moisture regimes viz., rainfed, irrigated and moisture stress condition and observed that SLA was lower in moisture stress condition compared to that in irrigated conditions in pot culture experiment. The relationship of SLA with WUE was negative and significant, whereas $\Delta^{13}C$ was positively related to SLA in both field and pot culture experiments. SLA had significant inverse relationship with SCMR and total chlorophyll content (project report, UAS-B, 1996).

Craufurd *et al.* (1999) concluded that WUE was negatively correlated with $\Delta^{13}C$ ($r = -0.78$) and SLA ($r = -0.70$), whereas SLA was positively correlated with $\Delta^{13}C$ ($r = 0.75$). Hence SLA is a good indirect selection criterion for $\Delta^{13}C$ and WUE while identifying genotypes of groundnut for adoption to the semi-arid tropics.

Jayalakhmi *et al*. (1999) reported positive association of SLA with Kernel yield, and harvest index (Arjunan *et al.*, 1997). Negative relationship of $\Delta^{13}C$ with shoot biomass and root dry matter while positive relationship with HI in groundnut was reported by Jayalakhmi *et al.* (2000).A strong negative and significant relationship of SPAD chlorophyll meter reading with SLA in few groundnut genotypes grown under field and glass house conditions was reported by Nageshwara Rao *et al*., (2001).

A significant positive relationship between WUE and SCMR ($r = 0.84$) was observed by Bindu Madhava *et al.* (2003) in groundnut. They Suggesed that a quick determination of SLN through SCMR could reflect intrinsic mesophyll efficiency and hence effectively estimate WUE in groundnut.

Bindu Madhava *et al.* (2003) provided evidence that the relationship between TE and SLA was predominantly due to strong association between SLA and SLN.

Sheshashayee *et al*. (2006) reported the significant positive relationship between SCMR and transpiration efficiency. They also found significant inverse relationship between SCMR and $\Delta^{13}C$. they opined that SLA is an indirect measure of leaf expansion. Higher SLA indicates higher leaf area per unit biomass and hence larger surface area for transpiration.

Latha *et al*., (2007) have reported negative correlation between WUE and $\Delta^{13}C$ (r = -0.87) and between WUE and SLA (r = -0.89). Nigam and Aruna (2008) showed highly significant negative correlation between SCMR and SLA and the relationship was insensitive to crop stage and season in groundnut.

2.3.2 Yield and its component characters

Grain yield in any crop depends on many component characters that influence yield either jointly or singly and either directly or indirectly through other related characters. Direct selection for yield *Per se* is often not effective because of lower heritability. Therefore, indirect selection for yield using traits with high heritability and strongly correlated with yield is often practiced for productivity improvement in crop plants and groundnut is not exception to this. The correlation between characters may exists due to various reasons such as pleotrophy, and genetic linkage. An understanding of the direction and extent of association of the component characters with economic yield is an essential pre-requisite for formulating best selection strategy in groundnut breeding programmes.

Abraham (1990) reported significant positive correlation of kernel yield with pods per plant, kernels per plant. 100-kernel weight and shelling per cent in a study involving 42 bunch type ground nut varieties.

Reddi *et al*. (1991) reported a strong and positive correlation of pod yield with kernel yield, sound mature kernels and 100-kernel weight in 32 diverse groundnut genotypes grown in three environments arising due to three different dates of sowing.

Correlation studies in 18 varieties of groundnut indicated significant and positive correlation of pod yield with pods per plant, shelling per cent, kernel weight and HI (Sharma and Varshney, 1995).

In a study involving 35 groundnut genotypes, a strong positive correlation of pod yield with and 100-kernel weight but weak negative association with shelling per cent was reported (Vasanthi *et al*., 1998).

Pod yield had significant positive correlation with plant height, number of branches per plant, number of mature pods per plant, shelling per cent, 100-kernel weight and kernel yield per plant at genotypic and phenotypic level (Venkataravana *et al*., 2000).

Number of pods per plant, 100-kernel weight, 100 pod weight, shelling per cent and days to 75 per cent flowering was positively and significantly correlated with yield per plant in groundnut (Roy *et al*., 2003).

In a study involving 15 valencia groundnut genotypes showed significant positive association of pod yield and kernel yield with kernels per plant, 100-kernel weight and biomass yield was recorded (Kavani *et al*., 2004).

III. MATERIAL AND METHODS

3.1. Experimental material

3.1.1 Inheritance studies

The basic material for the present study consisted of six groundnut parents viz. ICG 7243, ICG 6766, ICG 12988, ICG 10890, ICG 9418 and Chico.(Plate-2) These are bred and being maintained at International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) Patancheru, Hyderabad. The salient features of these parents (for drought tolerance conferring traits and 100-kernel weight) are given in Table 1.

Three straight crosses viz., ICG7243 × ICG 6766, ICG12988 × ICG10890, Chico × ICG9418 and reciprocal of the later cross i.e., ICG 9418 × Chico, and their backcrosses viz., (ICG 7243 × ICG 6766) × ICG 7243, (ICG 12988 × ICG 10890) × ICG 12988, (ICG 12988 × ICG10890) × ICG10890, (Chico × ICG 9418) × Chico, (Chico × ICG 9418) × ICG 9418, (ICG 9418 × Chico) × ICG 9418 and (ICG 9418 × Chico) × Chico were generated using manual emasculation and pollination at ICRISAT, Patancheru, Hyderabad. These F_1's of four crosses were selfed to obtain F_2 generation.

3.1.2 Carbon isotope discrimination

Three genotypes viz., JUG3, JUG26, ICGS 76 along with Chico (which was used for inheritance studies) were used for assessing carbon isotope discriminating ability. The first three of these four parents had high SCMR, readings and low SLA and then later one i.e., Chico had low SCMR and high SLA.

3.2 Methods

3.2.1 Design of the experiment

The six genotypes viz., ICG 9418, ICG6766, ICG7243, ICG10890, ICG12988, and Chico (designated as parents) with their three straight crosses, ICG7243 × ICG 6766, ICG12988 × ICG10890, Chico × ICG9418 and one reciprocal cross ICG 9418 × Chico and their first (F_1) and second filial (F_2) and back cross generations (B_1, B_2) were grown in Randomized Complete Block Design (RCBD) with two replications during 2007 rainy season and without replication (due to limited seed availability) during 2007-08 post rainy season at experimental fields ICRISAT, Patancheru, Andhra Pradesh, India. The fields have alfisol soil series (Udic- Rhodostolf) and situated at an altitude of 545 m above mean sea level, 17^0N latitude and 78^0E longitude with average rainfall of 700 mm during rainy season. The maximum temperature of 33.24^0C and minimum temperature of 13.7^0C, while 39^0C maximum temperature and 17^0C minimum temperature prevailed during rainy and post rainy seasons, respectively during crop growth period (http://intranet.icrisat.org).

Seeds of parents and F_1 generations were dibbled in single four meter row with spacing of 0.6m between rows. After 20 days of dibbling, the seedlings were thinned to maintain 0.1m between plants within a row. The seeds of segregating F_2 populations were dibbled in 6 rows of four meter length while those of back cross generations were dibbled in 2 rows of 4m length in a ridge-furrow system. While protective irrigation was given for rainy season crop, sufficient irrigation was provided to post rainy season crop. All the recommended crop production and protection practices were followed to raise a good and healthy crop (plate-1-2).

Table 1: Passport data and salient characters of groundnut genotypes used for the study

GENOTYPES	ORIGIN	FEATURES						
		SCMR		Specific Leaf Area		Branching Pattern	100-Kernel weight (g)	
		Rainy	PR	Rainy	PR		Rainy	PR
Chico	USA	Low	Low	High	High	Sequential	21	26
ICG6766	USA	High	High	Low	Low	Alternate	77	84
ICG7243	USA	High	High	Low	Low	Alternate	65	76
ICG9418	Martinique	Low	Low	Low	Low	Sequential	50	55
ICG10890	Peru	Medium	Medium	Medium	Medium	Sequential	39	59
ICG12988	India	Medium	medium	Medium	Medium	Sequential	26	40

SCMR= Soil Plant Analytical Development Chlorophyll Meter Reading

PR= Post Rainy

3.3 Recording of observations

Ten competitive plants in each parent and 20 plants in each F_1 and 70 plants in each back cross generation and 200 plants in each F_2 population were tagged randomly to record data on the following traits.

3.3.1. Pod yield per plant (g)

The weight of total number of pods per plant after optimum pod maturity was recorded and expressed in grams.

3.3.2. Kernel yield per plant (g)

The weight of the total kernels shelled from manual crushing of mature pods per plant was recorded and expressed in grams.

3.3.3. Seed length and seed width (mm)

Ten mature seeds were selected randomly from each plant in each generation and seed length and width were recorded in millimeter.

3.3.4. 100-Kernel Weight (g)

A random sample of 100 well-filled seeds (avoiding shriveled and broken ones) was drawn and its weight was recorded in grams.

3.3.5. Shelling percentage (%)

Pod weight was recorded from each plant in grams. Then, the weight of kernels after shelling the pods of same plant was recorded in grams. The shelling percentage was calculated as

$$\text{Shelling percentage } = \frac{\text{Kernel weight } (g)}{\text{Pod weight } (g)} \times 100$$

3.3.6. Specific leaf area (cm^2/g)

The fully expanded, healthy second leaf (in case of damage, the third leaf) from the apex of the main axis in each plant was collected in the plastic bags at 60 and 80 days after sowing (DAS) in morning hours and soon brought to the laboratory. The leaf area of the four leaflets was measured using a leaf area meter (LI-CDR, Area meter model 3000, LI, CDR INC., Lincon, NE) after which the leaves were oven dried at 80^0C for at least 48 hours to determine the leaf dry weight. SLA was computed using the following formula:

$$\text{SLA} = \frac{\text{Leaf area } \left(\text{cm}^2\right)}{\text{Dry leaf weight } \left(\text{g}\right)}$$

3.3.7. SPAD chlorophyll meter reading

Amongst several leaf characters, leaf thickness and chlorophyll content determines the leaf transmittance. Leaf nitrogen content normally influences the leaf chlorophyll content. A device has been developed by Minolta company, New Jersey USA (SPAD-502) which measures the light attenuation at 430 nm (The peak wave length absorption by chlorophyll a and chlorophyll b) and at 750 nm (near infrared) with no transmittance. The unitless value measured by the chlorophyll meter is termed as SCMR (SPAD chlorophyll meter reading) which indicate relative amount of leaf chlorophyll. The SPAD meter is a simple hand-held instrument, which operates with DC power of three volts.

The fully expanded second or third leaf from the apex of the main axis was used to record SCMR. Selected leaf was clamped avoiding the mid rib region and inserted into the sensor head of SPAD meter. A gentle stroke was given to record the SPAD reading and the average of such eight strokes per leaflet was considered. Since groundnut has tetra foliate leaf, SCMR was recorded in all the four leaflets and average value was computed. The SPAD chlorophyll meter readings were taken at 60 and 80 days after sowing in the crop raised during 2007 rainy season and 2007-08 post rainy season on equivalent cumulative thermal time (CTT), measured in degree-days ^{o}Cd, 10^{0}C as base temperature. The SCMR readings were taken on CTT at 1000^{0}C and 1270^{0}C in the crop raised during post rainy season, CTT would be reach 1000^{o}C and 1270^{o}Cd naturally at 60 and 80 days after sowing during rainy season. The CTT was estimated by the following formula:

$$\text{CTT}\left({}^{0}\text{Cd}\right) = \sum_{P}^{H} \frac{\left(T_{max} + T_{min}\right)}{2} - T_{base}$$

Where,

T_{max} = Daily maximum temperature

T_{min} = Daily minimum temperature

T_{base} = Mean base temperature for groundnut

P = Planting date

H = Harvest date

3.3.8 Quantification of Δ^{13}C in leaf samples

3.3.8.1 Processing of samples

Second to third fully expanded leaves were collected from each genotype and dried at 80^{0}C for three days. The dried leaves were powdered in a mortar and pestle. Care was taken to prevent any contamination by washing the pestle and mortar with alcohol after grinding each sample. Powdered leaf sample was put in eppendorf tube and properly labeled. The Δ^{13}C analysis was carried out at the National facility for quantification of stable isotopes in the Department of Crop Physiology, University of Agricultural Sciences (UAS), and Bangalore.

3.3.8.2 Mass Spectrometric Analysis

Carbon isotope ratios ($^{13}C/^{12}C$) in comparison with the Pee and Dee Belemnite standard were measured using continuous flow isotopic mass spectrometer (IRMS). The IRMS facility consists of flash elemental analyzer (CE-EA 1112), for sequential combustion of biomass samples and open slit interference (coulo 3). The processed and labeled leaf samples were accurately weighed in the range of 1.0 to 1.2 mg and put into silver capsules. The crimped capsules with the sample were placed sequentially in the carousel of the auto sampler. The sampler was dropped at specific interval of time along with a pulse of pure O_2 in to the oxidation reactor.

The combustion (oxidation) reactor contains chromic oxide and silvered cobaltous-cobaltic-oxide heated to 105^0C. The biomass is completely oxidized to produce CO_2, N_2O and H_2O. These gases were swept into the reduction furnace using helium carrier gas. The reduction column contains reduced copper in quartz tubes heated to 68^0C. In this reaction, the N_2O is reduced to N_2 and the excess O_2 is absorbed. The resultant gases are then flushed through scrubber to trap CO_2 and water. The pure CO_2 and N_2 gas after passing through a GC column (50 A molecular sieve) and a thermal conductivity detector (TCD) into the ion source of IRMS. At the source, CO_2 is ionized by electron impacts ionization to produce molecular radicals (CO^+). When accelerated radicals pass through a strong magnetic field it is deflected with the radius of deflection being proportional to the molecular mass of the radicals. These deflecting $^{12}CO_2$ and $^{13}CO_2$ are collected by the Faraday cups and the signal is amplified and transmitted to the computer and displayed.

Based on Fractionation (isotopic composition with respect to PDB), the ^{13}C discrimination ($\Delta^{13}C$) in the plant sample was computed as follows

$$\Delta^{13}C\ (\%) = \frac{\delta a\ 13C - \delta p\ ^{13}C}{1 + \delta p\ ^{13}C\ /\ 1000}$$

And expressed as parts per thousand (%) or per million.

3.4 Statistical analysis

Mean values of the data recorded on sample plants in each generation was used for statistical analysis.

3.4.1 Generation mean analysis

3.4.1.1 Joint scaling test

The parameters such as m, the mean of all possible genotypes arising out of selfing of a cross, [d] additive gene effect and [h] dominance deviation effects were estimated from the observed means of six generations (P_1, P_2, F_1, F_2, B_1, and B_2) using Cavalli (1952) joint scaling test as described by Mather and Jinks(1982). The estimates of these parameters are then used to calculate expected means which are then compared with observed means assuming the adequacy of additive-dominance model. Since six generation means were used to estimate three parameters a weighted least square analysis is employed because it enables precise estimation of m [d] [h] by reducing the error mean square associated with the segregating generations that contain a greater number of individuals than the non segregating generations. In this approach reciprocal of variance of the means of each generation is used as weight. Because the means of various generations may not be known with equal precision, the weights were used to estimate m [d] and [h] components.

Three normal equations are required to estimate m [d] and [h]. First normal equation is obtained by multiplying each element of first row in the Table 2 by the product of weight and co-efficient of m and adding over six generations.

Table 2 : Co-efficients of gene effects in six generation means analysis

GENERATIONS	GENE-EFFECTS		
	m	d	h
P_1	1	1	-
P_2	1	-1	-
F_1	1	-	1
F_2	1	-	0.5
BC_1	1	0.5	0.5
BC_2	1	-0.5	0.5

In a similar manner, second normal equation was obtained by multiplying each element of first row by the product of weight and coefficient of [d] and the third normal equation was obtained by multiplying each element of each row by the product of co-efficient [h] and its weight. The three normal equations obtained were as follows

$$a_{11}\, m + a_{12}\, d + a_{13}\, h = A_1$$

$$a_{21}\, m + a_{22}\, d + a_{23}\, h = A_2$$

$$a_{31}\, m + a_{32}\, d + a_{33}\, h = A_3$$

Where, $A_1 = i = 1$(weight $\times$ co-efficient of m $\times$ observed mean)

A2 = i = 1(weight $\times$ co-efficient of d $\times$ observed mean)

A3 = i = 1(weight $\times$ co-efficient of h $\times$ observed mean)

The three normal equations so derived were arranged in the following matrix form

$$\underbrace{\begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix}}_{[J]} \underbrace{\begin{bmatrix} m \\ d \\ h \end{bmatrix}}_{[M]} = \underbrace{\begin{bmatrix} A_1 \\ A_2 \\ A_3 \end{bmatrix}}_{[S]}$$

The elements of the three normal equations were obtained from the co-efficient matrix and termed as “Information matrix (J). The parameters to be estimated viz., m, [d] and [h] were arranged in a column matrix. The elements of normal equations obtained as a result of multiplication of observed values by co-efficient and weights were arranged in column matrix (S) called as “Score matrix”.

Estimates of m [d] and [h] were obtained as $M = SJ^{-1}$ where J^{-1}, is the inverse of information matrix, which is a variance-covariance matrix in which principal diagonal elements represent variances of the estimates of the parameters m [d] and [h].

Estimated values of m, [d] and [h] were then used to calculate expected means of six generations by using following formula:

$P_1 = m + [d]$

$P_2 = m - [d]$

$F_1 = m + [h]$

$F_2 = m + \frac{1}{2} [h]$

$B_1 = m + \frac{1}{2} [d] + \frac{1}{2} [h]$

$B_2 = m - \frac{1}{2} [d] + \frac{1}{2} [h]$

The deviations of observed means of six generations from those of expected means was tested using Chi-square test as follows:

$$\text{Chi}-\text{square} = \frac{(\text{observed generation mean} - \text{expected generation mean})^2}{\text{expected generation mean}} \times \text{weight}$$

The chi-square value was compared with table χ^2 at (6-3) degrees of freedom. The non-significance of chi-square values indicated the adequacy of additive-dominance model. Significance of chi-square test was indicative of non-adequacy of additive-dominance model. For such traits for which additive-dominance model was inadequate to explain their inheritance, the di-genic interaction effects, viz., additive × additive [i], additive × dominance [j] and dominance × dominance [l] were estimated employing six parameter model using perfect fit solution (Jinks and Jones, 1958)

3.4.1.2 Estimation of gene effects

The six parameter model (Jinks and Jones,1958) was used to estimate gene effects for the traits for which additive-dominance model was inadequate as indicated by joint scaling test.

$$m = \frac{1}{2}\overline{P_1} + \frac{1}{2}\overline{P_2} + 4\,\overline{F_2} - 2\,\overline{B_1} - 2\,\overline{B_2}$$

$$[d] = \frac{1}{2}\overline{P_1} - \frac{1}{2}\overline{P_2}$$

$$[h] = 6\,\overline{B_1} + 6\,\overline{B_2} - 8\,\overline{F_2} - \overline{F_1} - \frac{3}{2}\overline{P_1} - \frac{3}{2}\overline{P_2}$$

$$[\,i\,] = 2\,\overline{B_1} + 2\,\overline{B_2} - 4\,\overline{F_2}$$

$$[\,j\,] = 2\,\overline{B_1} - \overline{P_1} - 2\,\overline{B_2} + \overline{P_2}$$

$$[\,l\,] = \overline{P_1} + \overline{P_2} + 2\,\overline{F_1} + 4\overline{F_2} - 4\,\overline{B_1} - 4\,\overline{B_2}$$

Variances of gene effects were estimated as:

$$V_m = \frac{1}{4}V_{\overline{P_1}} + \frac{1}{4}V_{\overline{P_2}} + 16\,V_{\overline{F_2}} + 4\,V_{\overline{B_1}} + 4\,V_{\overline{B_2}}$$

$$V_{[d]} = \frac{1}{4}V_{\overline{P_1}} + \frac{1}{4}V_{\overline{P_2}}$$

$$V_{[h]} = 36\ V_{\overline{B_1}} + 36\ V_{\overline{B_2}} + 64\ V_{\overline{F_2}} + V_{\overline{F_1}} + \frac{9}{4}\ V_{\overline{P_1}} + \frac{9}{4}\ V_{\overline{P_2}}$$

$$V_{[i]} = 4\ V_{\overline{B_1}} + 4\ V_{\overline{B_2}} + 16\ V_{\overline{F_2}}$$

$$V_{[j]} = 4\ V_{\overline{B_1}} + V_{\overline{P_1}} + 4\ V_{\overline{B_2}} + V_{\overline{P_1}}$$

$$V_{[l]} = V_{\overline{P_1}} + V_{\overline{P_2}} + 4V_{\overline{F_1}} + 16V_{\overline{F_2}} + 16V_{\overline{B_1}} + 16V_{\overline{B_2}}$$

Standard errors of various gene effects were estimated as:

$$SE_m = \sqrt{V_m}$$

$$SE_{[d]} = \sqrt{V_{[d]}}$$

$$SE_{[h]} = \sqrt{V_{[h]}}$$

$$SE_{[i]} = \sqrt{V_{[i]}}$$

$$SE_{[j]} = \sqrt{V_{[j]}}$$

$$SE_{[l]} = \sqrt{V_{[l]}}$$

Significance of various gene effects were tested using‘t’ test as:

$$t_m = \frac{m}{SE_m}$$

$$t_{[d]} = \frac{[d]}{SE_{[d]}}$$

$$t_{[h]} = \frac{[h]}{SE_{[h]}}$$

$$t_{[i]} = \frac{[i]}{SE_{[i]}}$$

$$t_{[j]} = \frac{[j]}{SE_{[j]}}$$

$$t_{[l]} = \frac{[l]}{SE_{[l]}}$$

3.4.2 Detection of reciprocal differences

The reciprocal differences between Chico × ICG9418 and ICG 9418 × Chico cross were detected using two sample't' test as follows:

$$t = \frac{\left(\bar{X}_1 - \bar{X}_2\right) - \left(\mu_1 - \mu_2\right)}{\left[(SP^2\ \left(1/n_1 + 1/n_2\right)\right]^{\frac{1}{2}}}$$

Where,

$x_1 = F_1$ mean of straight cross

$x_2 = F_1$ mean of reciprocal cross

μ_1 = population mean of straight cross

μ_2 = population mean of reciprocal cross

SP^2 = Pooled variance of the direct and reciprocal cross F_1's

n_1 = Number of observations of direct cross F_1

n_2 = Number of observations of reciprocal cross F_1

3.4.3. Estimation of correlation coefficients

Correlation coefficients were computed to find the association amongst various characters using the formula given by Al-Jibouri *et al.* (1958)

$$r_p(xy) = \frac{Cov_p(xy)}{\sqrt{\sigma_p^2(x) \,.\, \sigma_p^2(y)}}$$

Where,

r_p (xy) is the phenotypic correlation coefficients between ‘x’ and ‘y’ characters

$Cov_p(xy)$ is the phenotypic covariance of ‘x’ and ‘y’ characters

$\sigma^2{}_p(x)$ is the phenotypic variance of ‘x’ character

$\sigma^2{}_p(y)$ is the phenotypic variance of ‘y’ character

The calculated value of ‘r’ was compared with table ‘r’ value at n-2 degree of freedom at 0.05 and 0.01 level of significance, where n refers to number of pairs of observations

In F_2 population of each cross skewness, the third degree statistic and kurtosis, the fourth degree statistic were estimated to understand the nature of distribution of different traits. Genetic expectation of skewness (-3/4 d^2 h) reveal the nature of genetic control of the traits (Fisher *et al.*1932). The parameter’s’ and ‘h’ represent additive and dominance gene effects, respectively. Kurtosis indicates relative number of genes controlling the traits (Robson, 1956).

IV. EXPERIMENTAL RESULTS

Results of present experiments is presented in the following heads

1. Mean performance
2. Inheritance studies
3. Maternal effects
4. Carbon isotope discrimination ratio
5. Character association

4.1 Mean performance

In general the mean values of all the six generations (P_1, P_2, F_1, F_2, B_1 and B_2) in all the four crosses for all the traits was higher in post rainy season compared to those in rainy season. The range of mean values of most of the generations in all the crosses and for all the traits in rainy season were slightly higher or comparable to those in post rainy season. Similar trend was noticed with respect to variance as well. F_1 means of most of the crosses and most of the traits were intermediate between their parents during both rainy and post rainy seasons (Table 3 to 12).

4.2 Inheritance studies

4.2.1 Joint scaling test

Both additive and dominance gene effects were highly significant for all traits in all the crosses during both rainy and post rainy seasons except in ICG 12988 × ICG 10890 for SLA at 80 DAS and seed length during post rainy season, in Chico × ICG 9418 and ICG 9418 × Chico for seed length during rainy season and in ICG 12988 × ICG 10890 for pod length during rainy season where only additive gene effects were non significant (Table -13). Similarly, dominant gene effects were non-significant for some of the traits and crosses such as SCMR at 80

Table 3: Estimates of mean, range and variance of parental, first and second filial and backcross generations of 4 groundnut crosses for SCMR at 60 days after sowing

Descriptive statistics	Mean ± S.E		Range		Variance	
	Rainy	Post rainy	Rainy	Post rainy	Rainy	Post rainy
Generation	ICG 7243 × ICG 6766					
P_1	45.38 ± 0.37	47.31 ± 0.37	43.00 – 48.00	44.50 – 50.00	2.08	2.09
P_2	49.37 ± 0.50	49.15 ± 0.49	45.00 – 51.00	46.00 – 52.00	3.05	2.87
F_1	45.11 ± 0.49	46.56 ± 0.37	42.00 – 48.00	44.00 – 49.00	2.90	2.22
F_2	44.08 ± 0.28	45.03± 0.40	31.14 – 55.10	24.10 – 58.10	17.8	23.8
B_1	42.48 ± 0.47	45.50 ± 0.72	33.64 – 49.83	40.75 – 50.79	8.33	8.87
B_2	43.71 ± 0.82	45.86 ± 1.13	36.44 – 50.23	39.41 – 51.51	14.9	20.5
ICG 12988 × ICG 10890						
P_1	37.77 ± 0.49	43.06 ± 0.43	35.00 – 41.00	40.00– 44.93	3.14	1.84
P_2	40.20 ± 0.47	43.84 ± 0.47	36.00 – 42.79	41.00 – 46.00	3.13	2.25
F_1	37.94 ± 0.41	46.00 ± 0.27	35.00 – 43.00	41.00 – 48.25	3.40	2.38
F_2	39.32 ± 0.35	41.97 ± 0.28	22.35 – 55.90	24.80 – 60.50	29.8	28.8
B_1	40.95 ± 0.69	38.38 ± 0.88	34.65 – 49.01	32.78 – 43.98	16.0	10.9
B_2	39.56 ± 0.74	41.40 ± 0.98	33.05 – 44.74	34.20 – 45.20	10.6	13.5
Chico × ICG 9418						
P_1	37.28 ± 0.42	40.13 ± 0.53	34.50 – 40.50	38.00 – 43.80	2.69	2.90
P_2	35.34 ± 0.64	39.13 ± 0.45	32.00 – 38.43	37.00 – 42.00	4.14	2.03
F_1	37.75± 0.33	41.24 ± 0.31	34.40 – 39.53	35.46 – 43.81	2.26	2.62
F_2	36.48 ± 0.30	41.88 ± 0.20	15.86 – 49.70	26.18 – 53.05	20.6	14.7
B_1	38.54 ± 0.74	41.92 ± 0.82	30.44 – 44.95	34.96 – 47.48	14.2	12.1
B_2	34.59 ± 0.60	39.57 ± 0.92	27.04 – 38.73	24.65 – 47.26	7.96	20.31
ICG 9418 × Chico						
P_1	36.51 ± 0.37	39.40 ± 0.54	34.06 – 40.95	37.10 – 42.20	3.30	3.01
P_2	37.74 ± 0.48	40.05 ± 0.45	35.57 – 41.02	36.36 – 41.12	2.58	2.103
F_1	36.20 ± 0.30	39.06 ± 0.25	37.00 – 43.00	36.78 – 42.65	3.00	2.143
F_2	36.93 ± 0.23	42.27 ± 0.18	22.28 – 50.00	27.50 – 55.99	17.95	16.77
B_1	36.38 ± 0.57	39.13 ± 0.94	27.48 – 55.34	34.43 – 45.58	15.99	12.56
B_2	38.0 ± 0.765	40.00 ± 0.90	33.79 – 46.93	32.94 – 45.99	6.93	14.78

Table 4: Estimates of mean, range and variance of parental, first and second filial and backcross generations of 4 groundnut crosses for SCMR at 80 days after sowing

Descriptive statistics	Mean ± S.E		Range		Variance	
	Rainy	Post rainy	Rainy	Post rainy	Rainy	Post rainy
Generation	ICG 7243 × ICG 6766					
P_1	44.55 ± 0.43	46.19 ± 0.38	42.23 – 47.23	44.10 – 48.97	2.284	1.121
P_2	48.01 ± 0.42	47.78 ± 0.38	45.03 – 49.28	45.58 – 49.45	1.462	1.954
F_1	46.14 ± 0.43	46.09 ± 0.39	43.04 – 48.03	43.32 – 49.25	2.146	2.373
F_2	43.65 ± 0.45	48.27 ± 0.38	26.55 – 58.50	26.15 – 62.50	23.22	23.56
B_1	43.63 ± 0.89	48.77 ± 0.95	34.84 – 51.79	42.11 – 55.75	20.35	15.48
B_2	42.00 ± 1.03	48.58 ± 0.95	36.95 – 48.13	42.06 – 54.55	12.53	14.73
ICG 12988 × ICG 10890						
P_1	37.47 ± 0.43	43.26 ± 0.36	35.84 – 40.22	40.12 – 45.73	2.061	1.814
P_2	38.70 ± 0.42	44.09 ± 0.38	36.24 – 40.54	40.95 – 47.08	2.120	1.942
F_1	36.76 ± 0.43	43.85 ± 0.29	34.24 – 39.75	41.05 – 46.23	2.452	1.985
F_2	38.59 ± 0.45	43.50 ± 0.23	19.18 – 51.30	22.51 – 56.12	28.24	16.41
B_1	36.62 ± 0.89	43.51 ± 0.93	30.05 – 45.55	37.64 – 49.76	20.91	14.86
B_2	41.00 ± 1.03	45.01 ± 0.89	32.50 – 49.05	37.19 – 48.86	19.13	12.70
Chico × ICG 9418						
P_1	37.14 ± 0.45	40.50 ± 0.37	34.33 – 39.23	37.99 – 42.99	2.303	2.062
P_2	34.87 ± 0.35	39.47 ± 0.38	32.80 – 38.25	37.21 – 41.61	1.933	2.181
F_1	36.21 ± 0.46	41.85 ± 0.20	33.85 – 39.40	40.49 – 43.79	2.380	1.015
F_2	33.14 ± 0.39	40.79 ± 0.23	17.69 – 52.20	15.26 – 53.79	26.97	18.37
B_1	35.79 ± 0.85	43.02 ± 0.84	29.99 – 46.25	32.50 – 48.44	13.73	13.63
B_2	29.27 ± 0.71	41.87 ± 0.74	22.33 – 35.43	35.91 – 49.40	11.76	12.31
ICG 9418 × Chico						
P_1	34.95 ± 0.65	39.58 ± 0.56	33.50 – 36.50	37.50 – 41.20	2.33	1.89
P_2	37.31 ± 0.41	40.41 ± 0.33	36.24 – 39.26	38.13 – 42.92	1.548	1.653
F_1	34.82 ± 0.57	40.18 ± 0.30	35.36 – 41.90	35.61 – 42.33	3.356	2.566
F_2	32.33 ± 0.34	40.29± 0.19	13.99 – 48.51	24.05 – 56.16	26.79	18.53
B_1	29.34 ± 0.79	40.81 ± 0.89	23.13 – 38.75	37.10 – 48.95	14.56	9.393
B_2	35.44 ± 1.05	43.80 ± 0.95	28.65 – 42.66	39.05 – 50.12	16.811	12.72

Table 5: Estimates of mean, range and variance of parental, first and second filial and backcross generations of 4 groundnut crosses for SLA at 60 days after sowing

Descriptive statistics	Mean ± S.E		Range		Variance	
	Rainy	Post rainy	Rainy	Post rainy	Rainy	Post rainy
Generation	ICG 7243 × ICG 6766					
P_1	113.2 ± 1.00	123.2 ± 1.14	109.5 – 121.5	118.5 – 130.8	15.16	13.13
P_2	109.1 ± 0.99	103.8 ± 0.58	102.5 – 116.5	101.1 – 106.2	13.73	3.368
F_1	112.4 ± 1.10	121.2 ± 0.43	105.3 – 120.5	119.2 – 124.2	15.81	2.627
F_2	120.8 ± 1.31	133.9 ± 1.42	86.07 – 253.0	71.0 – 250.0	382.40	281.0
B_1	115.6 ± 1.70	133.0 ± 1.45	102.0 – 134.1	124.7 – 145.1	95.44	35.76
B_2	120.0 ± 2.33	132.9 ± 1.28	115.9 – 149.0	120.1 – 141.2	119.70	24.64
ICG 12988 × ICG 10890						
P_1	133.7 ± 0.97	149.3 ± 1.41	129.4 – 142.6	146.1 – 60.30	12.45	19.94
P_2	132.5 ± 1.00	166.6 ± 1.54	125.6 – 140.2	158.3 – 175.3	13.01	21.51
F_1	131.1 ± 0.98	144.2 ± 0.67	123.5 – 137.3	135.6 – 149.9	14.68	11.84
F_2	139.4 ± 1.79	156.0 ± 1.52	88.80– 262.4	76.88 – 300.5	543.30	533.1
B_1	144.4 ± 1.91	155.0 ± 3.33	125.9 – 169.1	129.5 – 168.2	117.10	177.6
B_2	130.6 ± 1.62	150.0 ± 4.01	117.0 – 145.0	123.3 – 186.6	58.02	241.4
Chico × ICG 9418						
P_1	166.7 ± 1.14	186.6 ± 1.24	158.5 – 175.2	180.2 – 190.5	15.70	15.53
P_2	135.1 ± 0.91	160.2 ± 1.16	130.5 – 145.2	155.2 – 166.2	12.66	13.48
F_1	143.8 ± 0.81	169.9 ± 1.01	150.5 – 160.9	169.9 – 185.5	17.28	21.66
F_2	140.8 ± 1.46	172.2 ± 1.23	94.49 – 234.6	72.00 – 250.0	437.2	496.0
B_1	146.2 ± 1.69	163.4 ± 4.17	133.0 – 165.0	142.7 – 187.5	74.59	192.1
B_2	140.5 ± 1.62	141.8± 3.80	124.4 – 155.0	109.4 – 171.1	61.03	205.5
ICG 9418 × Chico						
P_1	134.2 ± 1.03	175.5 ± 1.40	127.5 – 141.5	169.3 – 180.3	15.08	19.81
P_2	171.9 ± 1.11	186.2 ± 1.27	165.8 – 179.2	180.3 – 190.3	13.54	16.15
F_1	160.9 ± 0.62	177.4 ± 0.88	128.9 – 139.8	130.8 – 152.4	10.67	21.27
F_2	141.0 ± 1.75	173.8 ± 1.16	86.19 – 272.7	30.50 – 250.2	643.2	593.4
B_1	144.6 ± 2.86	153.7 ± 4.71	110.5 – 185.2	127.4 – 180.3	237.5	311.6
B_2	155.1 ± 2.90	146.1 ± 4.43	110.5 – 178.3	105.9 – 196.7	193.9	354.7

Table 6: Estimates of mean, range and variance of parental, first and second filial and backcross generations of 4 groundnut crosses for SLA at 80 days after sowing

Descriptive statistics	Mean ± S.E		Range		Variance	
	Rainy	Post rainy	Rainy	Post rainy	Rainy	Post rainy
Generation	ICG 7243 × ICG 6766					
P_1	133.0 ± 1.17	131.4 ± 0.97	125.5 – 141.2	126.3 – 135.8	17.98	9.445
P_2	119.5 ± 1.42	112.3 ± 0.84	115.6 – 130.5	106.4 – 116.1	18.21	9.277
F_1	129.5 ± 1.05	131.4 ± 0.63	125.3 – 140.5	128.2 – 135.2	14.54	5.718
F_2	130.1 ± 1.59	132.7± 1.25	86.67 – 252.7	73.87 – 220.0	491.8	207.3
B_1	130.9 ± 1.94	129.4 ± 1.97	110.1 – 155.8	121.3 – 146.3	138.4	98.64
B_2	123.8 ± 2.47	124.6 ± 1.90	109.3 – 155.5	104.9 – 135.9	104.4	121.8
	ICG 12988 × ICG 10890					
P_1	143.1 ± 1.10	159.9 ± 1.41	135.1 – 145.9	150.5 – 165.3	13.37	27.91
P_2	137.5 ± 1.03	161.3 ± 1.30	134.0 – 144.5	152.2 – 170.3	10.79	25.34
F_1	138.3 ± 1.23	138.3 ± 1.04	131.5 – 144.5	135.2 – 154.8	18.16	20.68
F_2	149.8 ± 1.84	162.6 ± 1.82	96.53 – 233.1	88.76 – 290.1	483	328.2
B_1	150.1 ± 2.53	135.9 ± 3.62	120.5 – 176.5	116.2 – 158.3	141.6	157.2
B_2	143.4 ± 2.77	142.3 ± 2.50	123.2 – 165.5	118.5 – 162.0	138.8	100.3
	Chico × ICG 9418					
P_1	160.4 ± 1.19	185.5 ± 1.06	153.3 – 166.5	175.5 – 19.2	17.03	16.95
P_2	139.8 ± 1.23	163.6 ± 1.20	132.5 – 150.5	156.8 – 170.3	18.35	21.73
F_1	168.4 ± 1.29	170.0 ± 0.84	160.1 – 175.8	166.7 – 180.6	25.12	13.53
F_2	153.5 ± 1.73	179.3 ± 1.71	100.1 – 235.4	94.60 – 260.5	555.7	548.1
B_1	161.0 ± 3.25	163.0 ± 3.88	144.5 – 196.6	140.5 – 184.7	200.6	196.0
B_2	147.7 ± 3.00	147.4 ± 3.70	125.5 – 181.5	116.9 – 190.0	207.6	302.4
	ICG 9418 × Chico					
P_1	139.0 ± 1.58	168.7 ± 1.12	130.3 – 148.3	163.4 – 178.2	18.35	15.16
P_2	162.5 ± 1.58	194.2 ± 1.33	162.6 – 180.5	183.9 – 200.6	22.56	26.69
F_1	158.0 ± 0.80	175.1± 0.83	150.8 – 160.4	146.0 – 160.5	8.49	16.72
F_2	157.9 ± 1.49	177.1 ± 1.24	106.0 – 238.6	94.56 – 305.9	496.6	625.7
B_1	162.0 ± 2.43	149.2 ± 2.88	145.0 – 195.6	134.0 – 170.0	172.1	116.3
B_2	156.4 ± 3.14	154.2 ± 4.29	120.5 – 175.5	125.5 – 180.3	158.2	258.3

Table 7: Estimates of mean, range and variance of parental, first and second filial and backcross generations of 4 groundnut crosses for seed length

Descriptive statistics	Mean ± S.E		Range		Variance	
	Rainy	Post rainy	Rainy	Post rainy	Rainy	Post rainy
Generation	ICG 7243 × ICG 6766					
P_1	12.1 ± 0.12	13.8 ± 0.17	11.8 – 12.6	13.0 – 15.0	0.110	0.330
P_2	16.6 ± 0.18	17.8 ± 0.17	15.5 – 17.5	17.0 – 18.6	0.329	0.319
F_1	14.7 ± 0.17	15.5 ± 0.15	14.0 – 16.0	14.5 – 16.5	0.460	0.337
F_2	14.6 ± 0.15	15.3 ± 0.16	5.00 – 19.0	6.00 – 20.0	3.759	3.414
B_1	14.2 ± 0.43	15.1 ± 0.55	10.8 – 18.3	12.5 – 19.0	3.721	4.554
B_2	15.4 ± 0.54	16.4 ± 0.52	12.0 – 19.1	10.5 – 19.0	1.454	4.160
ICG 12988 × ICG 10890						
P_1	10.0 ± 0.38	11.1 ± 0.19	7.50 – 12.0	10.5 – 12.0	0.812	0.389
P_2	11.2 ± 0.32	12.0 ± 0.39	10.0 – 13.0	10.0 – 14.0	1.027	1.530
F_1	11.2 ± 0.26	12.3 ± 0.33	8.0 – 12.5	8.00 – 16.5	1.038	2.832
F_2	11.2 ± 0.09	11.7 ± 0.11	7.0 – 15.0	7.50 – 17.2	1.27	2.519
B_1	11.0 ± 0.14	12.2 ± 0.29	9.5 – 13.0	10.5 – 14.8	0.527	1.456
B_2	11.0 ± 0.21	11.9 ± 0.24	9.4 – 12.2	11.0 – 12.3	0.812	0.348
Chico × ICG 9418						
P_1	10.7 ± 0.11	11.6 ± 0.18	9.9 – 11.5	11.0 – 12.5	0.184	0.357
P_2	11.5 ± 0.17	12.9 ± 0.31	10.0 – 12.0	12.0 – 15.5	0.304	1.004
F_1	10.7 ± 0.20	10.9 ± 0.20	10.0 – 12.0	9.00– 13.5	0.420	1.208
F_2	11.6 ± 0.09	12.3 ± 0.08	9.0 – 15.0	5.00 – 19.6	1.262	2.129
B_1	12.2 ± 0.21	12.5 ± 0.20	11.1 – 13.4	11.0 – 14.0	0.647	0.783
B_2	11.2 ± 0.24	12.7 ± 0.31	9.6 – 13.0	10.5 – 14.5	0.868	1.157
ICG 9418 × Chico						
P_1	11.6 ± 0.26	13.0 ± 0.25	11.0 – 13.0	11.5 – 14.0	0.863	0.651
P_2	10.2 ± 0.10	12.4 ± 0.20	9.9 – 10.8	11.0 – 13.4	0.103	0.454
F_1	11.5 ± 0.18	12.6 ± 0.16	10.0 – 12.2	10.5 – 13.8	0.442	0.745
F_2	12.3 ± 0.13	13.0 ± 0.08	5.02 – 16.0	3.50 – 16.0	2.740	2.154
B_1	11.2 ± 0.25	12.5 ± 0.21	9.2 – 12.5	11.0 – 14.5	0.949	0.942
B_2	11.6 ± 0.30	13.0 ± 0.46	10.0 – 13.5	12.0 – 15.0	1.280	1.322

Table 8: Estimates of mean, range and variance of parental, first and second filial and backcross generations of 4 groundnut crosses for seed width.

Descriptive statistics	Mean ± S.E		Range		Variance	
	Rainy	Post rainy	Rainy	Post rainy	Rainy	Post rainy
Generation	ICG 7243 × ICG 6766					
P_1	8.0 ± 0.25	8.9 ± 0.17	7.5 – 9.5	8.0 – 9.6	0.466	0.34
P_2	7.0 ± 0.09	8.2 ± 0.13	6.4 – 7.5	7.5 – 9.0	0.096	0.169
F_1	7.6 ± 0.20	7.9 ± 0.19	6.0 – 8.6	6.3 – 9.0	0.575	0.577
F_2	7.8 ± 0.12	8.2 ± 0.09	5.0 – 16	6.0 – 12.5	2.176	1.110
B_1	6.4 ± 0.27	8.0 ± 0.32	4.0 – 8.8	5.5 – 10.5	1.477	1.536
B_2	6.4 ± 0.28	7.8 ± 0.17	5.0 – 9.2	6.5 – 9.0	1.270	0.445
ICG 12988 × ICG 10890						
P_1	8.0 ± 0.29	7.9± 0.21	5.0 – 8.00	7.0 – 9.5	0.840	0.467
P_2	7.0 ± 0.27	7.3 ± 0.13	5.0 – 7.50	7.0 – 9.5	0.660	0.178
F_1	8.0 ± 0.08	7.6 ± 0.22	6.0 – 7.20	5.0 – 9.5	0.101	1.286
F_2	6.5 ± 0.10	7.8 ± 0.07	3.6 – 13.0	4.0 – 10.0	1.625	1.065
B_1	6.5 ± 0.29	8.1 ± 0.15	5.8 – 11.5	7.0 – 9.5	2.170	0.397
B_2	7.1 ± 0.21	7.5 ± 0.30	9.4 – 12.2	6.3 – 8.3	0.812	0.567
Chico × ICG 9418						
P_1	7.1 ± 0.09	7.8 ± 0.14	6.0 – 8.10	7.0 – 8.30	0.144	0.207
P_2	7.6 ± 0.28	8.4 ± 0.13	6.0 – 9.00	7.5 – 9.00	0.832	0.172
F_1	7.1 ± 0.28	7.9 ± 0.08	6.0 – 8.80	6.9 – 9.20	0.731	0.209
F_2	7.0 ± 0.11	7.8 ± 0.06	3.5 – 15.0	3.5 – 18.0	1.988	1.347
B_1	7.3 ± 0.17	8.0 ± 0.21	5.0 – 10.2	6.0 – 11.0	0.424	0.802
B_2	7.4 ± 0.19	8.1 ± 0.25	5.00 – 9.5	6.5 – 9.60	0.555	0.806
ICG 9418 × Chico						
P_1	6.7 ± 0.21	7.8 ± 0.19	6.0 – 8.0	7.0 – 9.00	0.555	0.360
P_2	6.1 ± 0.12	8.5 ± 0.18	5.8 – 6.8	7.5 – 9.10	0.137	0.357
F_1	7.2 ± 0.12	7.5 ± 0.09	6.5 – 8.0	6.4 – 9.00	0.186	0.267
F_2	6.0 ± 0.08	8.0 ± 0.05	2.6 – 12.0	3.0 – 12.0	0.952	1.112
B_1	6.4 ± 0.17	7.4 ± 0.18	5.4 – 7.5	6.0 – 9.00	0.440	0.703
B_2	6.2 ± 0.12	7.4 ± 0.43	5.3 – 7.0	7.0 – 10.0	1.155	0.218

Table 9: Estimates of mean, range and variance of parental, first and second filial and backcross generations of 4 groundnut crosses for pod yield

Descriptive statistics	Mean ± S.E		Range		Variance	
	Rainy	Post rainy	Rainy	Post rainy	Rainy	Post rainy
Generation	ICG 7243 × ICG 6766					
P_1	18.0 ± 1.98	27.0 ± 1.87	10.5 – 25.8	20.7 – 34.8	39.25	36.020
P_2	22.8 ± 2.98	41.0 ± 2.66	10.3 – 30.5	35.1 – 47.7	41.01	33.3.1
F_1	30.60 ± 1.92	36.0 ± 2.40	22.6 – 36.5	30.2 – 42.3	35.50	28.30
F_2	26.32 ± 1.12	35.7 ± 2.11	2.6 – 81.50	2.500 – 110	358.2	514.2
B_1	15.3 ± 2.53	42.5 ± 2.92	10.5 – 70.8	4.50 – 98.9	108.1	111.3
B_2	14.95 ± 4.3	46.9 ± 3.12	15.5 – 69.8	28.3 – 55.0	225.2	393.2
ICG 12988 × ICG 10890						
P_1	18.12 ± 2.46	29.32 ± 2.42	15.5 – 26.4	24.1 – 32.1	34.12	25.21
P_2	10.02 ± 1.65	15.58 ± 1.59	8.90 – 16.8	10.5 – 20.1	33.12	18.12
F_1	15.0 ± 2.35	24.15 ± 2.55	11.6 – 30.5	15.4 – 38.0	38.32	25.20
F_2	20.121.105	23.65 ± 1.13	2.00 – 50.6	1.90 – 80.6	343.2	247.3
B_1	30.2 ± 4.68	44.82 ± 5.63	5.66 – 8.65	9.10 – 75.8	380.1	150.2
B_2	30.12 ± 5.6	35.96 ± 5.80	15.5 – 42.3	27.5 – 65.0	316.6	247.3
Chico × ICG 9418						
P_1	17.12 ± 1.56	25.47 ± 1.47	15.5 – 32.5	17.4 – 31.3	35.30	29.90
P_2	23.54 ± 1.13	31.82 ± 1.81	10.5 – 30.6	24.0 – 40.5	36.20	22.30
F_1	26.38 ± 2.13	39.40 ± 1.53	15.6 – 33.8	17.4 – 31.3	61.56	57.20
F_2	13.10 ± 1.86	39.35 ± 3.60	2.10 – 44.1	1.60 – 87.4	236.3	251.2
B_1	13.40 ± 4.12	37.72 ± 3.78	10.3 – 39.5	14.1 – 75.0	158.1	109.2
B_2	19.20 ± 5.32	22.76 ± 0.76	9.8 0– 40.2	20.2 – 59.3	99.1	97.10
ICG 9418 × Chico						
P_1	20.0 ± 1.36	30.07 ± 1.23	11.5 – 30.1	21.50 – 38	33.00	25.10
P_2	25.1 ± 2.38	29.8 ± 42.38	14.6 – 30.5	24.4 – 38.9	38.11	28.20
F_1	25.77 ± 3.5	34.4 ± 3.12	16.2 – 35.8	26.4 – 45.7	28.20	33.30
F_2	23.33 ± 0.9	19.33 ± 0.57	1.36 – 42.1	2.30 – 77.7	250.2	290.2
B_1	15.23 ± 5.1	30.06 ± 4.10	14.5 – 66.5	13.5 – 44.9	198.5	133.0
B_2	21.9 ± 4.90	26.11 ± 5.12	13.8 – 59.8	18.3 – 28.5	142.3	150.0

Table 10: Estimates of mean, range and variance of parental, first and second filial and backcross generations of 4 groundnut crosses for seed yield

Descriptive statistics	Mean ± S.E		Range		Variance	
	Rainy	Post rainy	Rainy	Post rainy	Rainy	Post rainy
Generation	ICG 7243 × ICG 6766					
P_1	10.13 ± 1.23	17.35 ± 1.05	8.00 – 14.5	13.6 – 22.1	15.30	12.13
P_2	14.12 ± 1.92	27.04 ± 1.85	9.50 – 25.2	20.0 – 30.2	23.23	25.30
F_1	18.42 ± 1.86	25.54 ± 2.35	9.56 – 30.2	19.0 – 40.5	20.30	25.23
F_2	16.23 ± 1.12	27.39 ± 1.41	1.56 – 68.3	0.90 – 70.1	90.56	100.2
B_1	9.30 ± 3.25	27.51 ± 2.96	5.60 – 15.5	9.75 – 66.3	105.5	50.81
B_2	9.20 ± 2.95	27.39 ± 3.22	5.60 – 15.2	11.6 – 52.0	40.60	79.20
ICG 12988 × ICG 10890						
P_1	11.30 ± 1.23	22.60 ± 1.36	6.80 – 18.9	19.0 – 28.60	15.50	20.20
P_2	6.410 ± 1.23	10.00 ± 0.70	3.80 – 10.5	8.00– 14.20	25.60	22.30
F_1	11.20 ± 1.12	17.30± 1.70	5.90 – 25.6	6.500 – 300	29.00	20.56
F_2	12.32 ± 1.95	14.64 ± 0.77	1.50 – 42.5	0.9 – 53.20	110.3	130.2
B_1	16.90 ± 5.23	31.14 ± 4.01	3.8 – 38.2	4.6 – 55.10	98.50	100.3
B_2	17.02 ± 4.89	23.21 ± 4.74	1.9 – 30.15	15.4 – 46.0	115.2	95.30
Chico × ICG 9418						
P_1	10.23 ± 1.34	18.65 ± 1.45	5.5 – 16.9	11.6 – 25.6	10.89	12.9
P_2	15.23 ± 1.65	23.54 ± 1.50	8.9 – 20.5	17.2 – 300	26.26	29.0
F_1	17.76 ± 1.68	32.16 ± 1.47	9.8 – 30.5	18.0– 40.6	25.38	22.6
F_2	8.500 ± 0.96	17.66 ± 0.58	1.1 – 30.5	1.70 – 67.7	98.80	79.5
B_1	8.800 ± 3.21	29.37 ± 2.17	5.5 – 42.3	11.2 – 41.1	58.60	46.2
B_2	12.200 ± 3.26	24.76 ± 3.07	3.8 – 40.6	7.2 – 40.5	73.50	44.3
ICG 9418 × Chico						
P_1	12.50 ± 2.31	20.82 ± 3.44	5.50 – 18.9	15.6 – 30.0	13.5	15.0
P_2	16.12 ± 1.23	22.37 ± 1.79	10.5 – 21.2	15.3 – 29.7	16.3	19.2
F_1	18.00 ± 1.23	25.00 ± 2.44	10.6 – 22.5	15.0 – 34.6	15.2	9.90
F_2	15.23 ± 0.45	15.46 ± 0.62	0.9 – 36.5	1.80 – 52.5	79.5	80.5
B_1	9.89 ± 3.25	21.96 ± 3.29	5.60 – 28.2	10.6 – 35.8	54.6	55.5
B_2	14.02 ± 4.12	19.00 ± 4.12	5.8 0– 33.6	11.2 – 27.6	66.9	80.1

Table 11: Estimates of mean, range and variance of parental, first and second filial and backcross generations of 4 groundnut crosses for 100-kernel weight

Descriptive statistics	Mean ± S.E		Range		Variance	
	Rainy	Post rainy	Rainy	Post rainy	Rainy	Post rainy
Generation	ICG 7243 × ICG 6766					
P_1	47.2 ± 1.04	58.2 ± 0.96	44.0 – 51.0	54.0 – 65.0	7.57	10.22
P_2	53.8 ± 1.34	72.9 ± 1.05	48.0 – 61.0	69.0 – 79.5	18.2	11.04
F_1	51.3 ± 1.98	63.8 ± 10.8	40.0 – 62.0	58.5 – 70.0	59.2	10.44
F_2	46.4 ± 1.21	54.7 ± 1.29	14.0 – 90.0	14.0 – 91.0	224.4	202.4
B_1	30.1 ± 1.39	53.6 ± 2.45	20.0 – 46.0	38.0 – 70.0	39.15	90.56
B_2	34.9 ± 1.52	55.3 ± 2.70	26.0 – 43.0	34.2 – 74.4	32.69	110.1
ICG 12988 × ICG 10890						
P_1	30.0 ± 0.53	35.4 ± 1.04	26.0 – 33.0	30.5 – 40.5	12.56	10.86
P_2	36.5 ± 0.53	41.0 ± 0.58	33.5 – 38.5	35.5 – 46.5	11.62	8.37
F_1	29.1 ± 0.76	44.5 ± 0.80	21.0 – 35.0	35.0 – 50.2	10.53	11.92
F_2	25.0 ± 0.65	42.7 ± 0.73	12.0 – 66.0	10.0 – 80.0	135.2	136.6
B_1	25.0 ± 1.62	44.3 ± 1.85	21.0 – 39.0	28.0 – 54.8	66.18	58.17
B_2	26.7 ± 2.02	39.8 ± 4.29	15.0 – 45.0	23.0 – 52.0	120.3	110.6
Chico × ICG 9418						
P_1	27.0 ± 0.88	37.0 ± 1.21	25.0 – 35.0	29.4 – 42.0	11.64	14.67
P_2	36.8 ± 1.04	46.8 ± 1.38	30.5 – 40.6	40.0 – 52.0	10.93	19.07
F_1	32.3 ± 0.87	42.3 ± 0.64	28.5 – 36.0	35.0 – 48.0	7.60	12.00
F_2	34.2 ± 0.50	44.0 ± 0.59	10.0 – 42.0	18.0 – 74.1	35.97	107.0
B_1	30.9 ± 1.68	40.9 ± 2.65	20.0 – 44.0	20.0 – 63.0	39.5	142.5
B_2	31.5 ± 2.27	41.5 ± 3.17	14.0 – 46.0	20.0 – 52.0	77.41	120.6
ICG 9418 × Chico						
P_1	28.0 ± 0.84	42.7 ± 0.81	25.0 – 31.0	39.0 – 46.0	8.62	6.68
P_2	21.3 ± 0.64	37.8 ± 1.00	20.0 – 25.0	32.4 – 44.0	3.75	11.1
F_1	30.3 ± 0.78	40.7 ± 0.88	38.0 – 46.0	30.0 – 48.0	7.93	21.85
F_2	21.9 ± 0.46	40.9 ± 0.52	8.0 – 38.0	12.0 – 66.0	29.9	88.62
B_1	23.4 ± 1.66	40.1 ± 1.85	14.0 – 36.0	21.0 – 52.3	41.4	68.99
B_2	26.7 ± 1.31	43.0 ± 1.44	20.0 – 33.0	26.0 – 55.5	24.18	65.05

Table 12: Estimates of mean, range and variance of parental, first and second filial and backcross generations of 4 groundnut crosses for shelling percentage

Descriptive statistics	Mean ± S.E		Range		Variance	
	Rainy	Post rainy	Rainy	Post rainy	Rainy	Post rainy
Generation	ICG 7243 × ICG 6766					
P_1	56.9 ± 1.33	64.0 ± 0.97	53.0 – 61.4	60.1 – 69.3	12.45	10.43
P_2	62.5 ± 1.28	68.2 ± 0.85	57.2 – 69.1	65.2 – 74.0	16.42	7.36
F_1	60.4 ± 0.98	63.6 ± 0.85	54.0 – 65.6	59.1 – 68.7	14.65	10.83
F_2	61.1 ± 0.67	62.5 ± 0.91	23.9 – 79.3	25.1 – 81.3	67.75	106.2
B_1	60.6 ± 0.84	61.0 ± 1.31	54.5 – 68.2	52.9 – 67.5	14.37	25.93
B_2	61.0 ± 1.24	61.8 ± 1.42	52.4 – 67.4	50.9 – 69.4	21.77	30.51
ICG 12988 × ICG 10890						
P_1	70.2 ± 1.42	75.5 ± 1.22	65.5 – 73.2	67.1 – 78.8	20.42	15.04
P_2	64.1 ± 1.44	69.8 ± 1.48	58.8 – 2755	63.6 – 79.7	20.91	22.02
F_1	60.1 ± 0.91	65.7 ± 0.77	57.4 – 69.2	58.5 – 73.0	12.48	15.46
F_2	61.2 ± 0.64	66.8 ± 0.66	22.8 – 79.9	37.8 – 84.3	56.99	85.91
B_1	64.3 ± 1.98	68.9 ± 1.93	20.5 – 65.0	50.5 – 83.4	98.03	63.78
B_2	59.3 ± 3.15	63.1 ± 3.59	33.0 – 76.0	53.7 – 76.5	179.1	77.58
Chico × ICG 9418						
P_1	59.8 ± 0.99	72.0 ± 0.88	51.2 – 66.1	68.2 – 75.5	10.82	7.809
P_2	65.2 ± 0.91	73.6 ± 0.75	59.2 – 68.3	80.2 – 77.2	8.36	5.724
F_1	63.9 ± 0.99	75.5 ± 0.54	60.0 – 69.2	70.0 – 80.0	9.96	8.528
F_2	64.9 ± 0.51	74.8 ± 0.44	44.7 – 78.6	42.4 – 91.2	37.98	58.87
B_1	62.4 ± 1.60	73.1 ± 1.69	44.6 – 371.0	58.0 – 82.2	35.86	51.78
B_2	63.7 ± 1.16	67.6 ± 2.61	54.2 – 971.2	48.9 – 78.4	20.38	82.23
ICG 9418 × Chico						
P_1	60.1 ± 0.80	72.2 ± 1.10	58.4 – 66.1	66.4 – 77.3	7.67	12.22
P_2	64.4 ± 0.64	77.1 ± 0.91	62.5 – 68.1	72.1 – 71.4	3.753	9.29
F_1	69.8 ± 0.82	70.5 ± 0.71	61.9 – 74.6	66.0 – 78.6	8.814	14.48
F_2	74.1 ± 0.68	74.8 ± 0.51	41.6 – 88.4	23.8 – 90.2	64.05	82.45
B_1	65.0 ± 1.80	70.7 ± 2.07	51.7 – 76.3	53.4 – 89.9	48.64	86.24
B_2	64.1 ± 2.19	73.2 ± 1.65	43.5 – 75.8	52.6 – 90.6	67.21	54.83

Table13: Joint scaling test for assessing the adequacy of additive- dominance model for the inheritance of traits related to drought tolerance, and yield and its component traits in groundnut

Character	Cross	Season	m	[d]	[h]	Chi-square value
SCMR 60DAS	C1	Rainy	46.71**	-1.99**	-2.98**	70.96**
	C1	Post rainy	47.88**	-0.88**	-1.62**	35.02**
	C2	Rainy	39.31**	-1.02**	-0.91*	20.03**
	C2	Post rainy	42.70**	-0.59**	2.56**	124.48**
	C3	Rainy	36.13**	1.24**	1.04**	10.50**
	C3	Post rainy	40.15**	0.49**	1.74**	40.75**
	C4	Rainy	37.09**	-0.70**	0.0745	6.087
	C4	Post rainy	44.12**	0.56**	1.23**	44.23**
SCMR 80DAS	C1	Rainy	45.73**	-1.57**	-0.91**	69.00**
	C1	Post rainy	47.26**	-0.74**	-0.64	23.95**
	C2	Rainy	38.24**	-0.73**	-1.13**	14.61**
	C2	Post rainy	43.51**	-0.49**	-0.02	12.98**
	C3	Rainy	35.57**	1.36**	-1.07**	90.92**
	C3	Post rainy	40.03**	0.52**	1.89**	9.60*
	C4	Rainy	35.18**	-2593**	-0.815*	131.40**
	C4	Post rainy	40.16**	-0.44**	0.26	15.34**
SLA 60DAS	C1	Rainy	112.1**	1.785**	2.47**	142.73**
	C1	Post rainy	115.7**	9.35**	7.63**	388.17**
	C2	Rainy	134.1**	1.08**	-1.57**	81.01**
	C2	Post rainy	158.2**	-8.66**	-13.5**	9.84*
	C3	Rainy	150.3**	15.45**	-7.23**	71.99**
	C3	Post rainy	172.2**	14.44**	-1.45	43.56**
	C4	Rainy	151.3**	-18.36**	7.56**	263.56**
	C4	Post rainy	180.4**	-5.55**	-15.5**	31.39**
SLA 80DAS	C1	Rainy	126.4**	6.72**	3.34**	4.86
	C1	Post rainy	122.6**	9.39**	9.53**	23.65**
	C2	Rainy	141.7**	2.99**	-0.60**	108.28**
	C2	Post rainy	162.2**	-0.973	-18.6**	40.78**
	C3	Rainy	150.4**	10.43**	-4.09**	7.816
	C3	Post rainy	175.5**	10.84**	-4.35**	27.92**
	C4	Rainy	155.8**	-16.41**	2.18**	80.81**
	C4	Post rainy	181.5**	-12.88**	-11.6**	16.08**
Seed Length(mm)	C1	Rainy	14.40**	-2.22**	0.37	3.26
	C1	Post rainy	15.77**	-2.02**	-0.32**	5.11
	C2	Rainy	10.64**	-0.57**	0.95**	7.62
	C2	Post rainy	11.20**	0.004	1.27**	2.64
	C3	Rainy	10.96**	-0.1	0.75**	49.22**
	C3	Post rainy	12.78**	-0.708**	-1.05**	36.70**
	C4	Rainy	10.90**	0.59**	0.65**	9.01*
	C4	Post rainy	12.61**	0.057	0.039	14.06**

Table 13.Contd…

Seed Width(mm)	C1	Rainy	7.43**	0.45**	-0.27**	69.97**
	C1	Post rainy	8.54**	0.40**	-0.75**	1.90
	C2	Rainy	7.20**	-1.29**	-0.15**	35.68**
	C2	Post rainy	7.725**	0.390**	0.21	2.93
	C3	Rainy	6.03**	0.074	0.57*	11.58**
	C3	Post rainy	7.97**	-0.29**	-0.20**	4.36
	C4	Rainy	5.95**	0.78**	0.85**	45.68**
	C4	Post rainy	7.73**	-0.24*	-0.43**	14.26**
Pod Yield(gm)	C1	Rainy	17.12**	-1.39**	11.1**	37.99**
	C1	Post rainy	35.00**	-6.50**	3.95	13.25**
	C2	Rainy	14.38**	2.99	-10.6**	35.9**
	C2	Post rainy	19.57**	11.19**	8.04**	19.38**
	C3	Rainy	16.23**	-5.15**	-1.17**	75.96**
	C3	Post rainy	23.94**	-1.99**	7.46**	102.20**
	C4	Rainy	8.44**	-2.14**	8.14**	25.52**
	C4	Post rainy	23.35**	2.92**	8.37**	49.84**
Seed yield(gm)	C1	Rainy	12.06**	-1.90**	4.40*	52.46**
	C1	Post rainy	22.32**	-4.66**	4.66*	3.57
	C2	Rainy	10.94**	2.00**	6.07**	7.82*
	C2	Post rainy	15.60**	7.33**	2.41	12.05**
	C3	Rainy	8.71**	-2.12**	2.66**	43.05**
	C3	Post rainy	17.22**	-1.44**	7.30**	89.76**
	C4	Rainy	4.04**	-1.37**	11.1**	35.41**
	C4	Post rainy	16.93**	-2.70**	-5.29**	26.29**
100-kernelwt(gm)	C1	Rainy	48.15**	-3.22**	-10.9**	167.99**
	C1	Post rainy	63.67**	-6.50**	-6.13**	54.70**
	C2	Rainy	25.87**	1.69**	3.66**	9.141*
	C2	Post rainy	37.53**	4.36**	8.64**	2.88
	C3	Rainy	22.74**	-2.59**	6.33**	6.68
	C3	Post rainy	43.06**	-4.84**	-0.144	7.29
	C4	Rainy	20.82**	0.74**	6.37**	96.05**
	C4	Post rainy	39.95**	1.79**	1.70	1.85
SHP (%)	C1	Rainy	60.69**	-2.04**	0.77	3.53
	C1	Post rainy	65.21**	-2.28**	-3.68**	10.59*
	C2	Rainy	60.12**	-2.64**	1.57**	7.61
	C2	Post rainy	70.73**	2.18**	-6.16**	4.55
	C3	Rainy	63.04**	-2.43**	2.00	6.7
	C3	Post rainy	73.05**	-0.65**	2.63**	7.75
	C4	Rainy	62.72**	-1.45**	6.88**	4.00
	C4	Post rainy	74.42**	-2.86**	-2.95	10.82*

C1=ICG 7243x ICG 6766, C2=ICG 12988 × ICG 10890, C3=Chico × ICG 9418, C4=ICG 9418 × Chico. SHP=Shelling Percentage
* Significance at P=0.05 ** Significance at P=0.01

DAS in ICG 7243 × ICG 6766, ICG 12988 × ICG 10890 and ICG 9418 × Chico crosses during post rainy season, in Chico × ICG 9418 for SLA at 80 DAS during post rainy season, in ICG 7243 × ICG 6766 and ICG 9418 × Chico crosses for seed length during post rainy season, in ICG 12988 × ICG 10890 for seed width during post rainy season, in ICG 7243 × ICG 6766 for pod yield during post rainy season, in ICG 12988 × ICG 10890 for seed yield during post rainy season, in ICG 9418 × Chico for 100-kernel weight during both rainy and post rainy seasons, in Chico × ICG 9418 for shelling percentage during rainy season and in its reciprocal cross, ICG 9418 × Chico for shelling during post rainy season.

The non significance of χ^2 test indicated adequacy of additive-dominance model for the expression of SCMR at 60 DAS in ICG 9418 × Chico during rainy season, for SLA at 80 DAS in ICG 7243 × ICG 6766 and Chico × ICG 9418 during rainy season for seed length, in ICG 7243 × ICG 6766 and ICG 12988 × ICG 10890 crosses during both rainy and post rainy seasons, for seed width in ICG 7243 × ICG 6766, ICG 12988 × ICG 10890 and Chico × ICG 9418 crosses during post rainy season, for seed yield in ICG 7243 × ICG 6766 during post rainy season and for 100-kernel weight in ICG 12988 × ICG 10890 and ICG 9418 × Chico during post rainy season, for 100-kernel weight in Chico × ICG 9418 during both rainy and post rainy seasons, for shelling percentage in ICG 12988 × ICG 10890 and Chico × ICG 9418 during both rainy and post rainy seasons and in ICG 7243 × ICG 6766 and ICG 9418 × Chico for shelling percentage during rainy season. For rest of traits and in crosses, additive-dominance model was inadequate as revealed by significance of chi-square test. In general, the estimates of additive gene effects in all the crosses for all the traits was higher in rainy season as compared to those in post rainy season irrespective of direction of their effects. Contrastingly, the estimates of dominance effects in all the crosses for most of the characters was higher in post rainy season compared to those in rainy season irrespective of direction of gene effects. Thus, the magnitude of gene effects were varied with season of evaluation, as true with *per se* performance of progeny in various generations (Table 13).

4.2.2. Gene effects

In crosses and traits where additive-dominance model was inadequate, di-genic epistatic gene effects were estimated following Jinks and Jones (1958) perfect fit solutions. The perfect fit solution estimates revealed significance of main genetic effects, [d] and [h] in most of the crosses for most of the traits in both rainy and post rainy seasons (Table 14). However, dominance gene effects were not significant in some of the crosses for all the traits except seed yield. For example, dominance gene effects were not significant in ICG 7243 × ICG 6766 for SCMR at 60 DAS and 80 DAS during post rainy season in Chico × ICG 9418 for SCMR at 60 DAS during both the seasons, in ICG 12988 × ICG 10890 for SLA at 60 DAS during both the seasons, in ICG 12988 × ICG 10890 for seed width during both the seasons and in ICG 9418 × Chico for100-kernel weight during both the seasons. For SCMR and SLA at 60 DAS and 80 DAS, the magnitude of dominance gene effects were substantially higher (with net negative effects) than that of additive effects in all the crosses.

For pod yield and seed yield, dominance gene effects were significant in all the crosses in both rainy and post rainy seasons. Further the magnitude of dominant gene effects were considerably higher than that of additive gene effects in all the crosses. The net sign of dominant gene effects were positive in ICG 7243 × ICG 6766,ICG 12988 × ICG 10890 and Chico× ICG 9418 while the net sign of dominant gene effects were negative in ICG 9418 × Chico for pod yield and seed yield.

Table 14: Estimates of additive, dominance and di-genic epistatic gene effects of traits related to drought tolerance and yield and its contributing traits in ground nut

Character	Cross	Season	Gene effects						Type of epitasis
			m	[d]	[h]	[i]	[j]	[l]	
SCMR 60DAS	C1	Rainy	51.32**	-1.99**	-22.75**	-3.94	1.53	16.54**	Duplicate interaction
	C1	Post rainy	45.65**	-0.92**	-3.39	2.572**	1.132	4.29	Duplicate interaction
	C2	Rainy	35.27**	-1.21**	13.615*	3.741	5.209*	-10.91*	Duplicate interaction
	C2	Post rainy	51.76**	-0.38	-33.49**	-8.31**	-5.26*	27.81**	Duplicate interaction
	C3	Rainy	35.98**	0.971**	0.608	0.3362	5.95**	0.797	Complimentary interaction
	C3	Post rainy	44.21**	0.498**	-5.56	-4.58*	3.713	1.843	Duplicate interaction
	C4	Rainy	37.09**	-0.70**	0.0745				Absent
	C4	Post rainy	31.69**	-0.32	22.39*	8.02*	-3.87	-15.02**	Duplicate interaction
SCMR 80DAS	C1	Rainy	49.62**	-1.73**	-20.41**	-3.34	6.72**	16.93**	Duplicate interaction
	C1	Post rainy	45.37**	-0.794**	10.88	1.611	1.951	-10.16*	Duplicate interaction
	C2	Rainy	37.19**	-0.615**	6.019	0.893	-7.53**	-6.456	Duplicate interaction
	C2	Post rainy	37.99**	-0.417**	13.52	5.68*	-2.16	-7.67	Duplicate interaction
	C3	Rainy	38.43**	1.135**	-18.22**	-2.433	10.75**	15.26**	Duplicate interaction
	C3	Post rainy	33.34**	0.516*	21.27**	6.64**	1.27	12.76**	Complimentary interaction
	C4	Rainy	38.58**	-1.17**	-19.51*	-2.44	-9.84**	16.68**	Duplicate interaction
	C4	Post rainy	32.60**	-0.414**	23.84**	7.39**	-5.14*	-16.26**	Duplicate interaction
SLA 60DAS	C1	Rainy	98.14**	2.06**	76.62**	13.060	-38.05**	-62.30**	Duplicate interaction
	C1	Post rainy	117.0**	9.67**	63.13**	-3.51	-19.08**	-58.97**	Duplicate interaction
	C2	Rainy	141.0**	8.706**	3.660	-7.78	26.08**	-13.57	Duplicate interaction
	C2	Post rainy	172.6**	-8.23**	-38.0	-14.2**	26.4	9.69	Duplicate interaction
	C3	Rainy	141.4**	15.80**	-5.17	9.49	-19.4***	7.894	Duplicate interaction
	C3	Post rainy	252.2**	13.21**	-240.0**	-78.80**	16.66	160.2**	Duplicate interaction
	C4	Rainy	117.4**	-18.85**	50.14**	35.66**	16.62**	-6.17	Duplicate interaction
	C4	Post rainy	276.3**	-5.345**	-301.4**	-95.45**	25.93	193.0**	Duplicate interaction

Table 14.Contd…

SLA 80DAS	C1	Rainy	126.4**	6.72**	3.34**				Absent
	C1	Post rainy	144.7**	9.55**	-34.81	-22.87**	-9.54	21.44	Duplicate interaction
	C2	Rainy	152.2**	2.75**	3.451	-11.91*	7.975	-16.69	Duplicate interaction
	C2	Post rainy	254.6**	10.69**	-251.8**	-93.96**	-11.28	135..2**	Duplicate interaction
	C3	Rainy	150.4**	10.43**	-4.09**				Absent
	C3	Post rainy	271.0**	10.98**	-265.6**	-96.41**	9.169	164.6**	Duplicate interaction
	C4	Rainy	149.9**	-16.89**	24.29	5.71	44.66**	-16.83	Duplicate interaction
	C4	Post rainy	283.0**	-12.73**	-309.9**	-101.5**	15.34	196.3**	Duplicate interaction
Seed Length(mm)	C1	Rainy	14.40**	-2.22**	0.37				Absent
	C1	Post rainy	15.77**	-2.02**	-0.32**				Absent
	C2	Rainy	10.64**	-0.57**	0.95**				Absent
	C2	Post rainy	11.20**	0.004	1.27**				Absent
	C3	Rainy	10.62**	-0.444**	3.69	0.481	2.682**	-3.55**	Duplicate interaction
	C3	Post rainy	11.20**	-0.65**	5.017*	1.067	0.9555	-5.25**	Duplicate interaction
	C4	Rainy	14.54**	0.69**	-5.98	-35.79	-2.17**	2.94	Duplicate interaction
	C4	Post rainy	10.1**	0.5**	6.73*	2.4	-1.00	-4.26*	Duplicate interaction
Seed Width(mm)	C1	Rainy	12.53**	0.507**	-14.21**	-5.02**	-1.02	9.30**	Duplicate interaction
	C1	Post rainy	8.54**	0.40**	-0.75**				Absent
	C2	Rainy	6.30**	0.50**	-0.90	1.20	-2.20**	2.60	Duplicate interaction
	C2	Post rainy	7.725**	0.390**	0.21				Absent
	C3	Rainy	5.89**	-0.315**	3.197	1.43*	0.409	-1.966	Duplicate interaction
	C3	Post rainy	7.97**	-0.29**	-0.20**				Absent
	C4	Rainy	5.292**	0.258**	0.972	1.099*	-0.157	0.973	Complimentary interaction
	C4	Post rainy	6.97**	-0.35*	1.16	1.18	2.00**	-0.48	Duplicate interaction
Pod Yield(gm)	C1	Rainy	75.09**	-2.20	-142.7**	-56.49**	6.54	98.23**	Duplicate interaction
	C1	Post rainy	-2.01**	-7.02**	112.9**	36.06*	5.10	-74.88**	Duplicate interaction
	C2	Rainy	-45.97**	7.00**	200.1**	58.97**	5.39	-134.1**	Duplicate interaction
	C2	Post rainy	-48.22**	10.49**	215.1**	66.95**	-3.27	-142.7**	Duplicate interaction
	C3	Rainy	-27.28**	4.5**	119.5**	37.78**	0.777	-77.03**	Duplicate interaction
	C3	Post rainy	-34.43**	-3.173**	154.9**	63.08**	9.59	-81.11**	Duplicate interaction

Table 14: Contd…

	C4	Rainy	-33.68**	-2.85*	132.6**	51.95**	10.11	-67.65**	Duplicate interaction
	C4	Post rainy	57.6**	2.47	-85.9*	-30.00	9.28	61.00**	Duplicate interaction
Seed yield(gm)	C1	Rainy	52.7**	-2.27**	-100.6**	-39.60**	4.68	67.04**	Duplicate interaction
	C1	Post rainy	22.32**	-4.66**	4.66*				Absent
	C2	Rainy	-27.28**	4.500**	119.5**	37.78**	0.777	-77.03**	Duplicate interaction
	C2	Post rainy	-27.57**	7.18**	131.1**	42.99**	1.500	-86.26**	Duplicate interaction
	C3	Rainy	-21.53**	-2.44**	106.8**	37.63**	14.10	-56.98**	Duplicate interaction
	C3	Post rainy	-16.53**	-2.44*	88.09**	37.63**	14.10	-39.38**	Duplicate interaction
	C4	Rainy	32.95**	-2.50	-51.16**	-20.22**	4.77	31.44	Duplicate interaction
	C4	Post rainy	40.05**	-0.39	-58.7	-18.9	8.6	43.28*	Duplicate interaction
100-Kernel wt(gm)	C1	Rainy	106.4**	-3.30**	-184.7**	-55.85**	-3.05	129.6**	Duplicate interaction
	C1	Post rainy	66.54**	-7.32**	-44.53	-0.94	11.19	41.80**	Duplicate interaction
	C2	Rainy	21.96**	7.50*	4.93	3.53	-18.35**	2.268	Complimentary interaction
	C2	Post rainy	37.53**	4.36**	8.64**				Absent
	C3	Rainy	22.74**	-2.59**	6.33**				Absent
	C3	Post rainy	43.06**	-4.84**	-0.144				Absent
	C4	Rainy	2.29**	3.37**	10.69	12.41**	-13.52**	17.39	Complimentary interaction
	C4	Post rainy	39.95**	1.79**	1.70				Absent
SHP (%)	C1	Rainy	60.69**	-2.04**	0.77				Absent
	C1	Post rainy	60.12**	-2.64**	1.57**				Absent
	C2	Rainy	70.73**	2.18**	-6.16**				Absent
	C2	Post rainy	63.04**	-2.43**	2.00				Absent
	C3	Rainy	73.05**	-0.65**	2.63**				Absent
	C3	Post rainy	62.72**	-1.45**	6.88**				Absent
	C4	Rainy	60.12**	-2.64**	1.57**				Absent
	C4	Post rainy	108.9**	-3.82**	-71.87**	-37.61**	2.65	33.54*	Duplicate interaction

C1=ICG 7243× ICG 6766, C2=ICG 12988 × ICG 10890, C3=Chico × ICG 9418, C4=ICG 9418 × Chico .SHP=Shelling Percentage
* Significance at P = 0.05 ** Significance at P=0.01

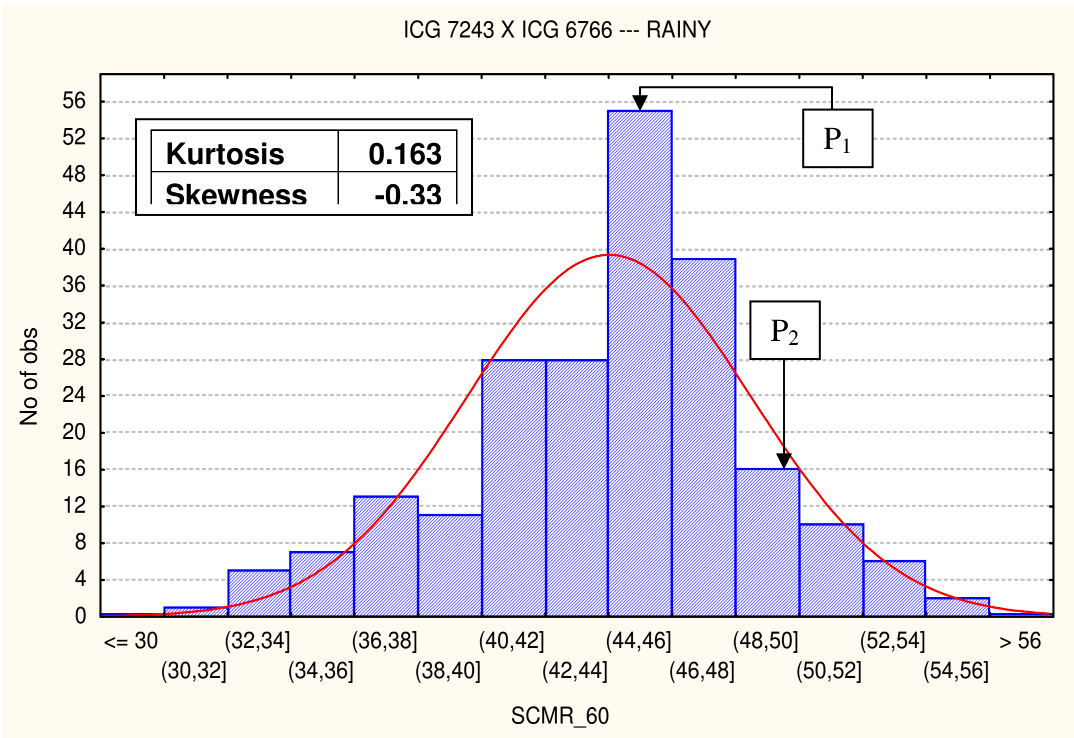

Fig 1: Distribution of F_2 of ICG 7243 × ICG 6766 cross for SCMR at 60 days after sowing during rainy season

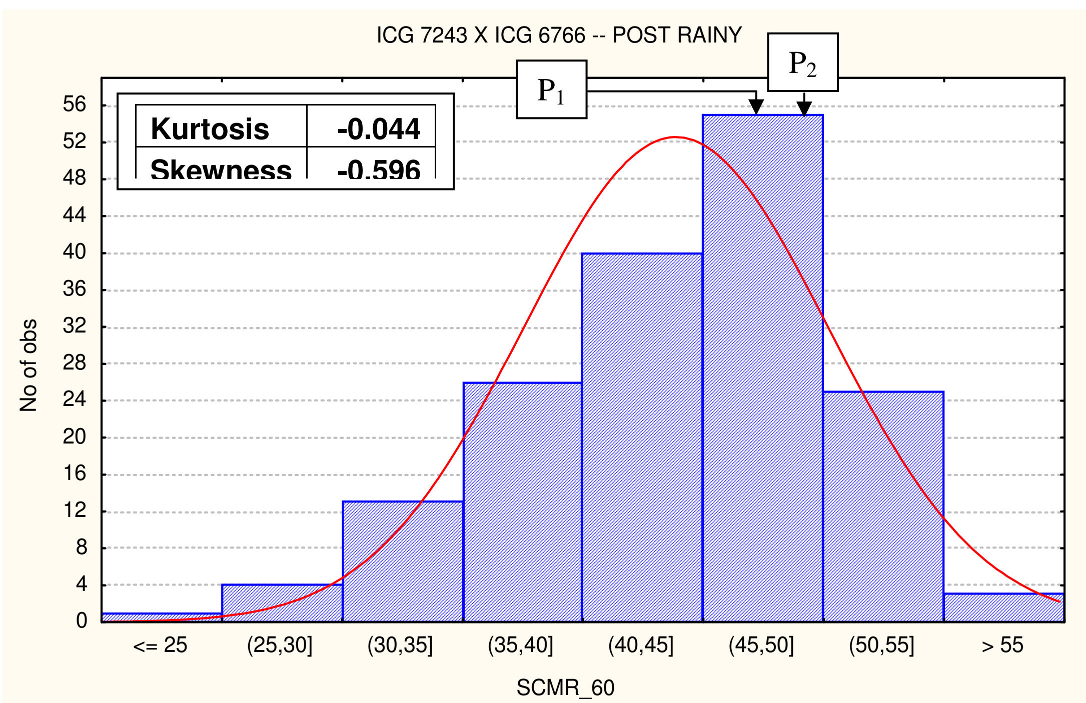

Fig 2: Distribution of F_2 of ICG 7243 × ICG 6766 cross for SCMR at 60 days after sowing during post rainy season

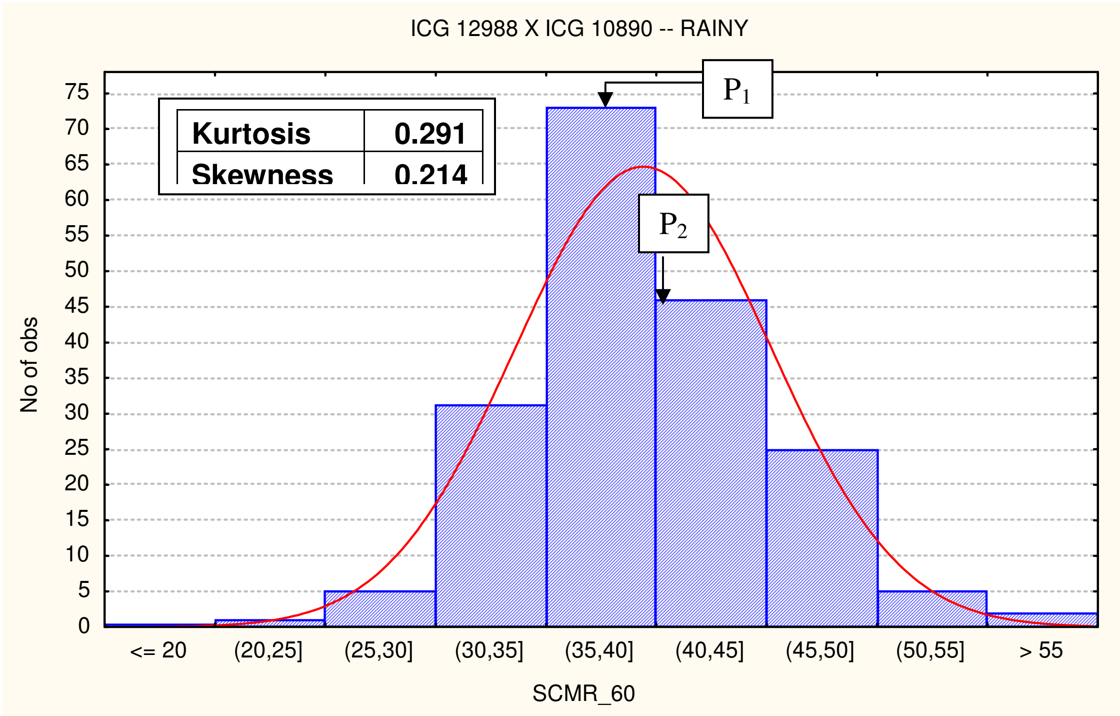

Fig 3: Distribution of F_2 of ICG 12988 × ICG 10890 cross for SCMR at 60 days after sowing during rainy season

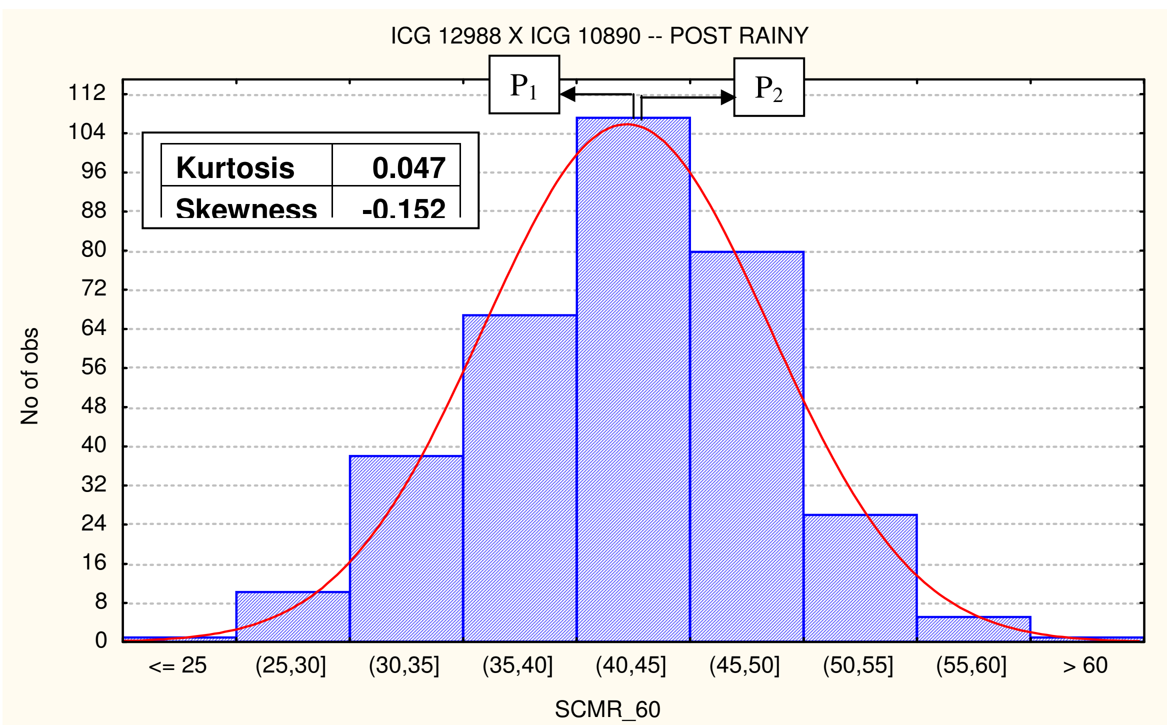

Fig 4: Distribution of F_2 of ICG 12988 × ICG 10890 cross for SCMR at 60 days after sowing during post rainy season

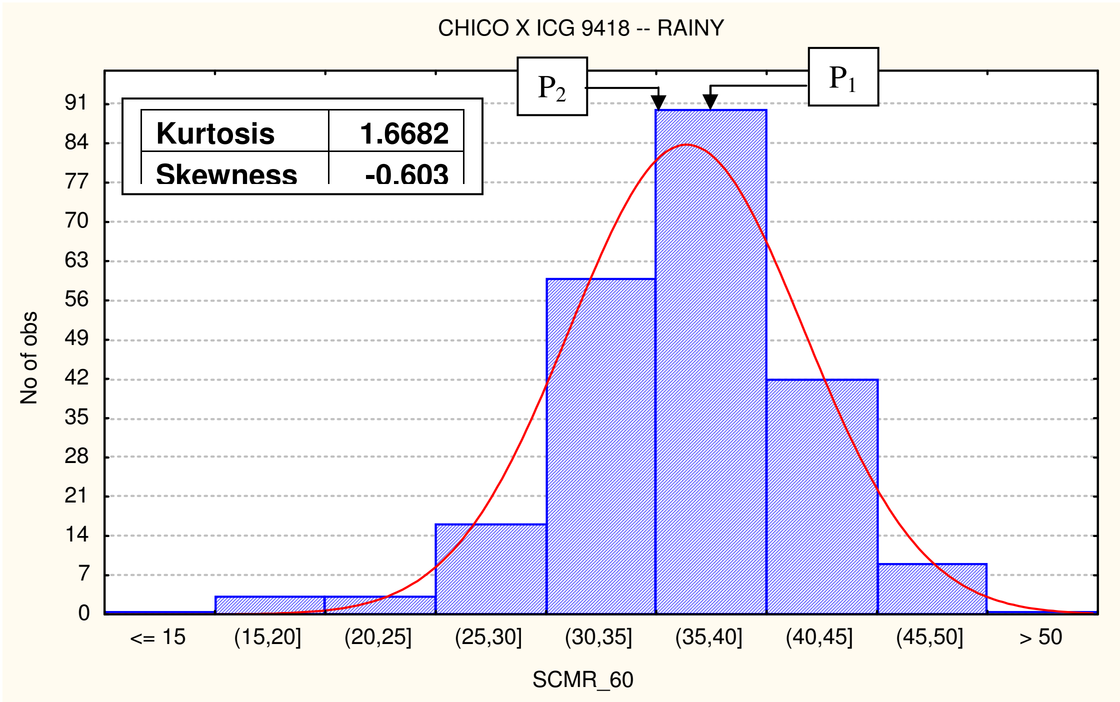

Fig 5: Distribution of F_2 of Chico × ICG 9418 cross for SCMR at 60 days after sowing during rainy season

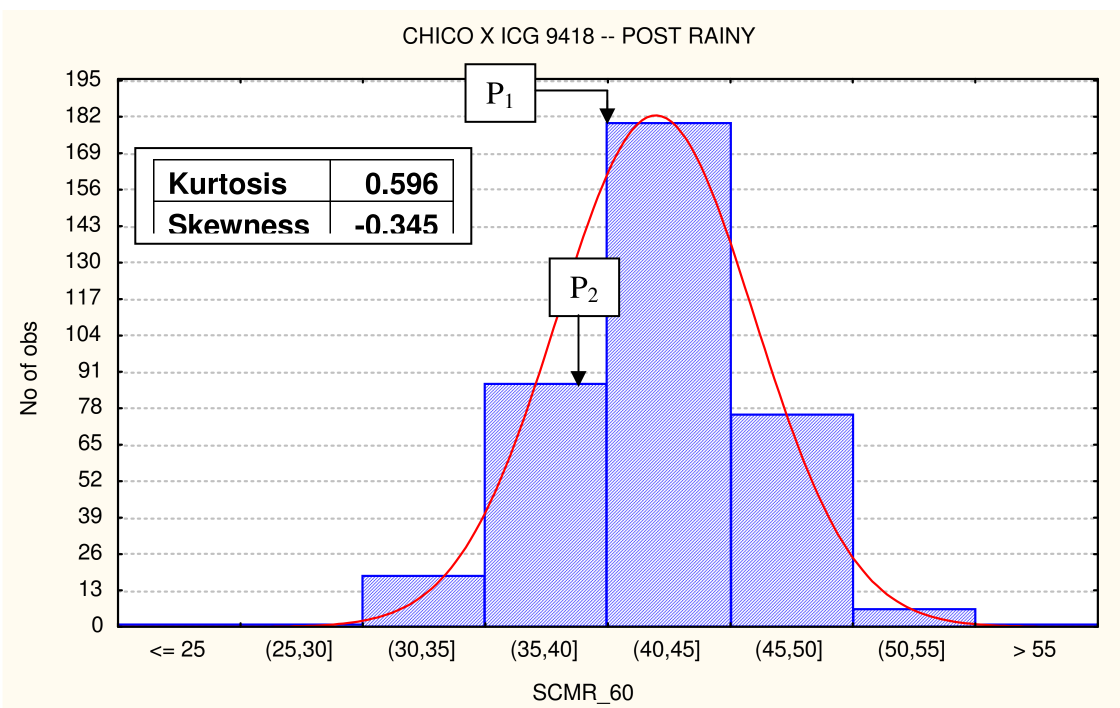

Fig 6: Distribution of F_2 of Chico × ICG 9418 cross for SCMR at 60 days after sowing during post rainy season

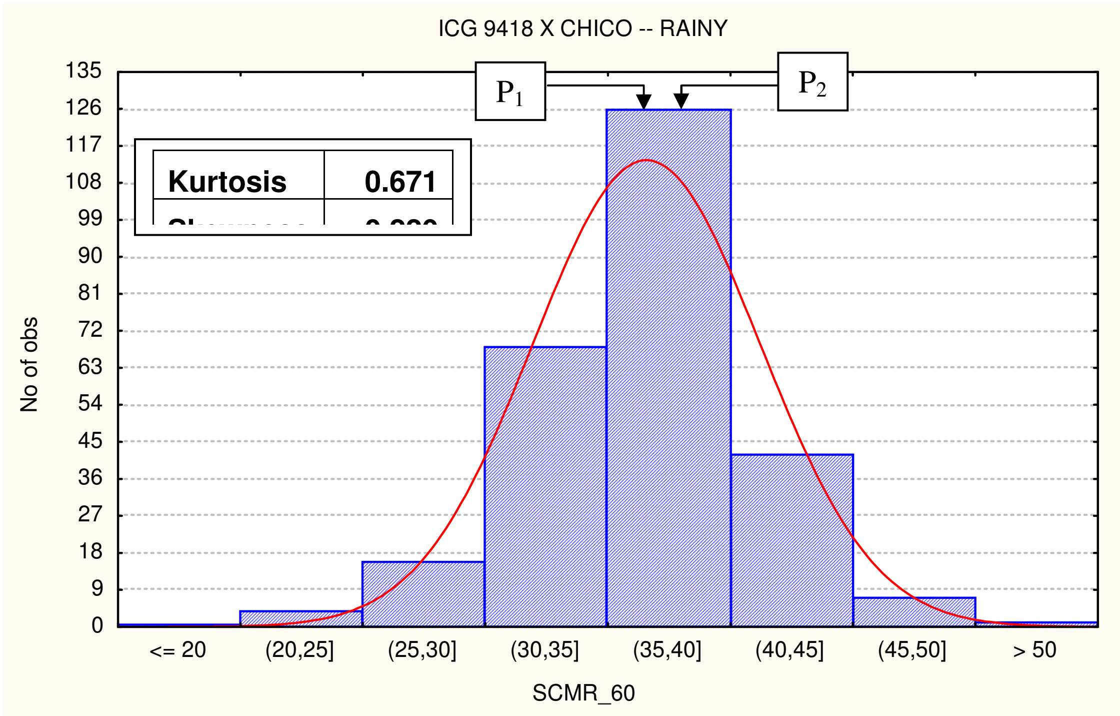

Fig 7: Distribution of F_2 of ICG 9418 × Chico cross for SCMR at 60 days after sowing during rainy season

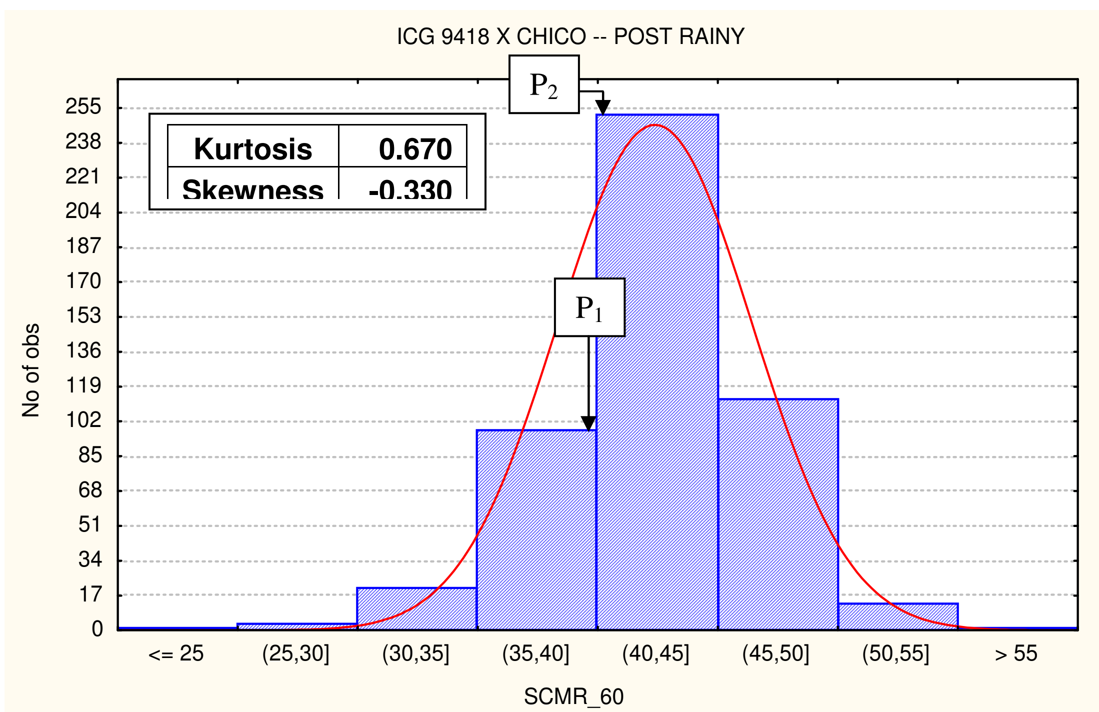

Fig 8: Distribution of F_2 of ICG 9418 × Chico cross for SCMR at 60 days after sowing during post rainy season

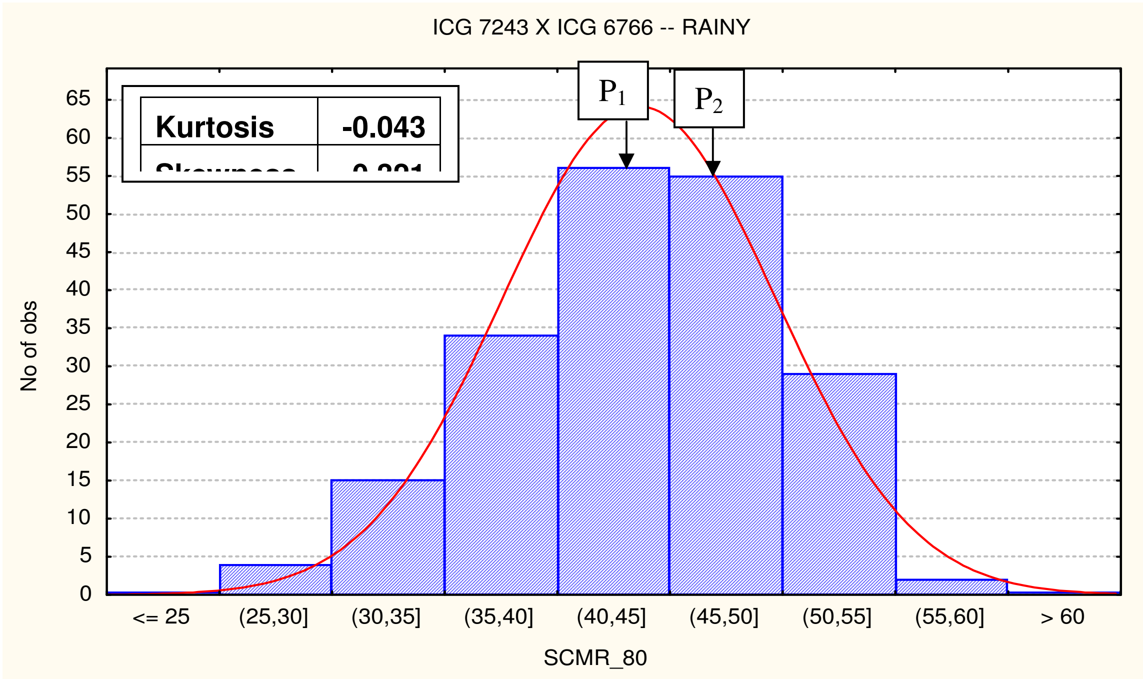

Fig 9: Distribution of F_2 of ICG 7243 × ICG 6766 cross for SCMR at 80 days after sowing during rainy season

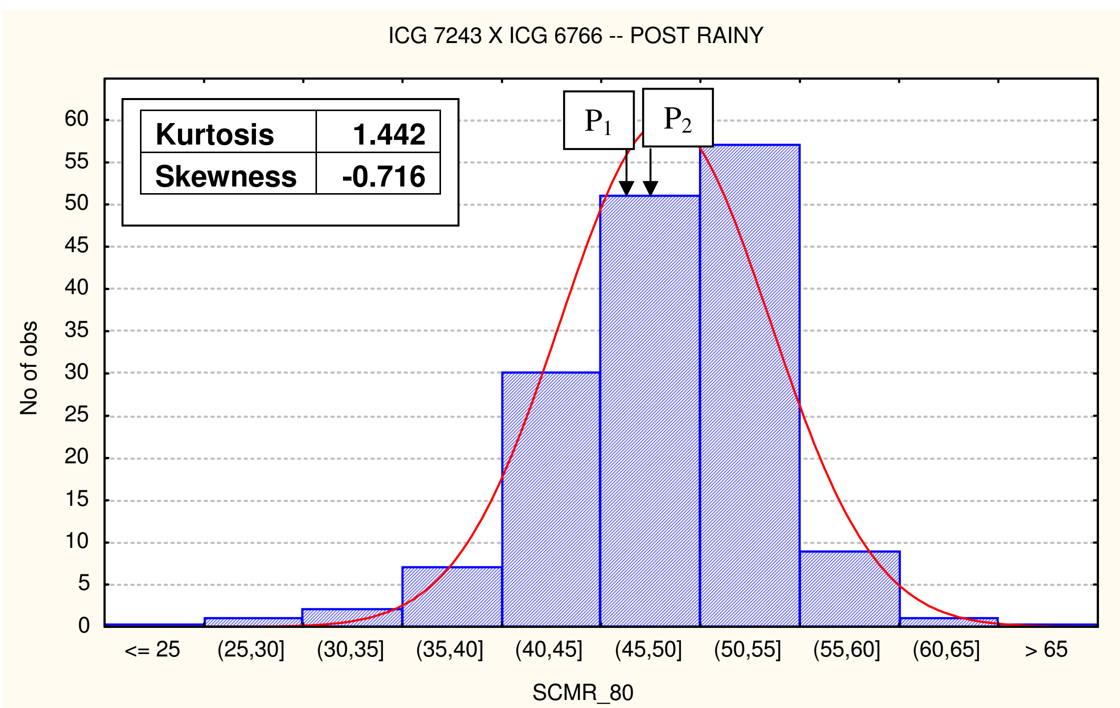

Fig 10: Distribution of F_2 of ICG7243 × ICG 6766 cross for SCMR at 80 days after sowing during post rainy season

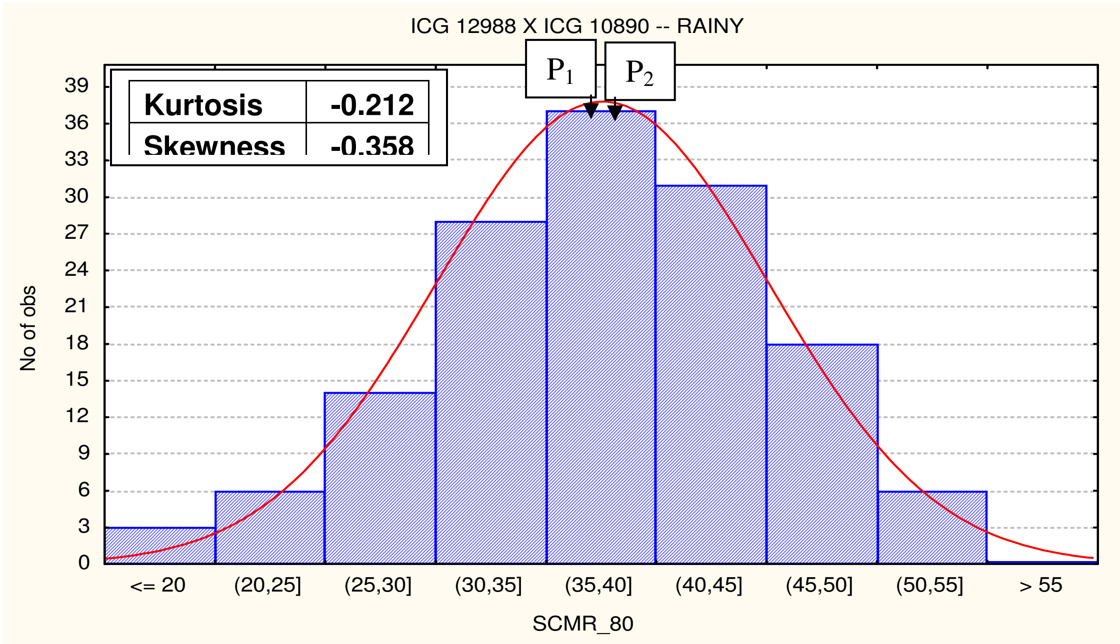

Fig 11: Distribution of F_2 of ICG 12988 × ICG 10890 cross for SCMR at 80 days after sowing during rainy season

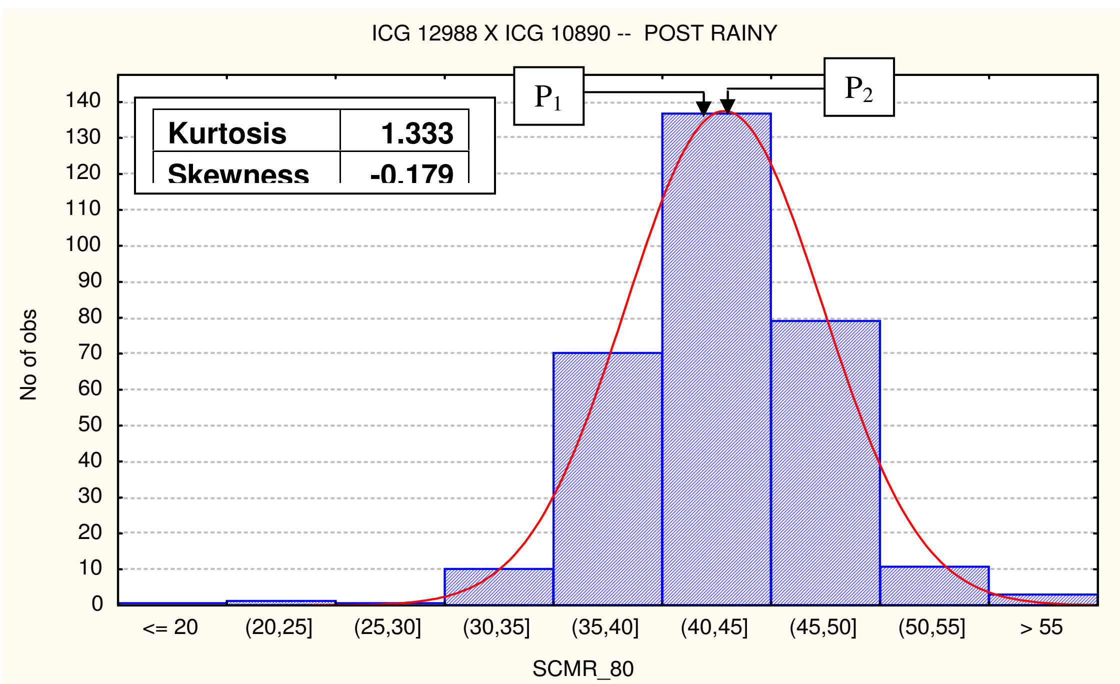

Fig 12: Distribution of F_2 of ICG 12988 × ICG 10890 cross for SCMR at 80 days after sowing during post rainy season

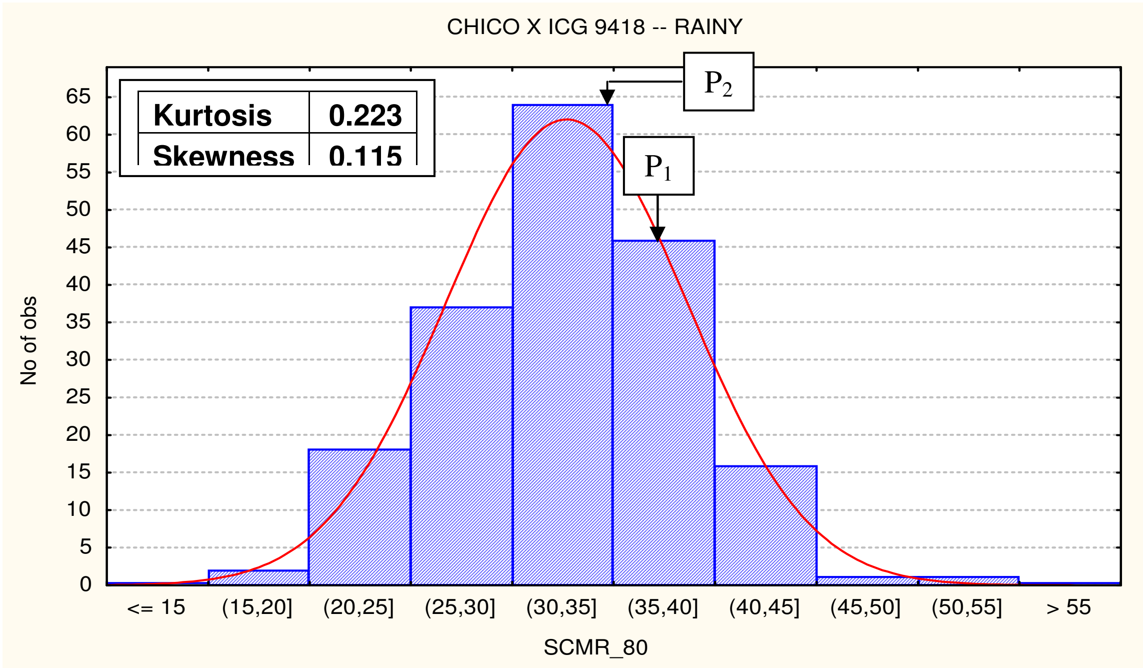

Fig 13: Distribution of F_2 of Chico × ICG 9418 cross for SCMR at 80 days after sowing during rainy season

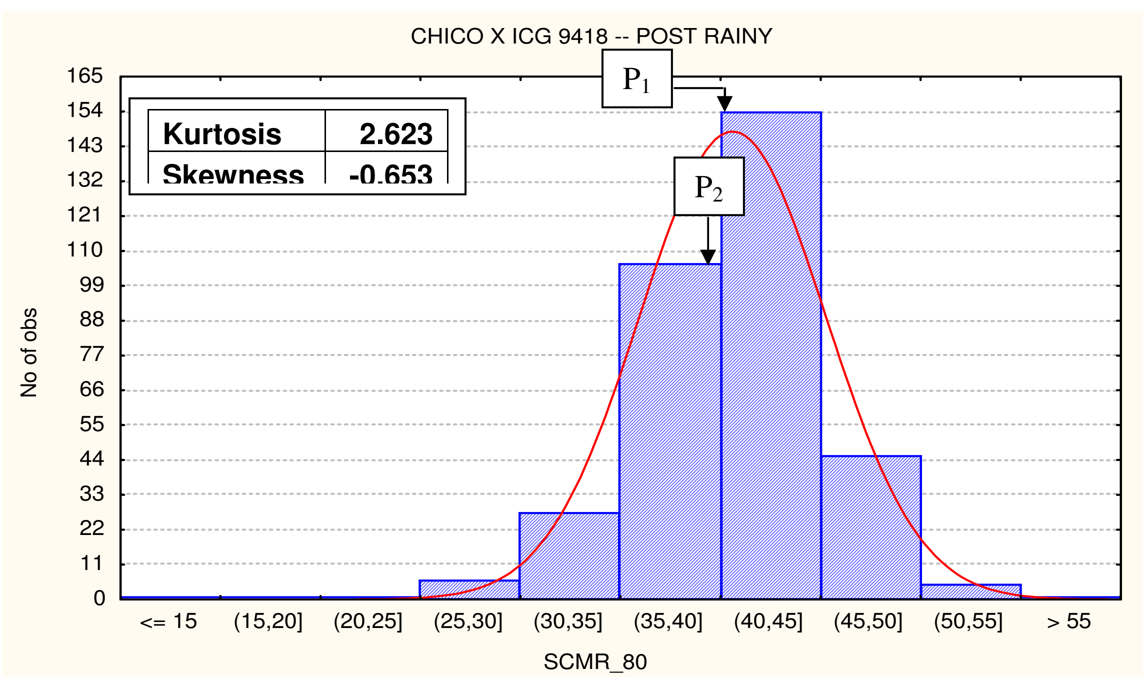

Fig 14: Distribution of F_2 of Chico × ICG 9418 cross for SCMR at 80 days after sowing during post rainy season

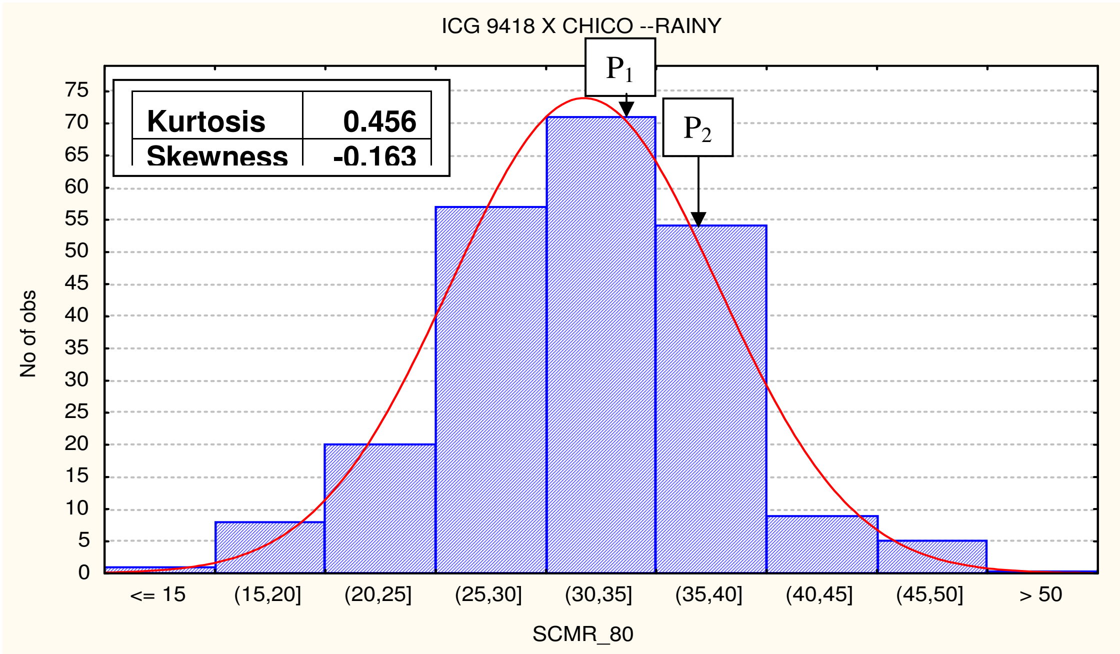

Fig 15: Distribution of F_2 of ICG 9418 × Chico cross for SCMR at 80 days after sowing during rainy season

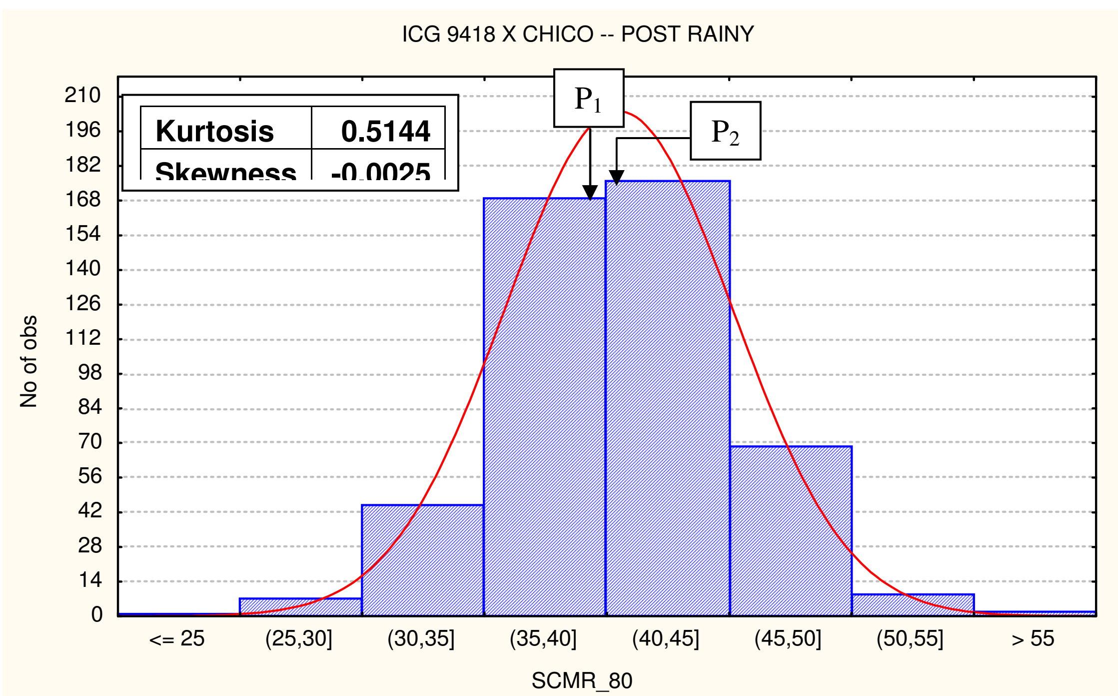

Fig 16: Distribution of F_2 of ICG 9418 × Chico cross for SCMR at 80 days after sowing during post rainy season

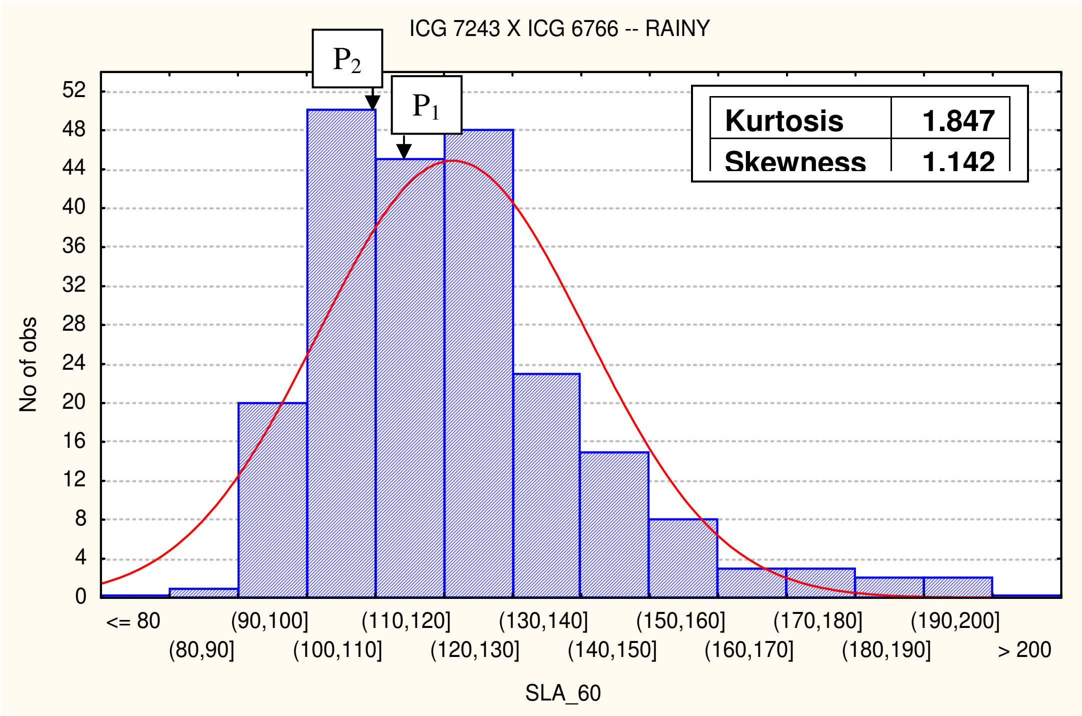

Fig 17: Distribution of F_2 of ICG 7243 × ICG 6766 cross for SLA at 60 days after sowing during rainy season

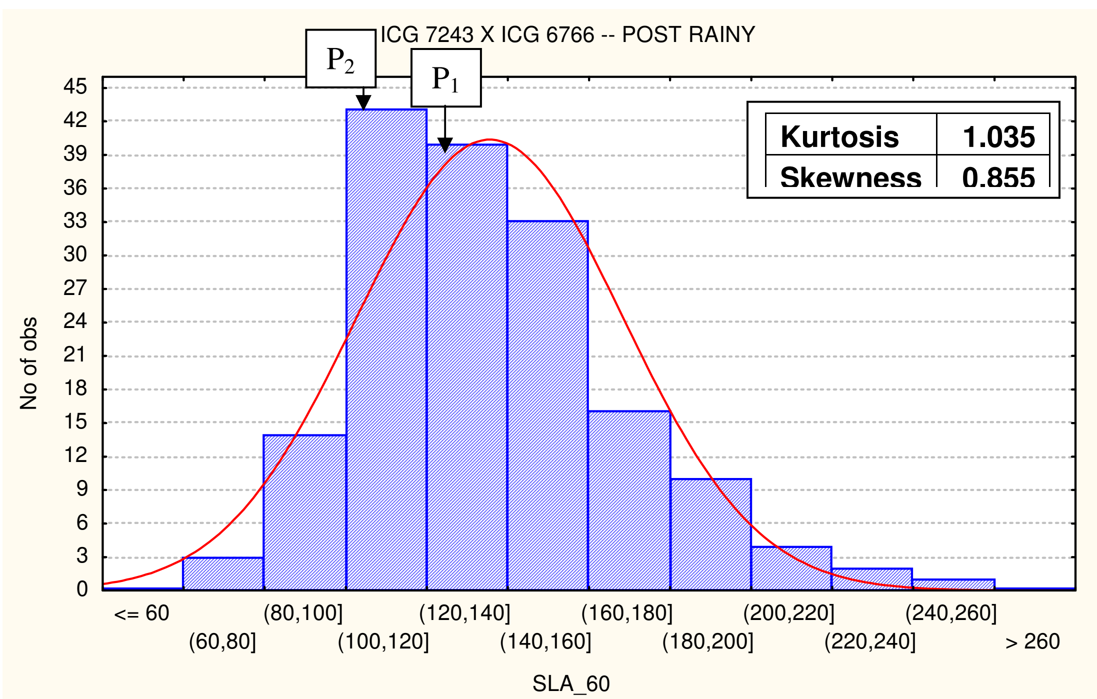

Fig 18: Distribution of F_2 of ICG 12988 × ICG 10890 cross for SLA at 60 days after sowing during post rainy season

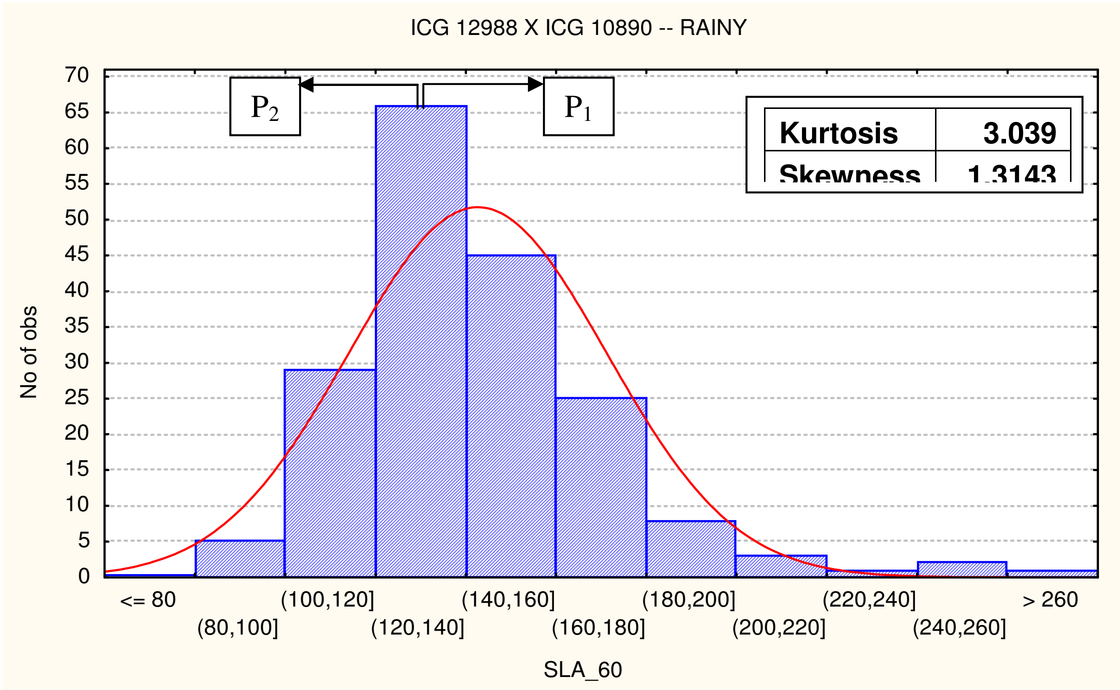

Fig 19: Distribution of F_2 of ICG 12988 × ICG 10890 cross for SLA at 60 days after sowing during rainy season

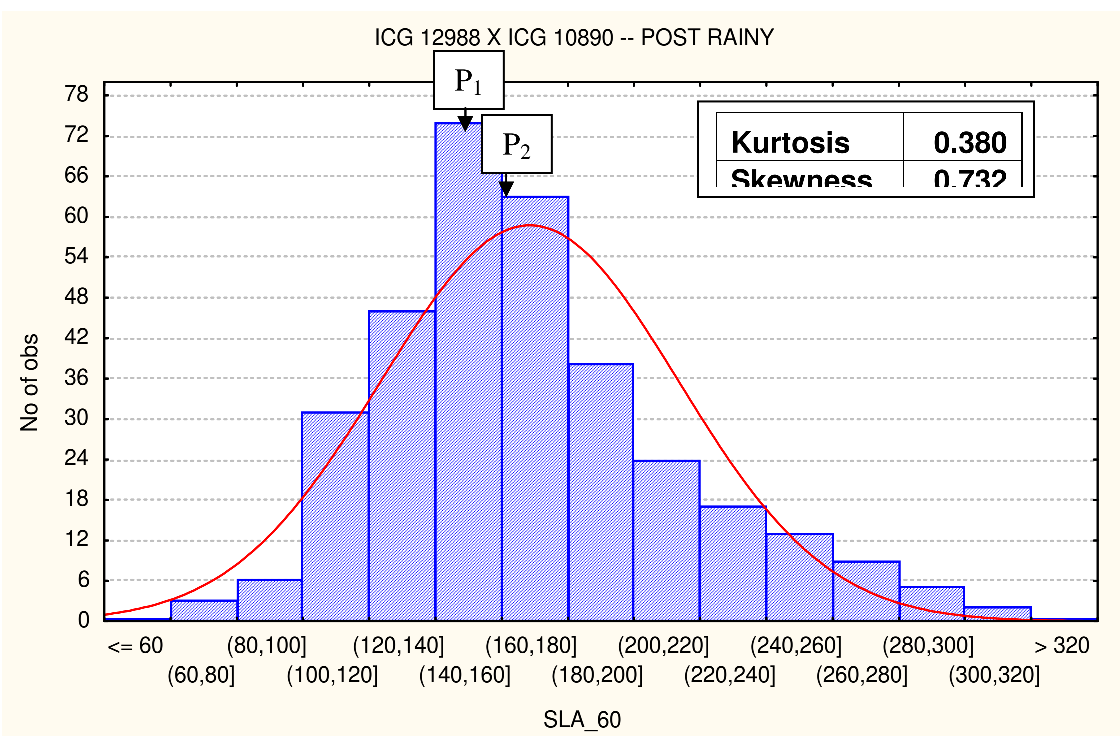

Fig 20: Distribution of F_2 of ICG 12988 × ICG 10890 cross for SLA at 60 days after sowing during post rainy season

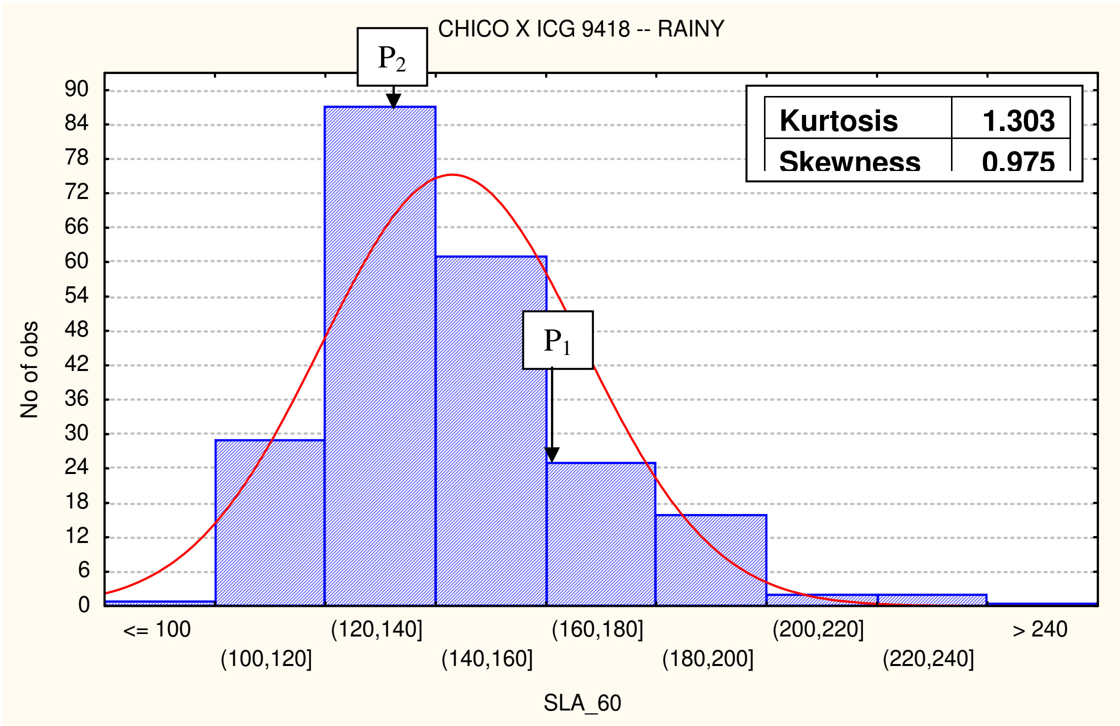

Fig 21: Distribution of F_2 of Chico × ICG 9418 cross for SLA at 60 days after sowing during rainy season

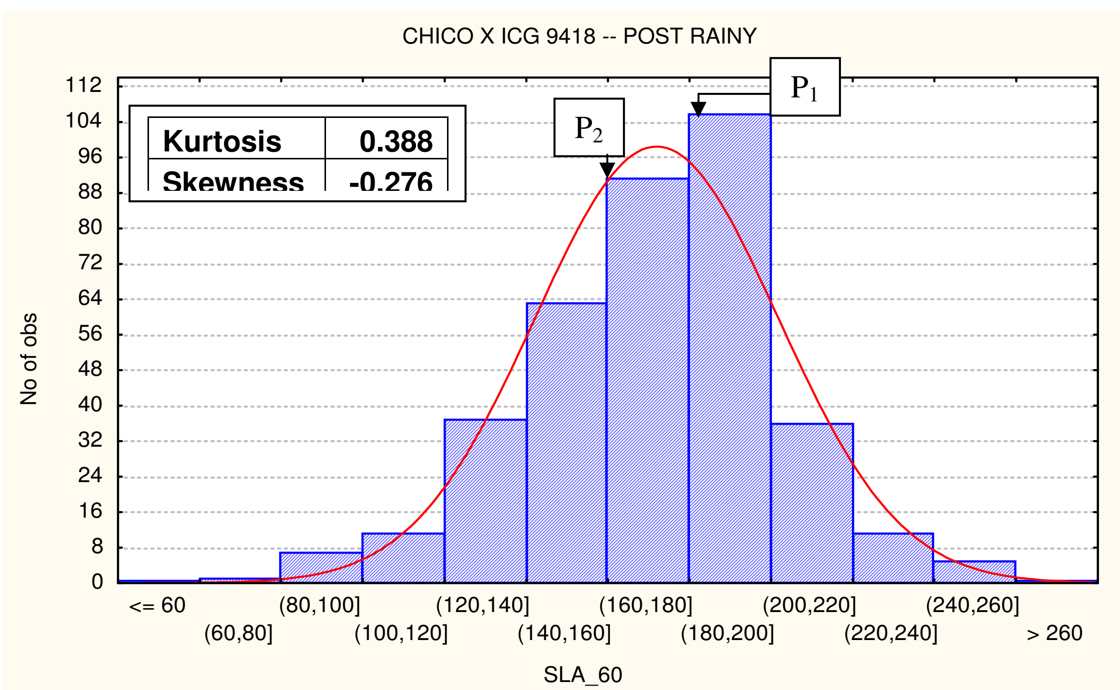

Fig 22: Distribution of F_2 of Chico × ICG 9418 cross for SLA at 60 days after sowing during post rainy season

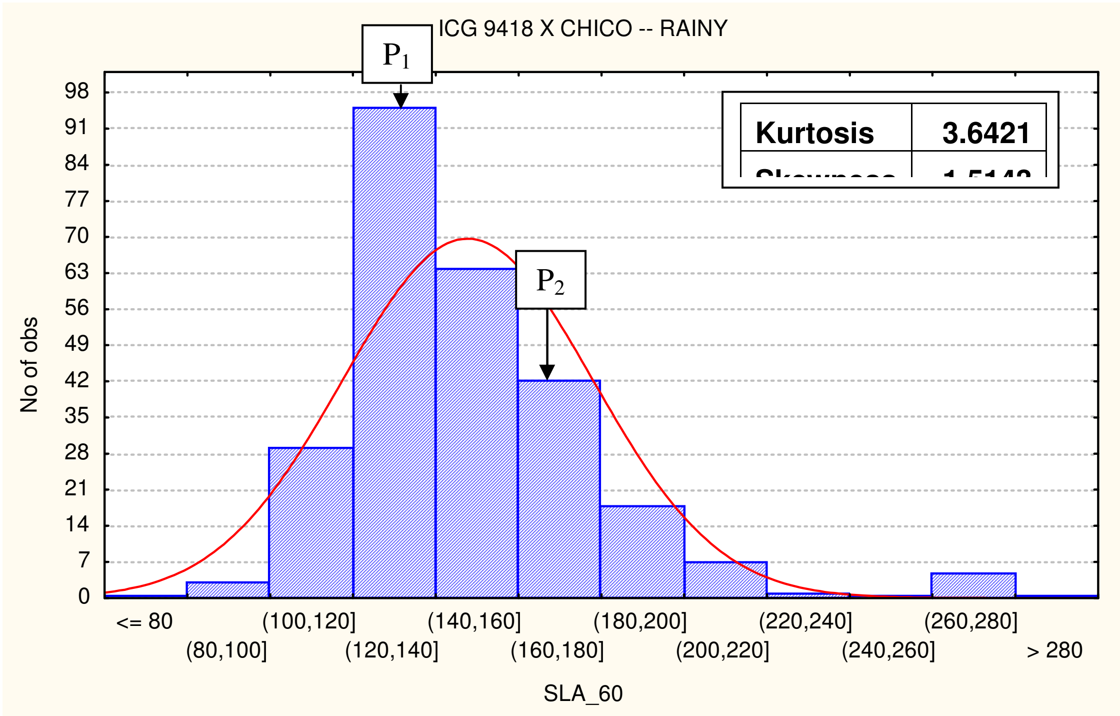

Fig 23: Distribution of F_2 of ICG 9418 × Chico cross for SLA at 60 days after sowing during rainy season

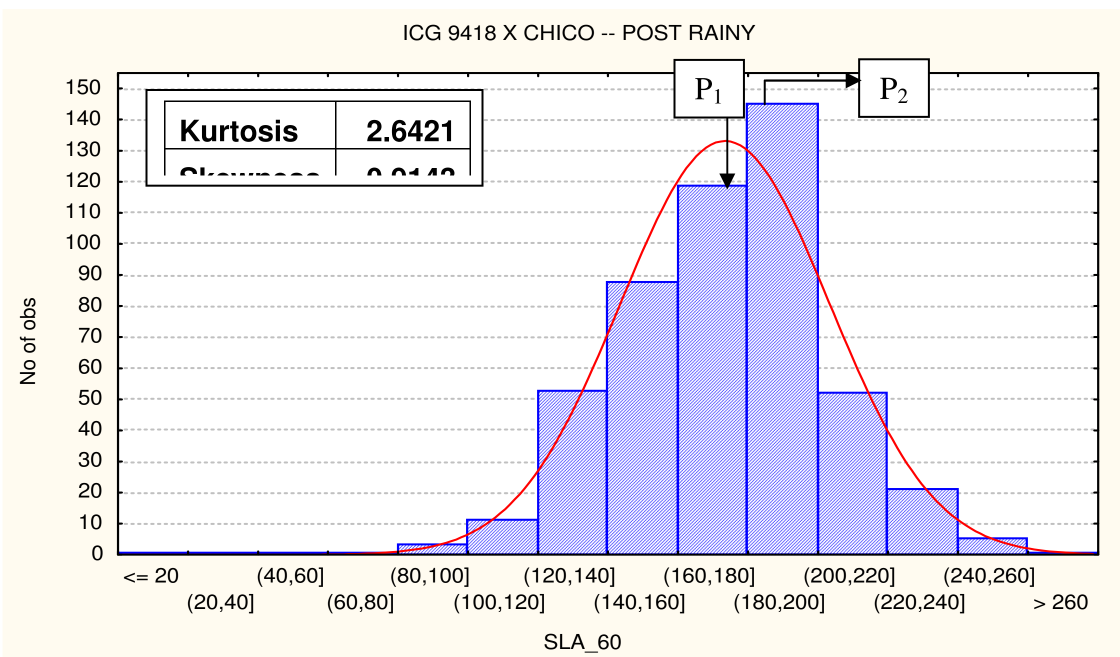

Fig 24: Distribution of F_2 of ICG 9418 × Chico cross for SLA at 60 days after sowing during post rainy season

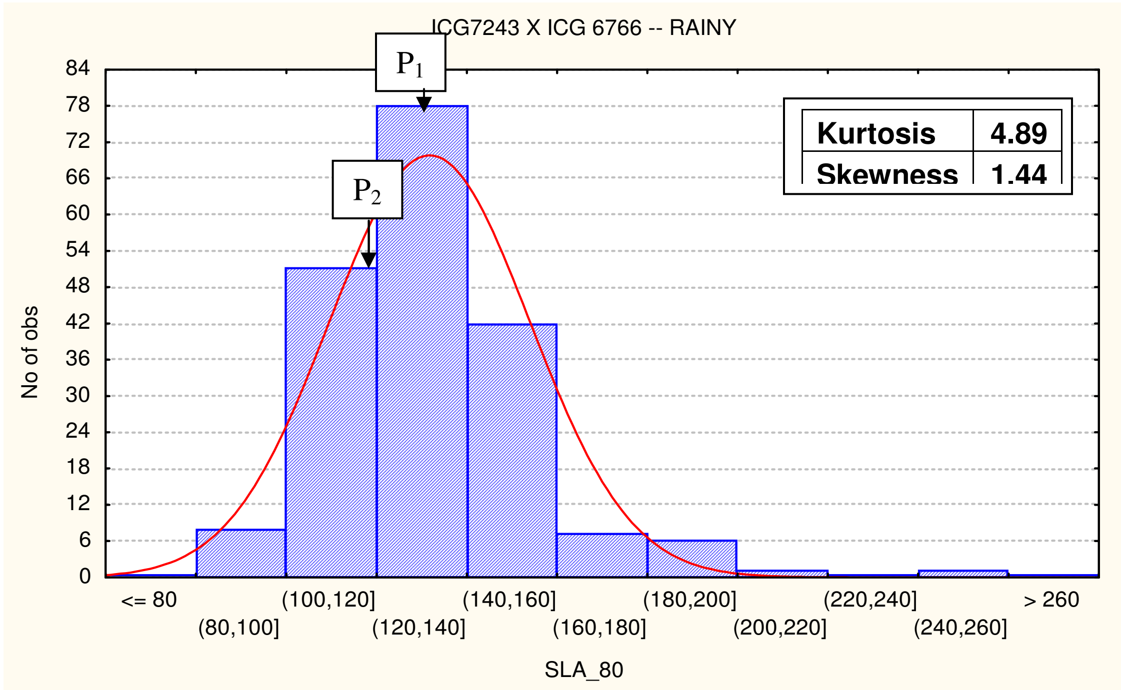

Fig 25: Distribution of F_2 of ICG 7243 × ICG 6766 cross for SLA at 80 days after sowing during rainy season

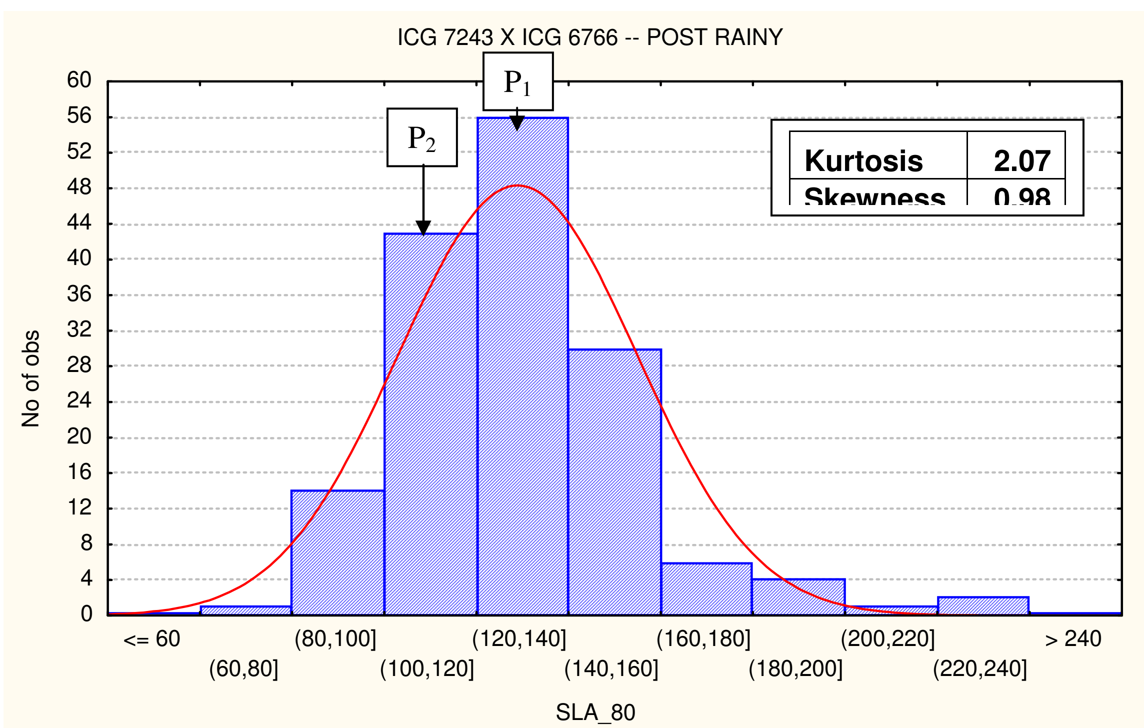

Fig 26: Distribution of F_2 of ICG 7243 × ICG 6766 cross for SLA at 80 days after sowing during post rainy season

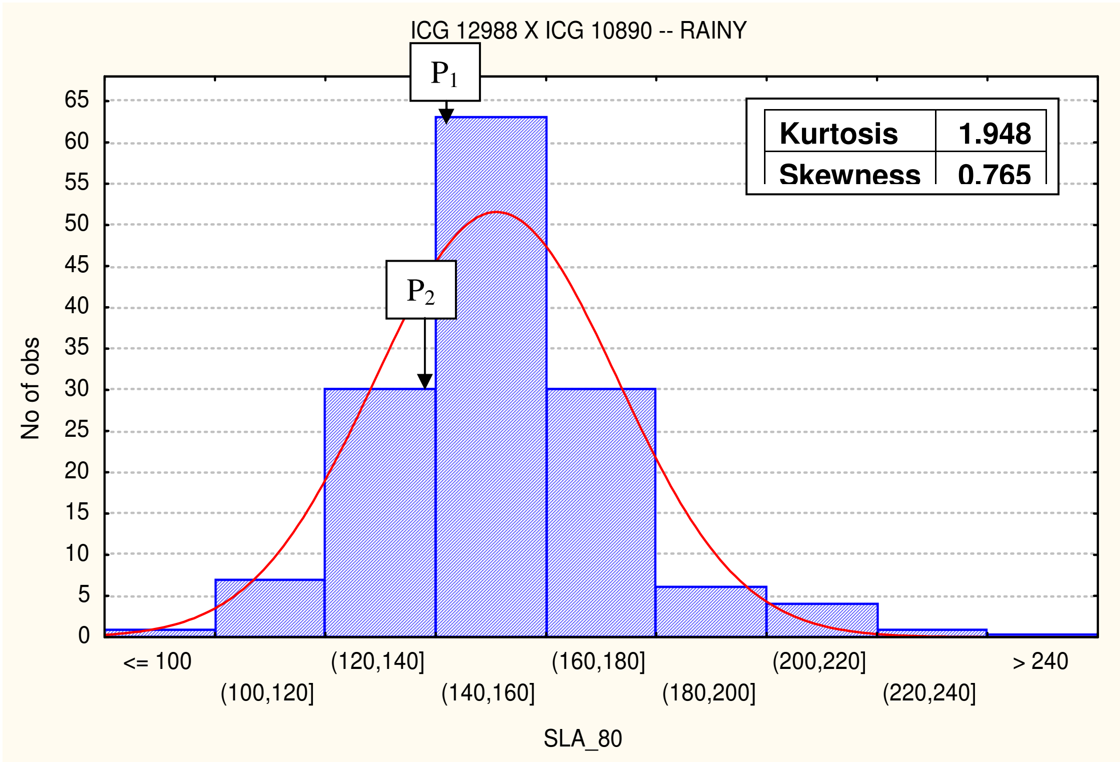

Fig 27: Distribution of F_2 of ICG 12988 × ICG 10890 cross for SLA at 80 days after sowing during rainy season

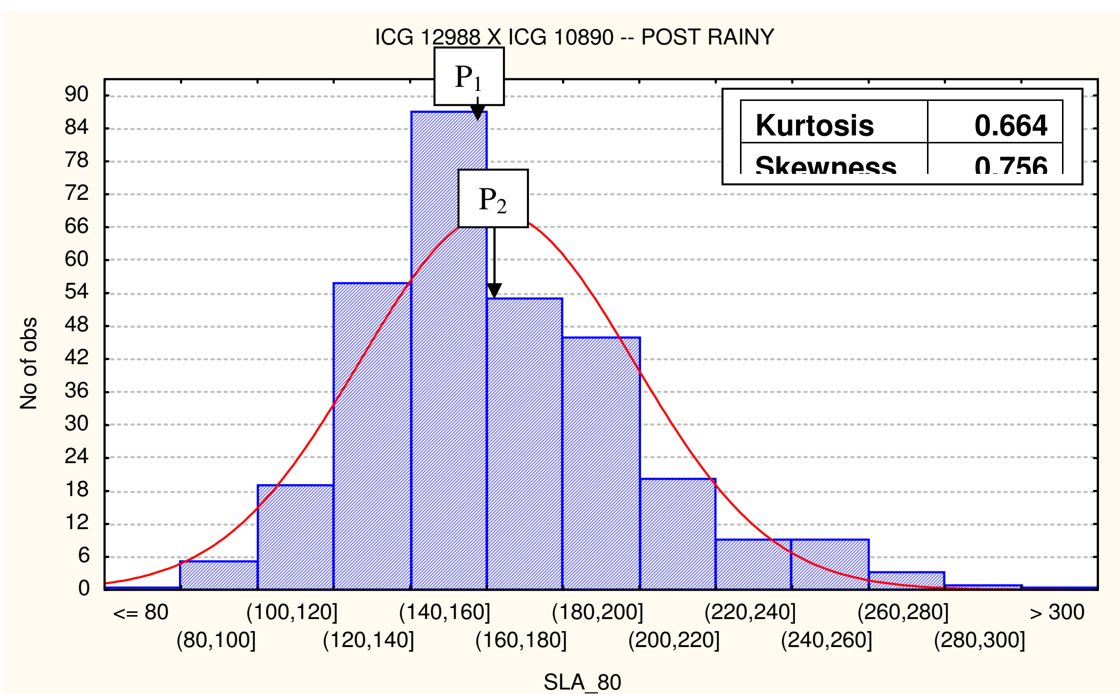

Fig 28: Distribution of F_2 of ICG 12988 × ICG 10890 cross for SLA at 80 days after sowing during post rainy season

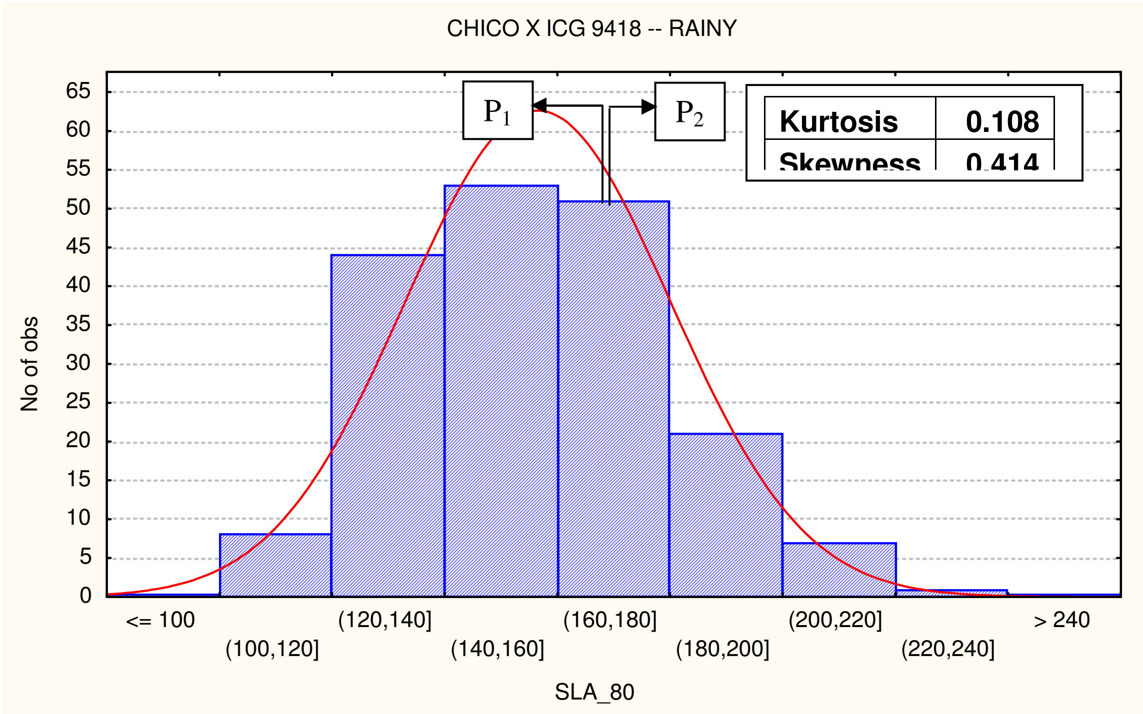

Fig 29: Distribution of F_2 of Chico × ICG 9418 cross for SLA at 80 days after sowing during rainy season

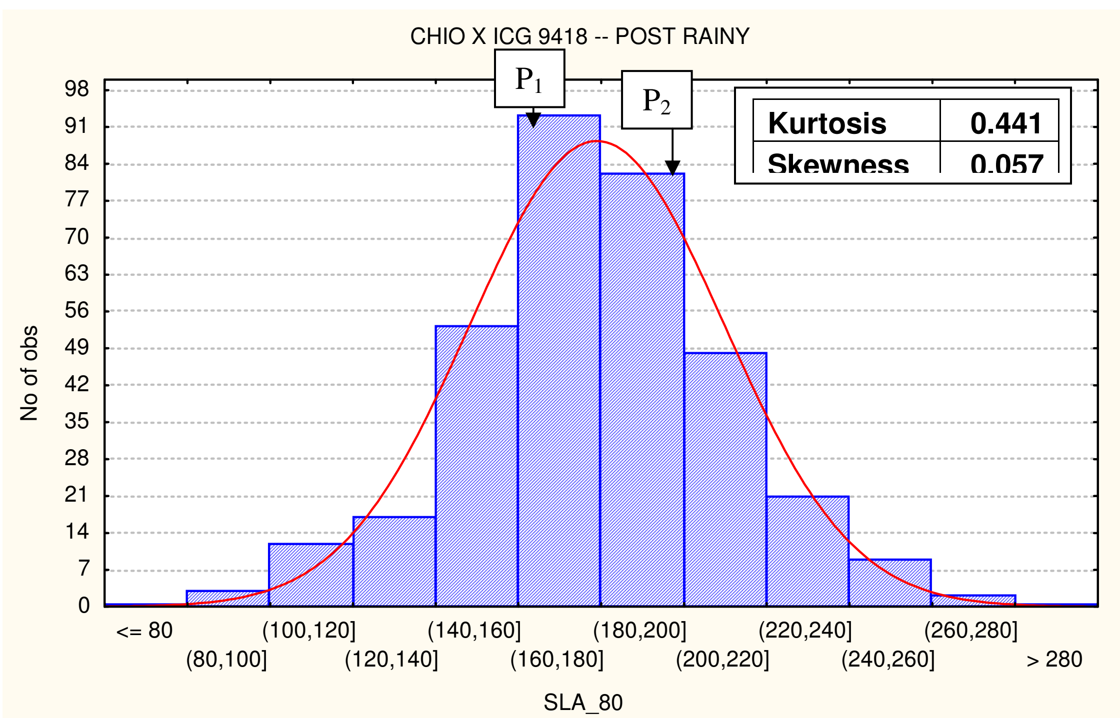

Fig 30: Distribution of F_2 of Chico × ICG 9418 cross for SLA at 80 days after sowing during post rainy season

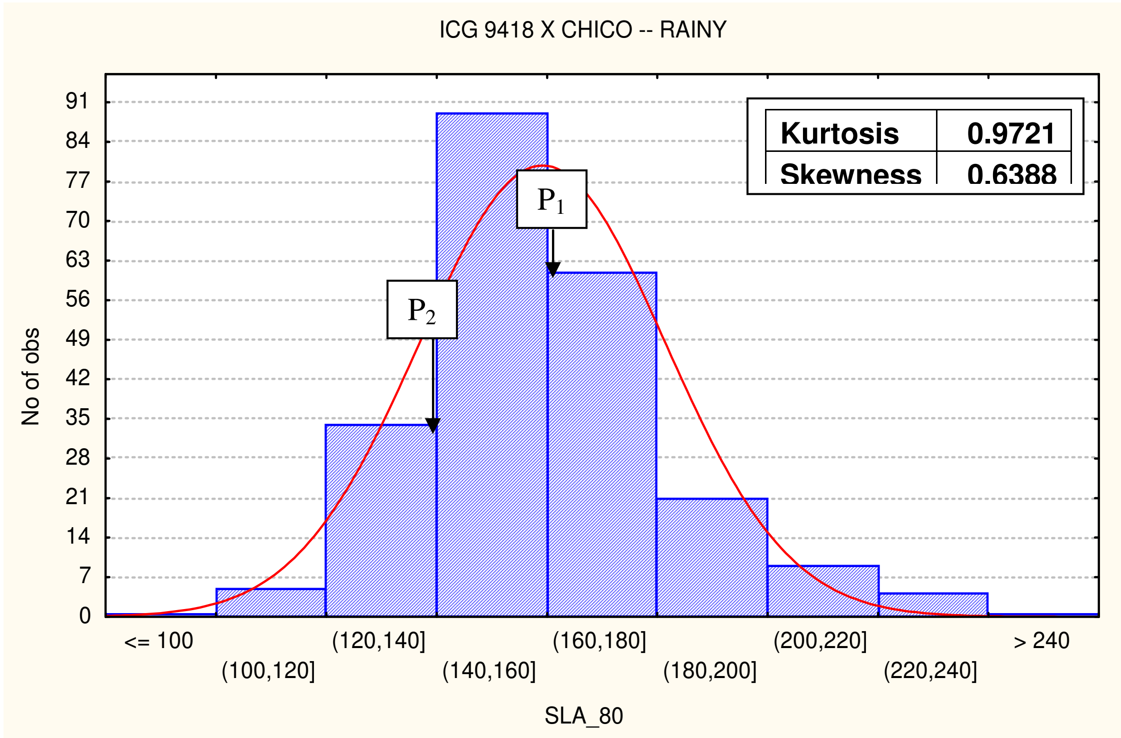

Fig 31: Distribution of F_2 of ICG 9418 × Chico cross for SLA at 80 days after sowing during rainy season

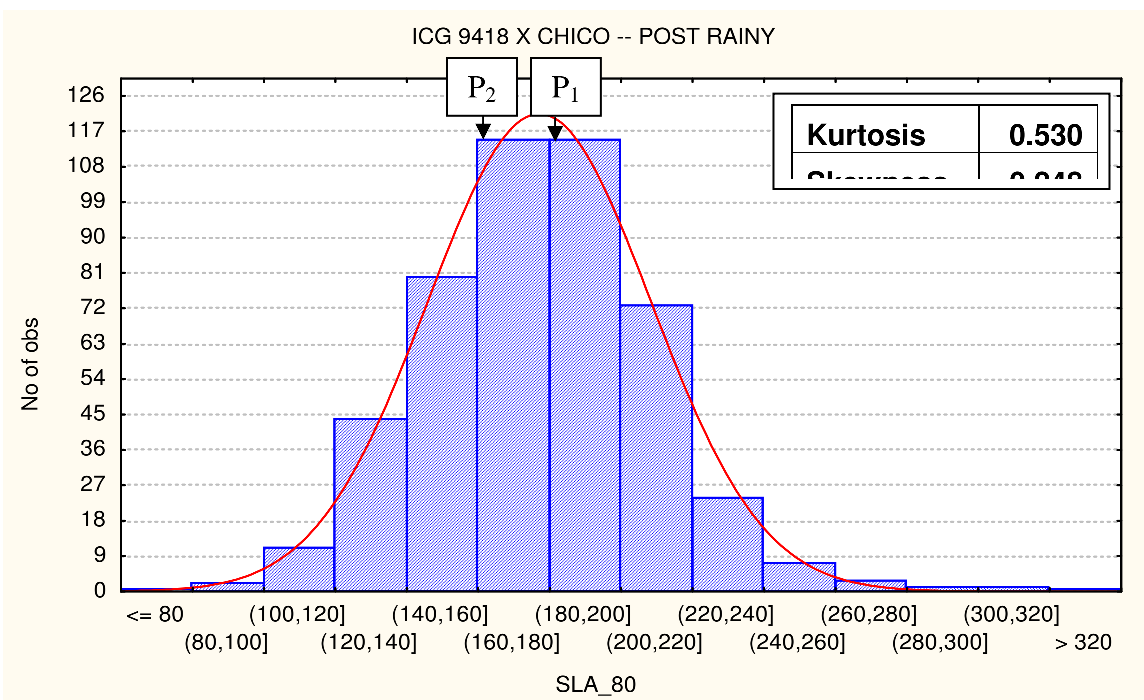

Fig 32: Distribution of F_2 of ICG 9418 × Chico cross for SLA at 80 days after sowing during post rainy season

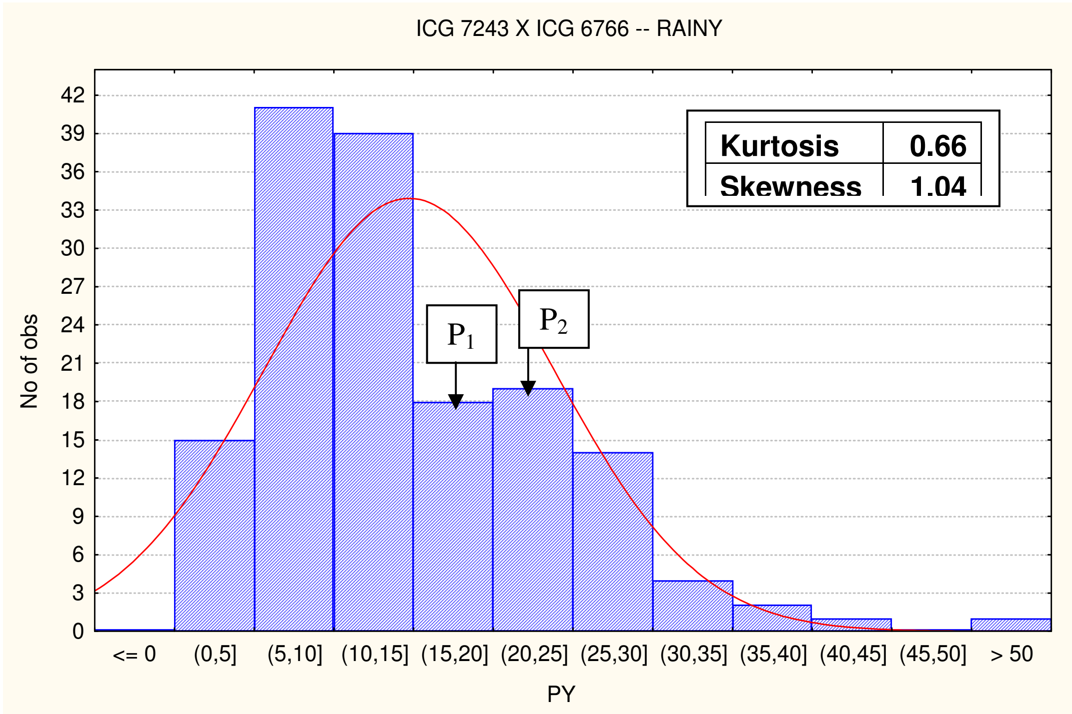

Fig 33: Distribution of F_2 of ICG 7243 × ICG6766 cross for pod yield during rainy season

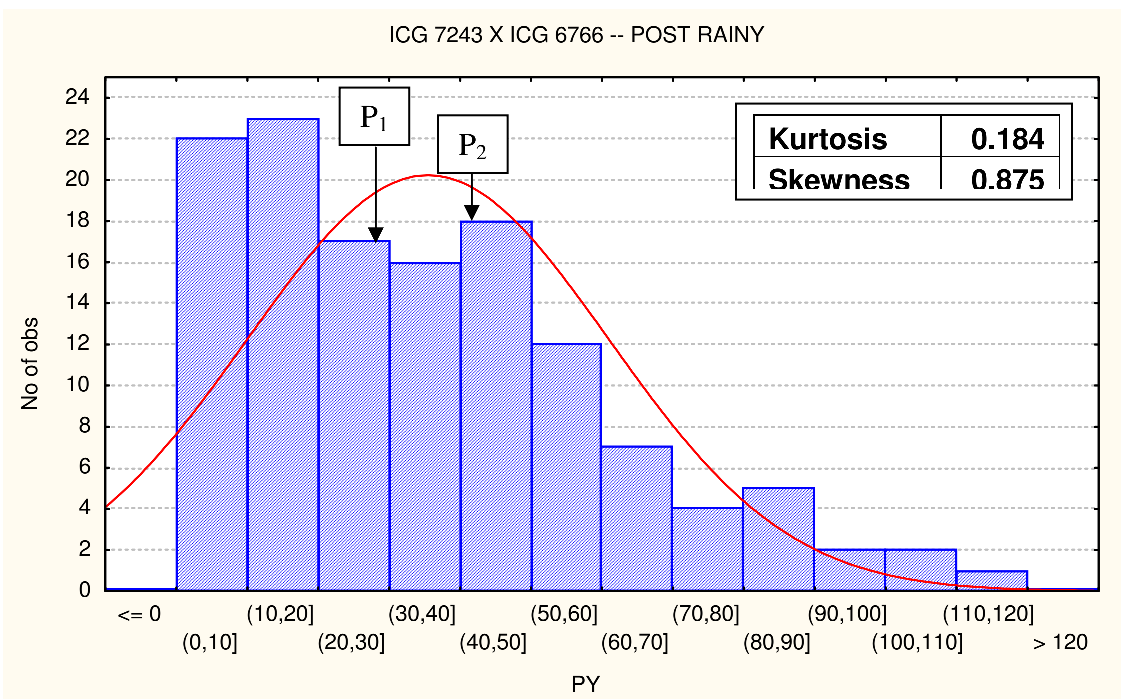

Fig 34: Distribution of F_2 of ICG 7243 × ICG 6766 cross for pod yield during post rainy season

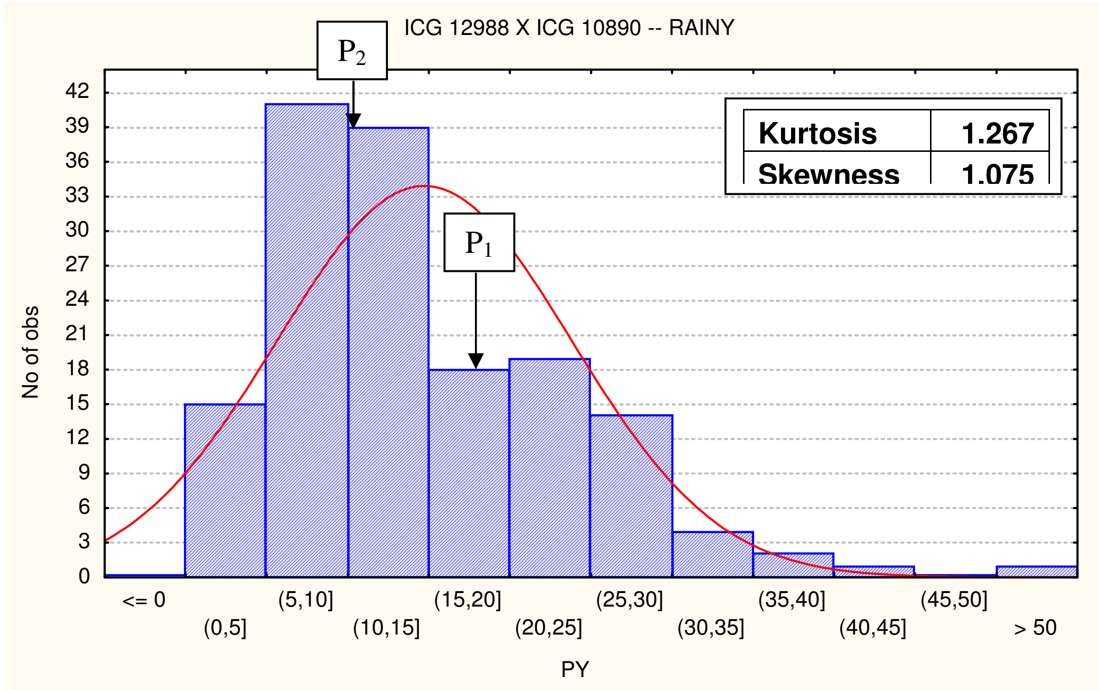

Fig 35: Distribution of F_2 of ICG 12988 × ICG 10890 cross for pod yield during rainy season

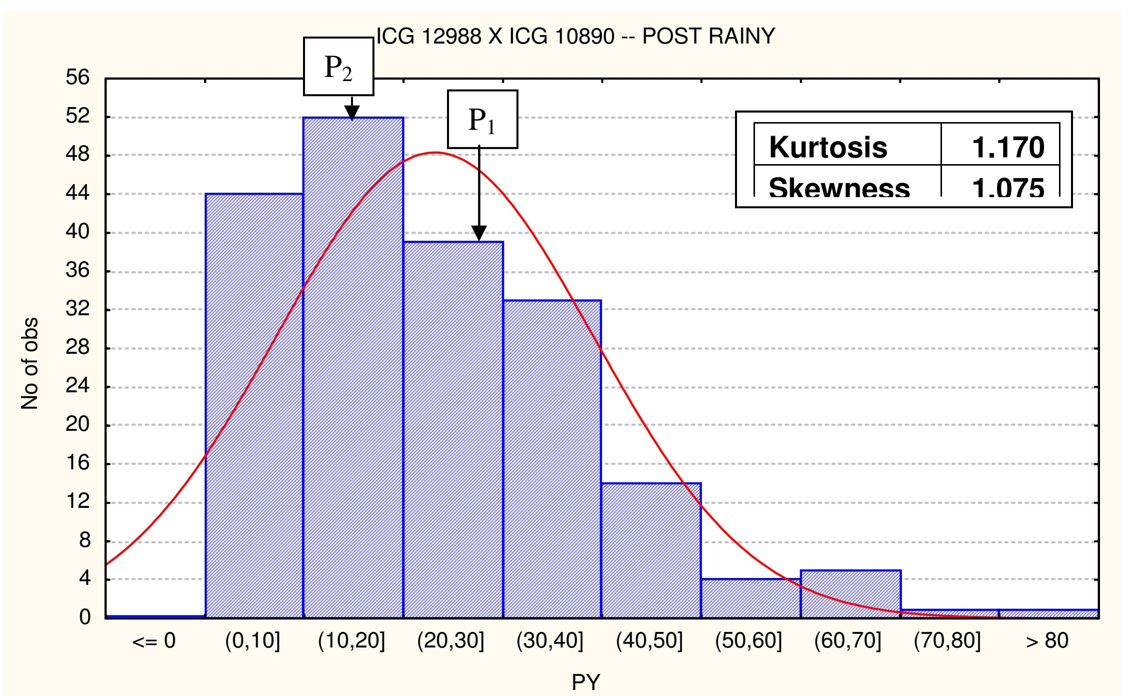

Fig 36: Distribution of F_2 of ICG 12988 × ICG 10890 cross for pod yield during post rainy season

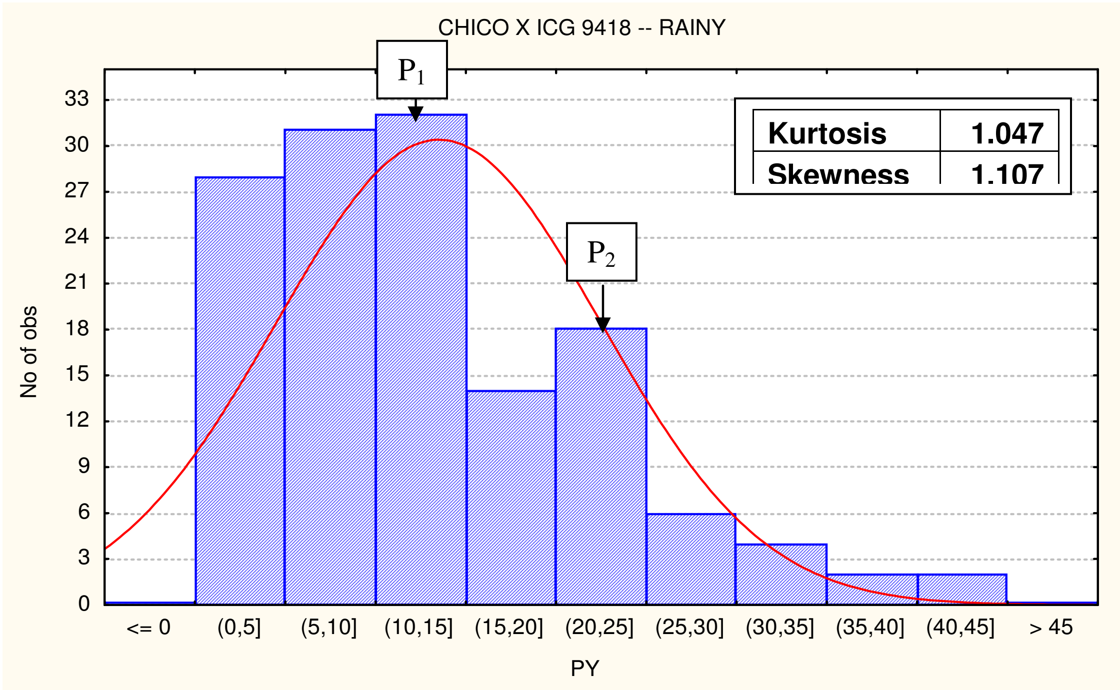

Fig 37: Distribution of F_2 of Chico × ICG 9418 cross for pod yield during rainy season

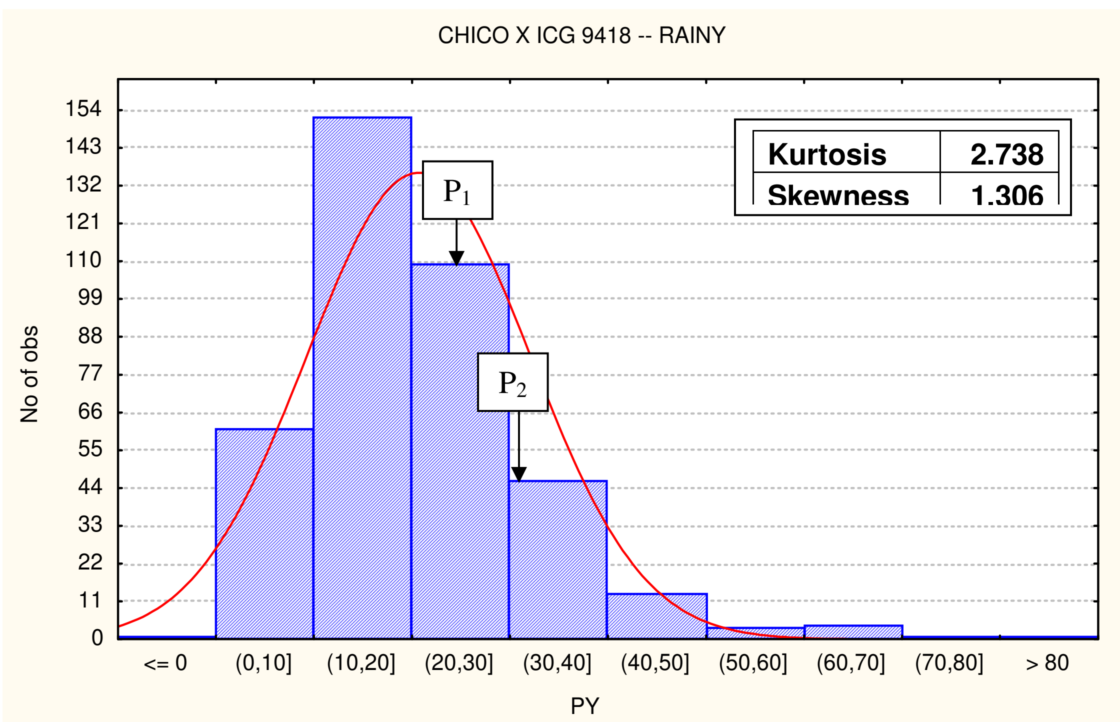

Fig 38: Distribution of F_2 of Chico × ICG 9418 cross for pod yield during post rainy season

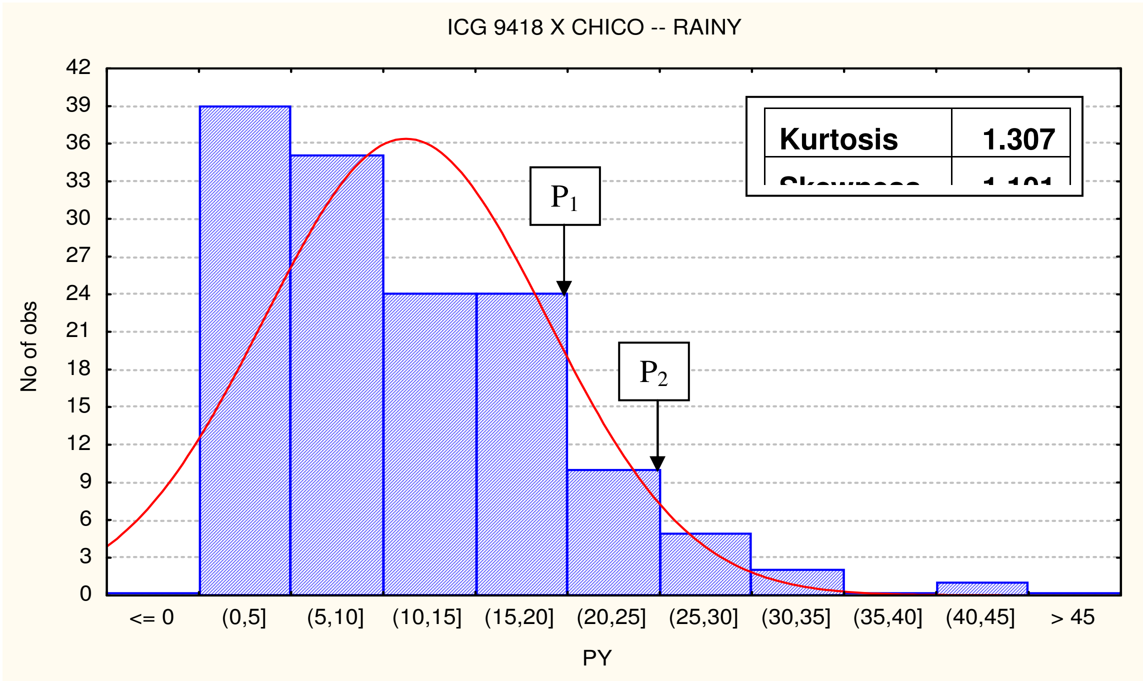

Fig 39: Distribution of F_2 of ICG 9418 × Chico cross for pod yield during rainy season

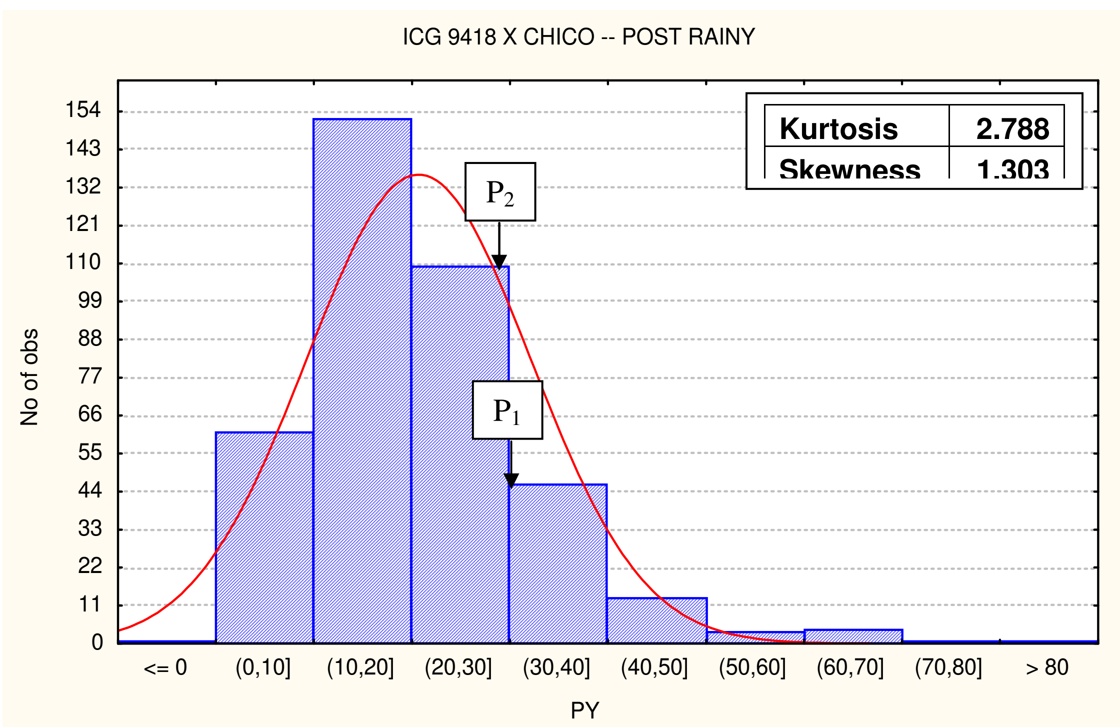

Fig 40: Distribution of F_2 of ICG 9418 × Chico cross for pod yield during post rainy season

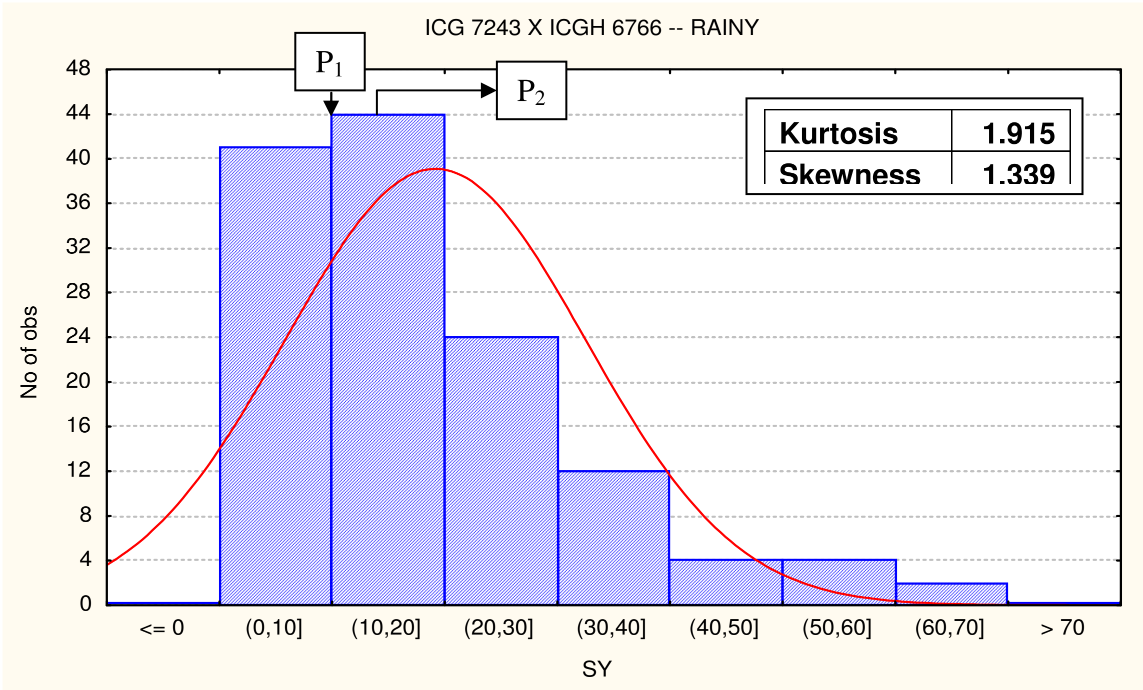

Fig 41: Distribution of F_2 of ICG 7243 × ICG 6766 cross for seed yield during rainy season

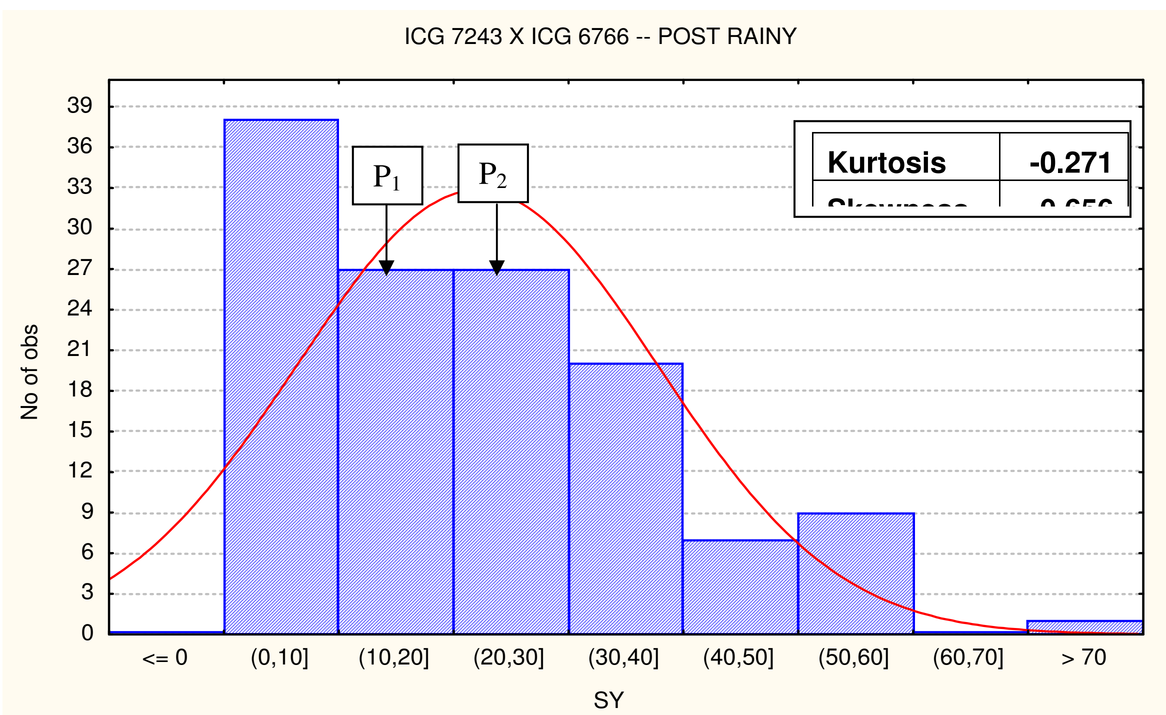

Fig 42: Distribution of F_2 of ICG 7243 × ICG 6766 cross for seed yield during post rainy season

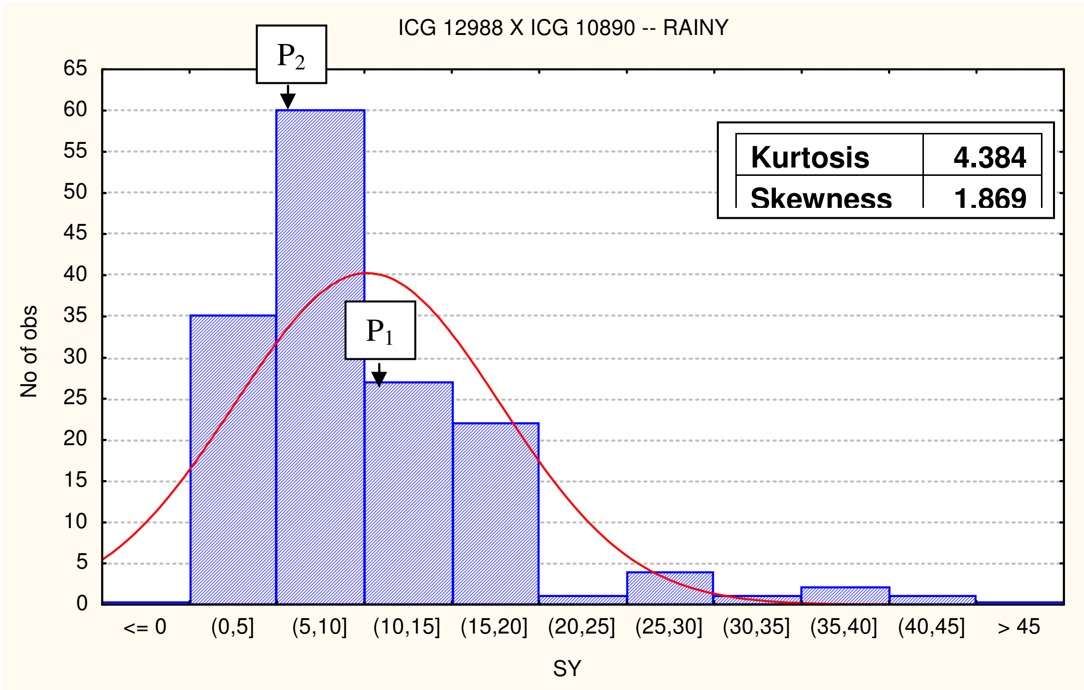

Fig 43: Distribution of F_2 of ICG 12988 × ICG10890 cross for seed yield during rainy season

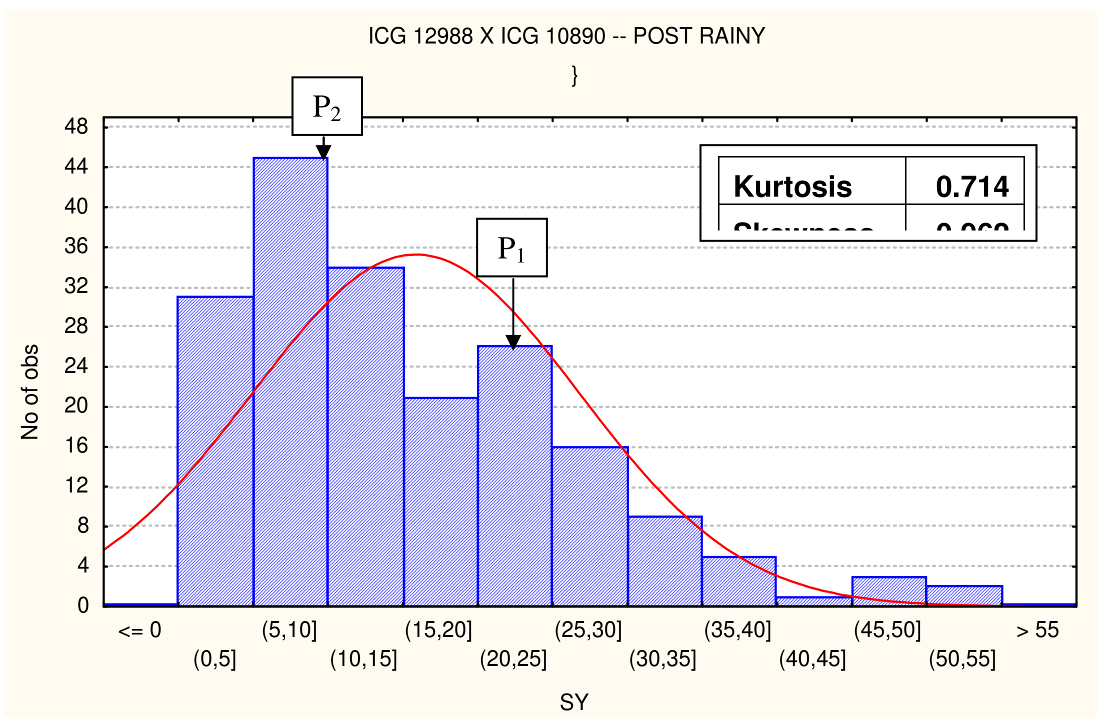

Fig 44: Distribution of F_2 of ICG 12988 × ICG 10890 cross for seed yield during post rainy season

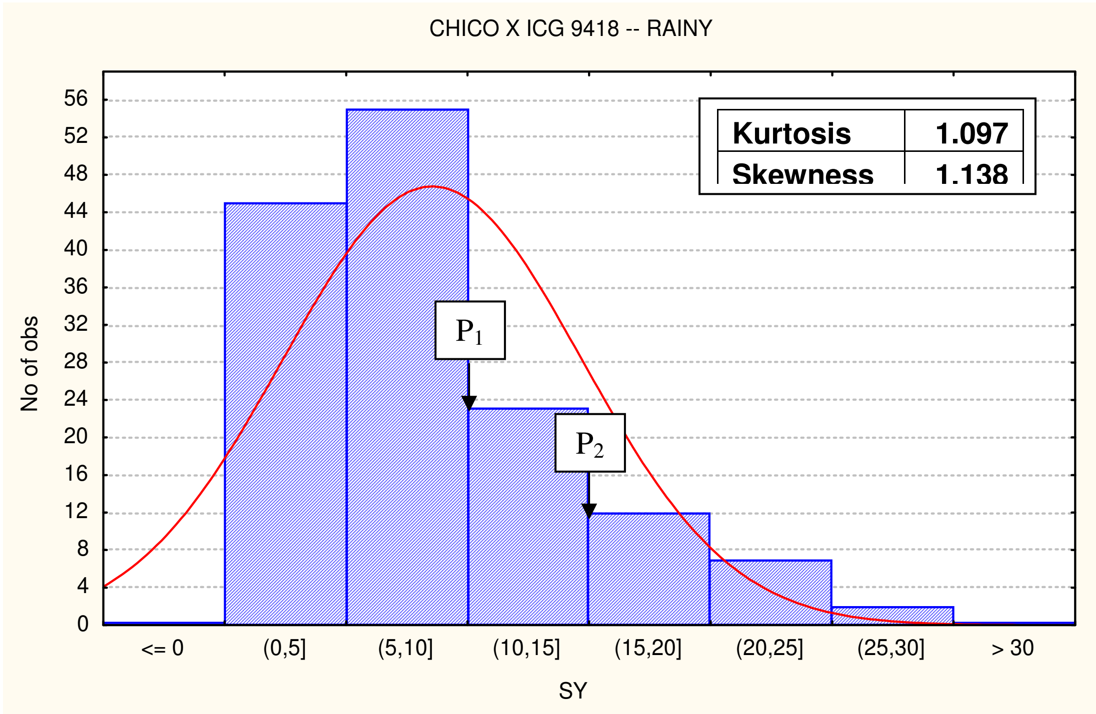

Fig 45: Distribution of F_2 of Chico × ICG 9418 cross for seed yield during rainy season

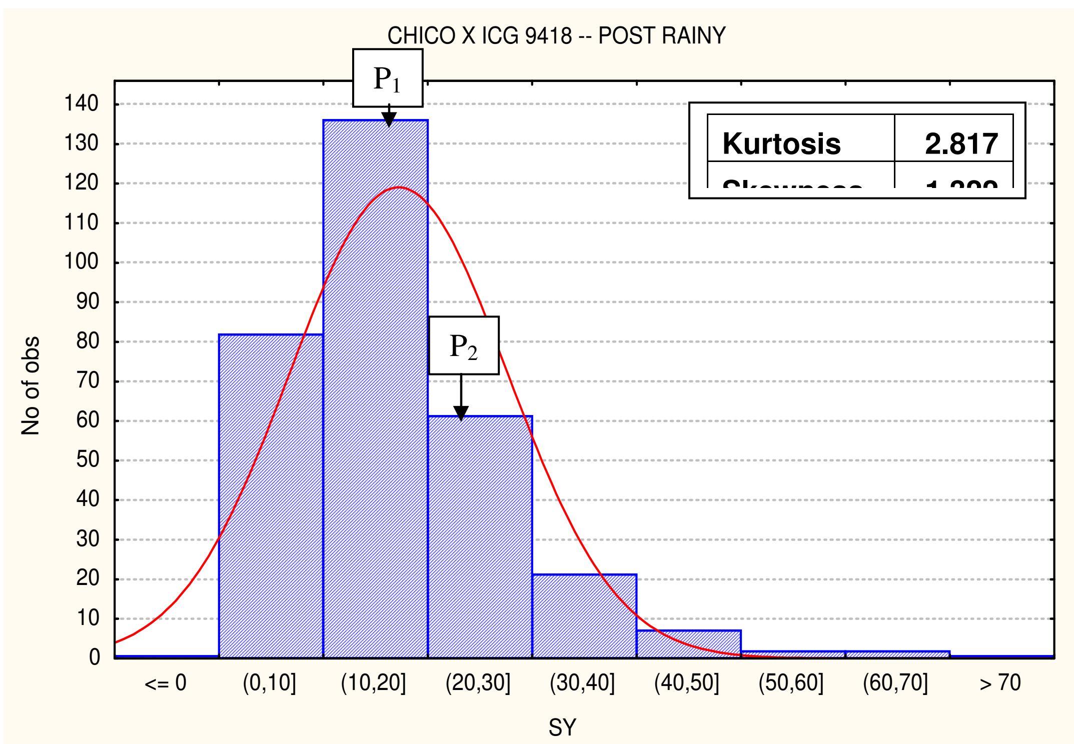

Fig 46: Distribution of F_2 of Chico × ICG 9418 cross for seed yield during post rainy season

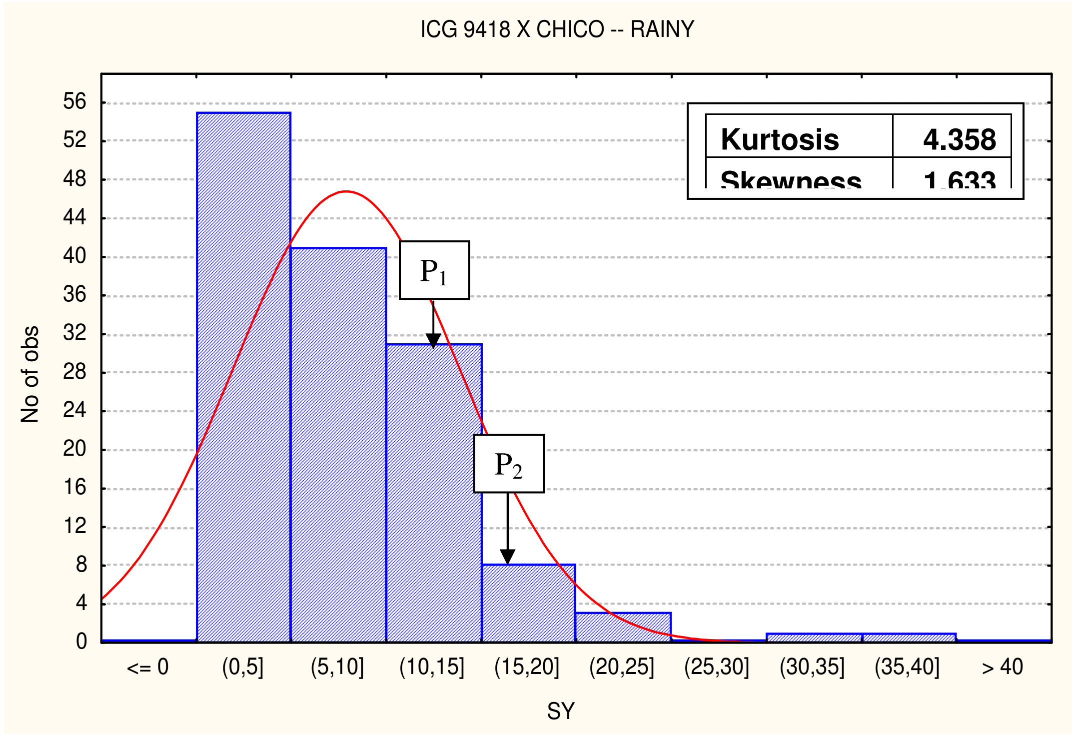

Fig 47: Distribution of F_2 of ICG 9418 × Chico cross for seed yield during rainy season

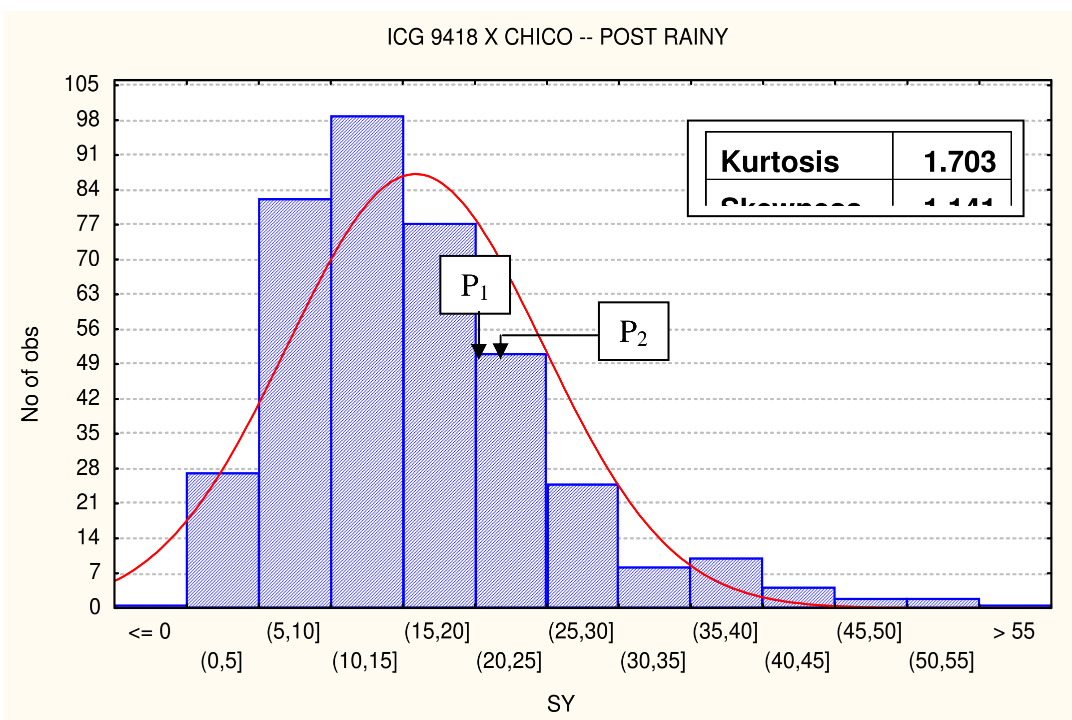

Fig 48: Distribution of F_2 of ICG 9418 × Chico cross for seed yield during post rainy season

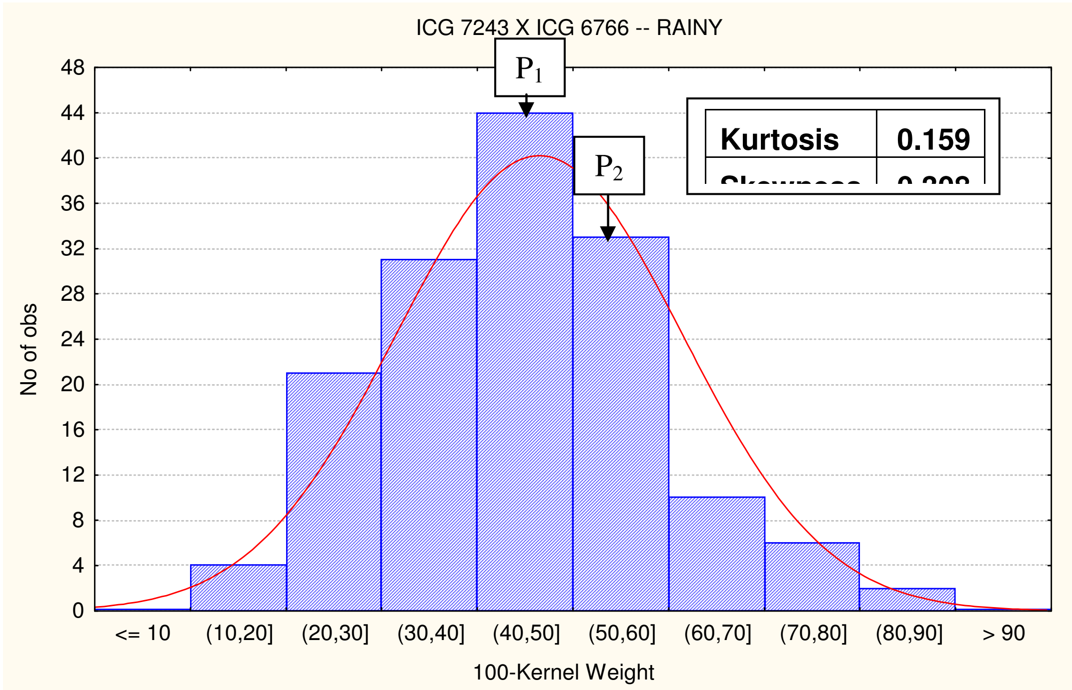

Fig 49: Distribution of F_2 of ICG7243 × ICG 6766 cross for 100-Kernel weight during rainy season

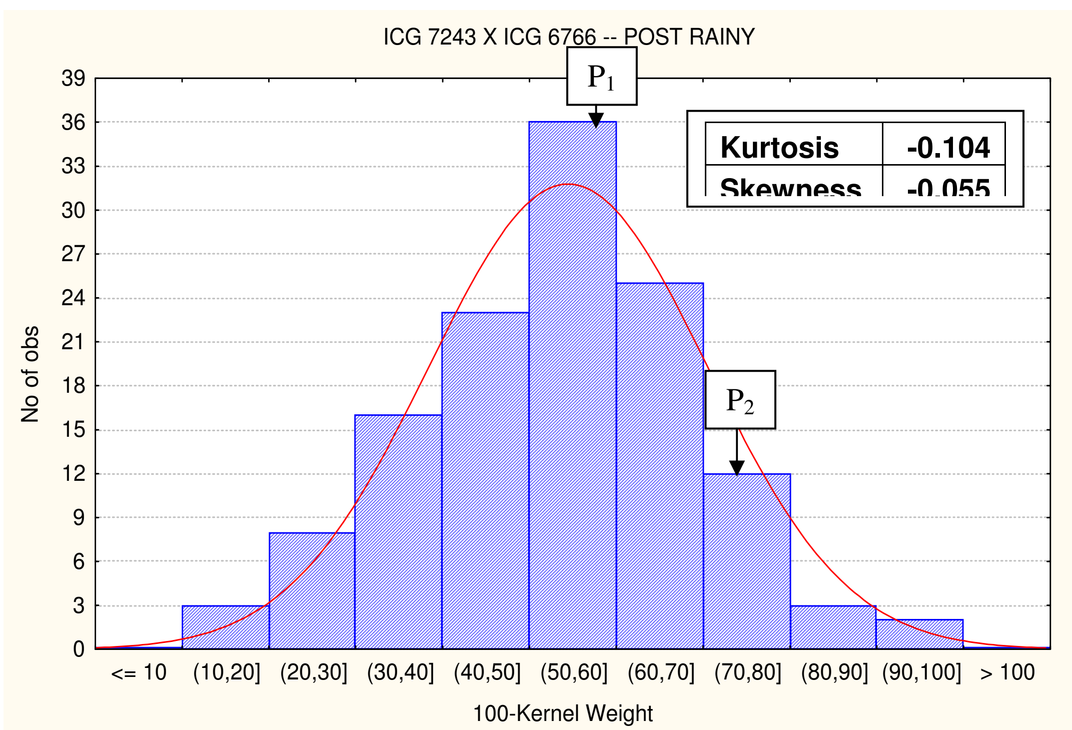

Fig 50: Distribution of F_2 of ICG7243 × ICG 6766 cross for 100-Kernel weight during post rainy season

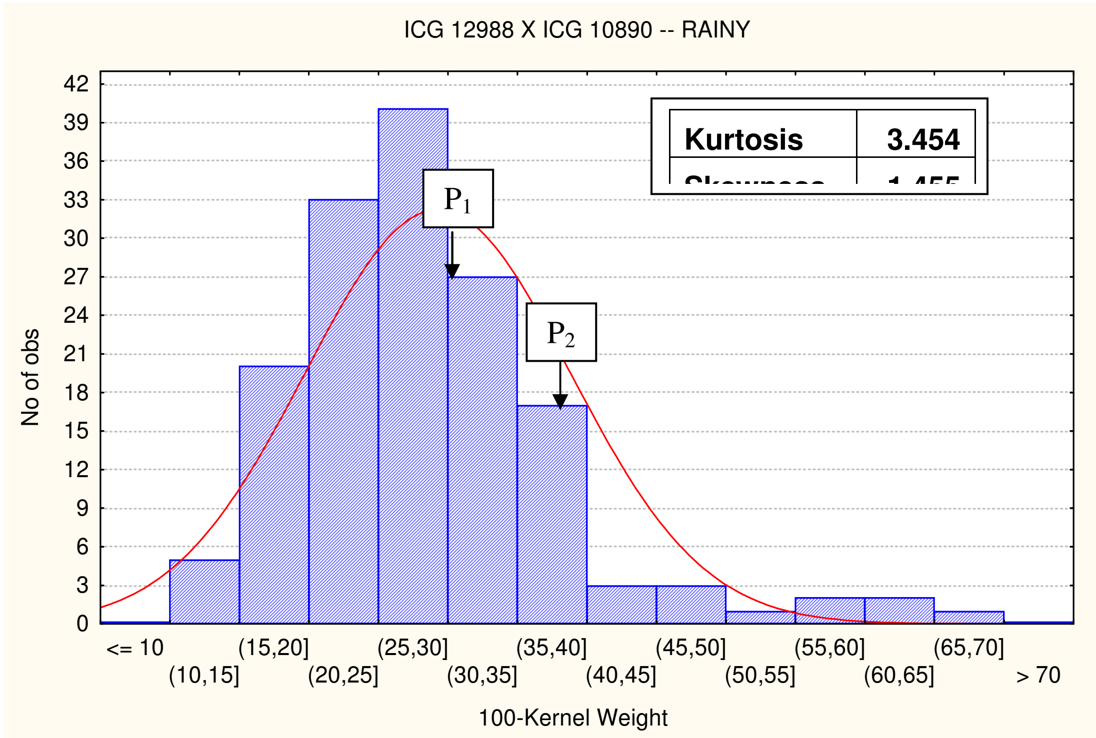

Fig 51: Distribution of F_2 of ICG 12988 × ICG 10890 cross for 100-Kernel weight during rainy season

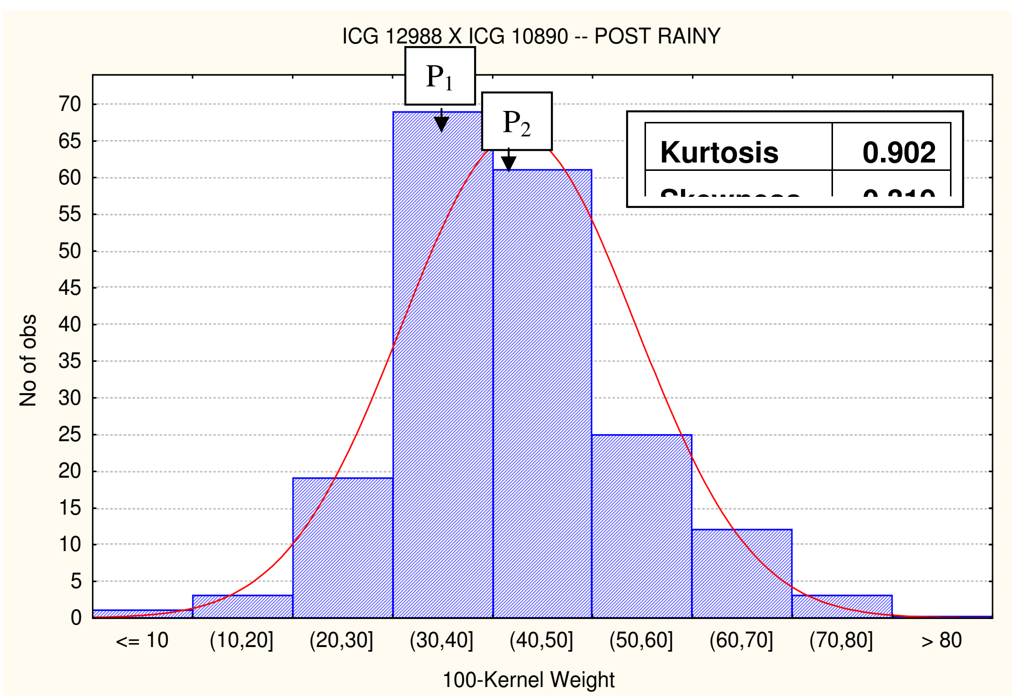

Fig 52: Distribution of F_2 of ICG 12988 × ICG 10890 cross for 100-Kernel weight during post rainy season

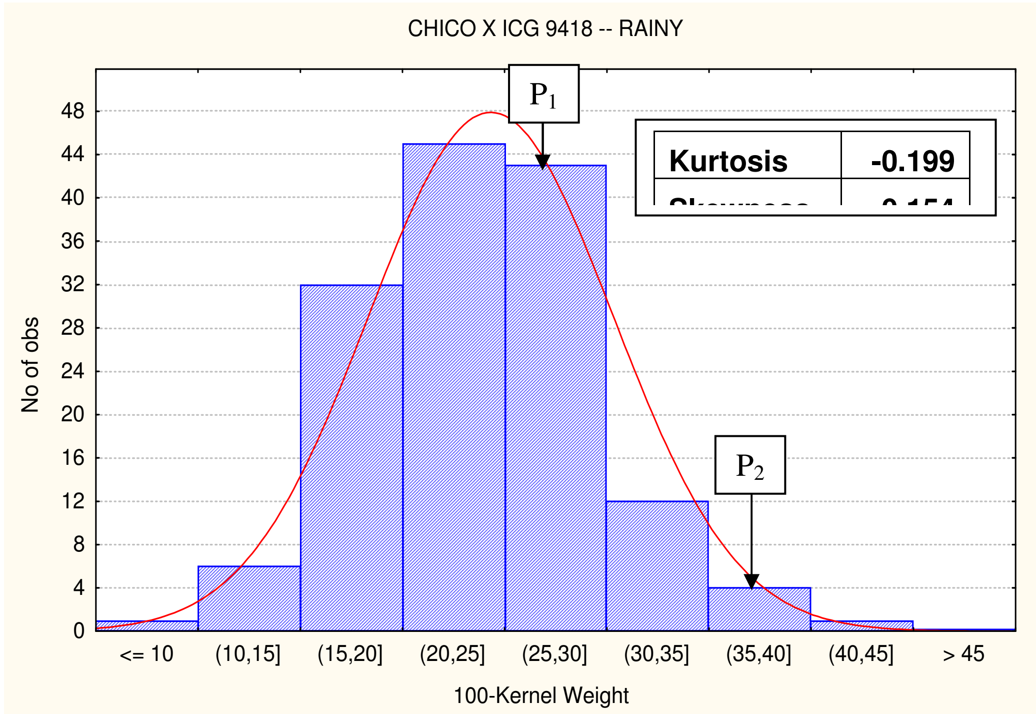

Fig 53: Distribution of F_2 of Chico × ICG 9418 cross for 100-Kernel weight during rainy season

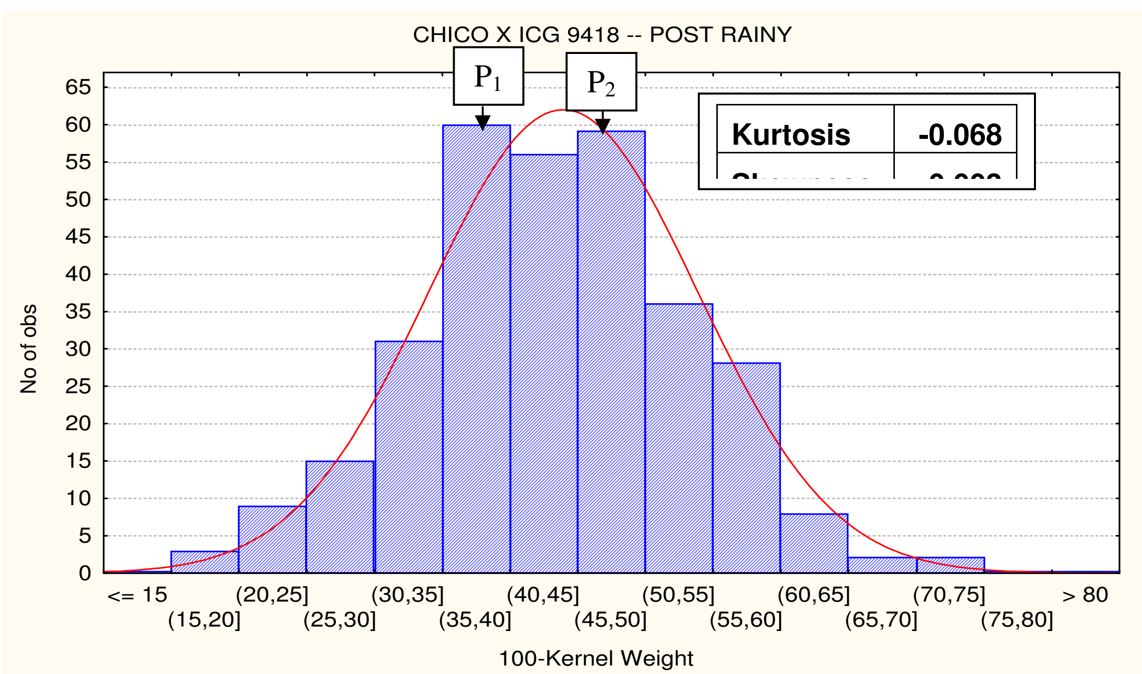

Fig 54: Distribution of F_2 of Chico × ICG 9418 cross for 100-Kernel weight during post rainy season

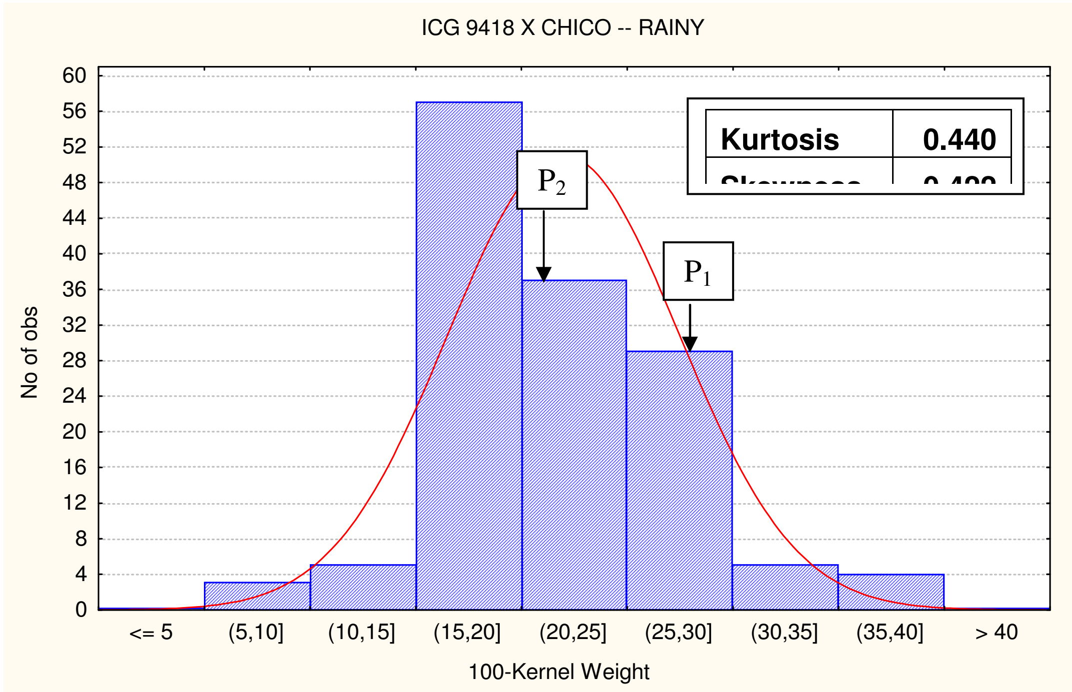

Fig 55: Distribution of F_2 of ICG 9418 × Chico cross for 100-Kernel weight during rainy season

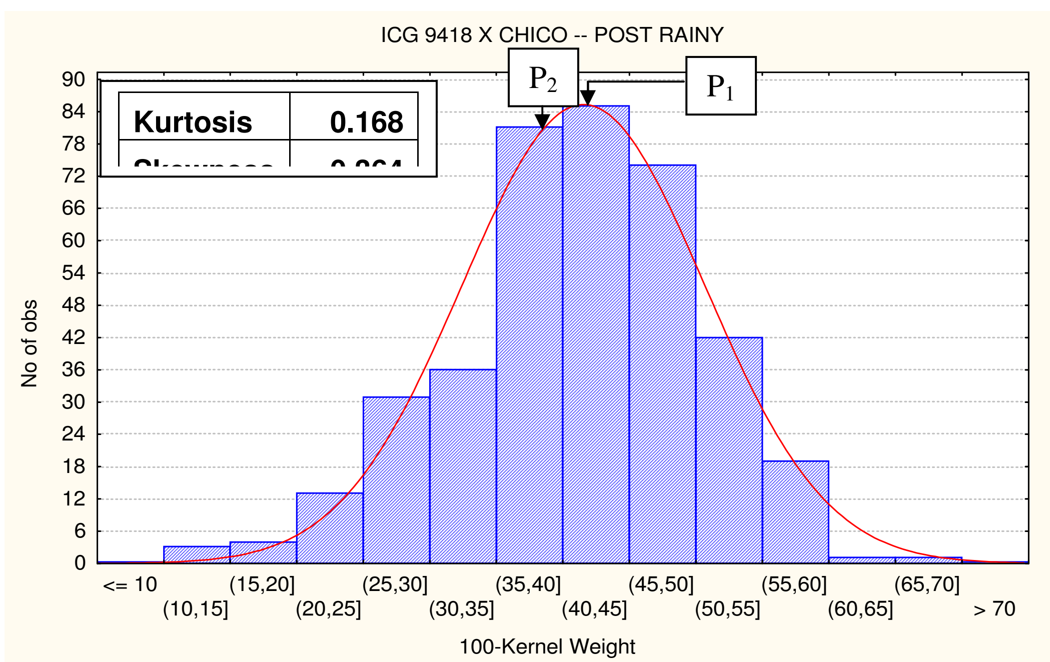

Fig 56: Distribution of F_2 of ICG 9418 × Chico cross for 100-Kernel weight during post rainy season

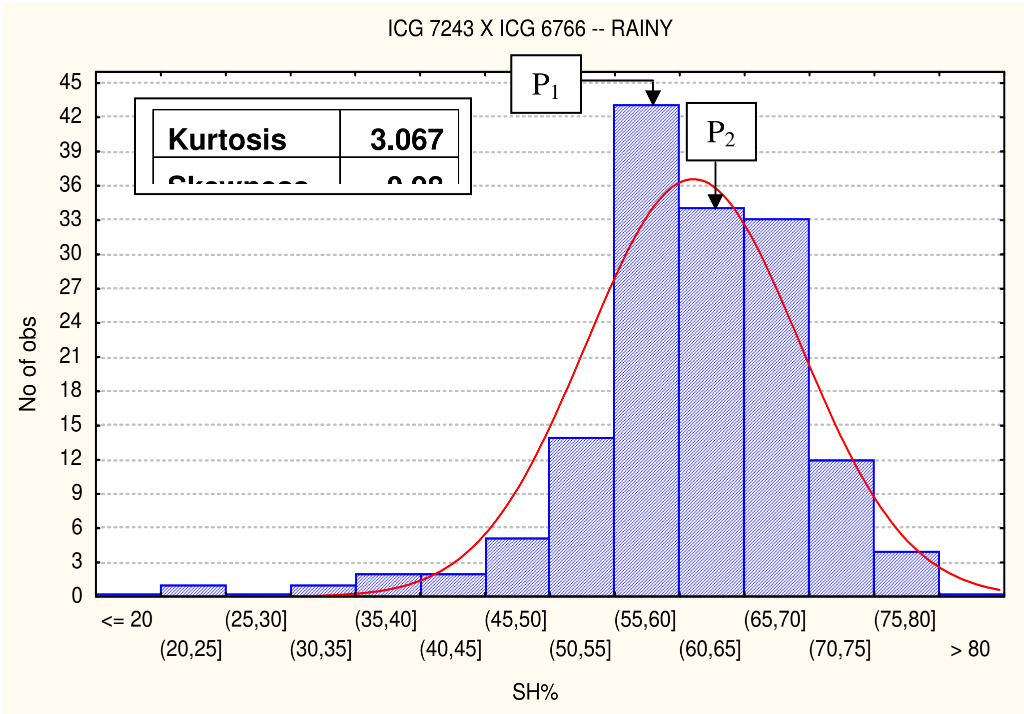

Fig 57: Distribution of F_2 of ICG7243 × ICG 6766 cross for shelling percentage during rainy season

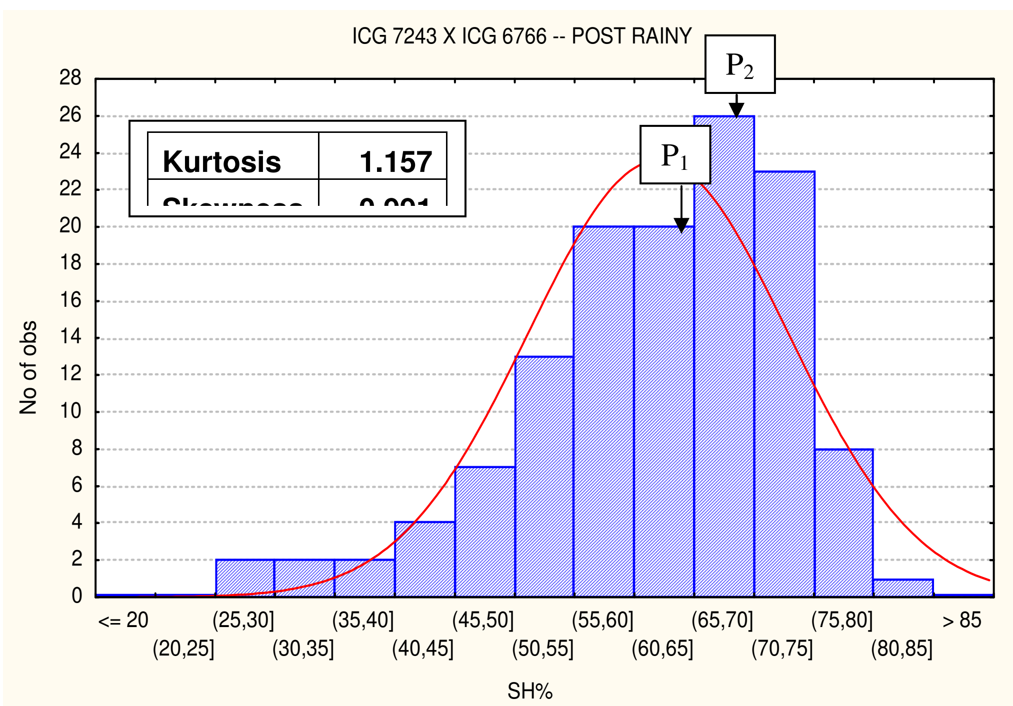

Fig 58: Distribution of F_2 of ICG 7243 × ICG 6766 cross for shelling percentage during post rainy season

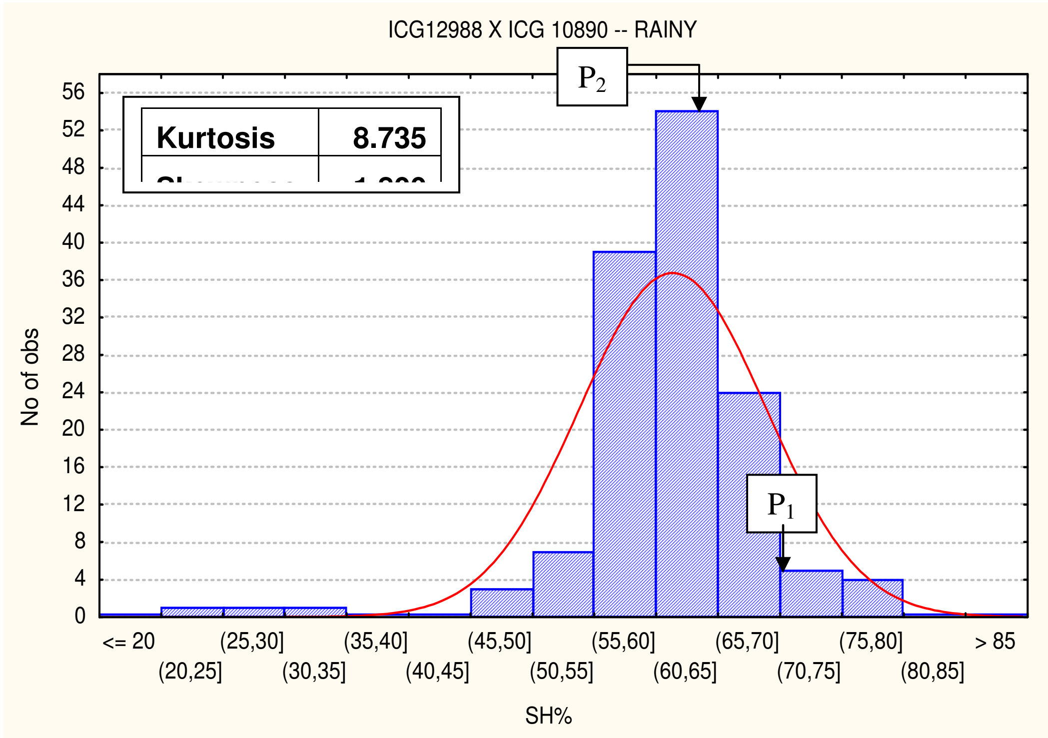

Fig 59: Distribution of F_2 of ICG 12988 × ICG 10890 cross for shelling percentage during rainy season

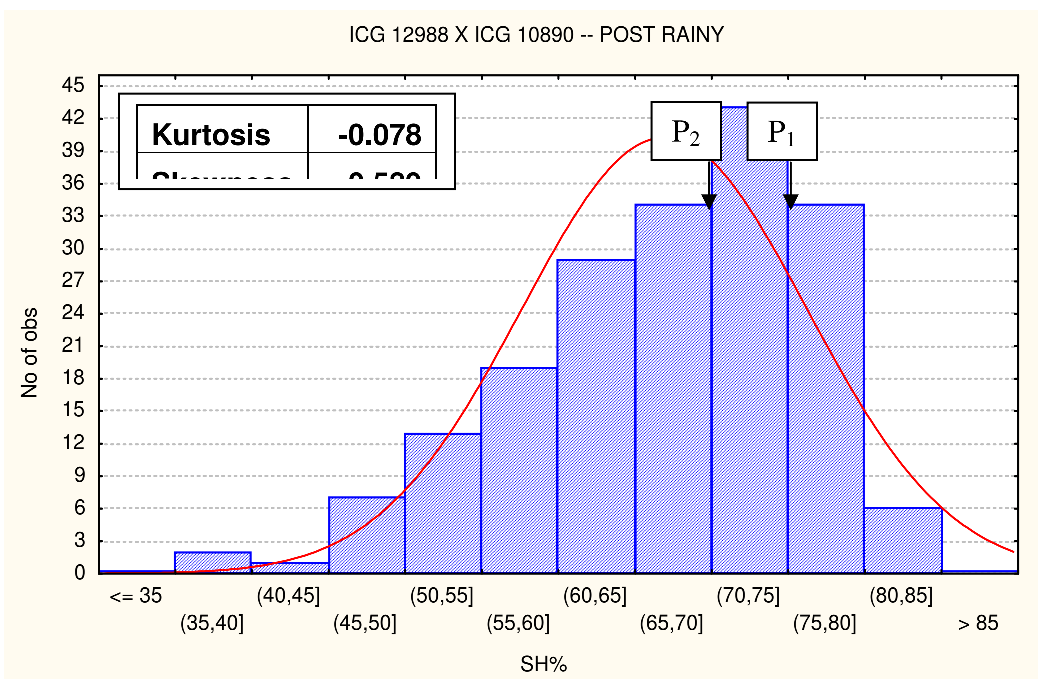

Fig 60: Distribution of F_2 of ICG 12988 × ICG 10890 cross for shelling percentage during post rainy season

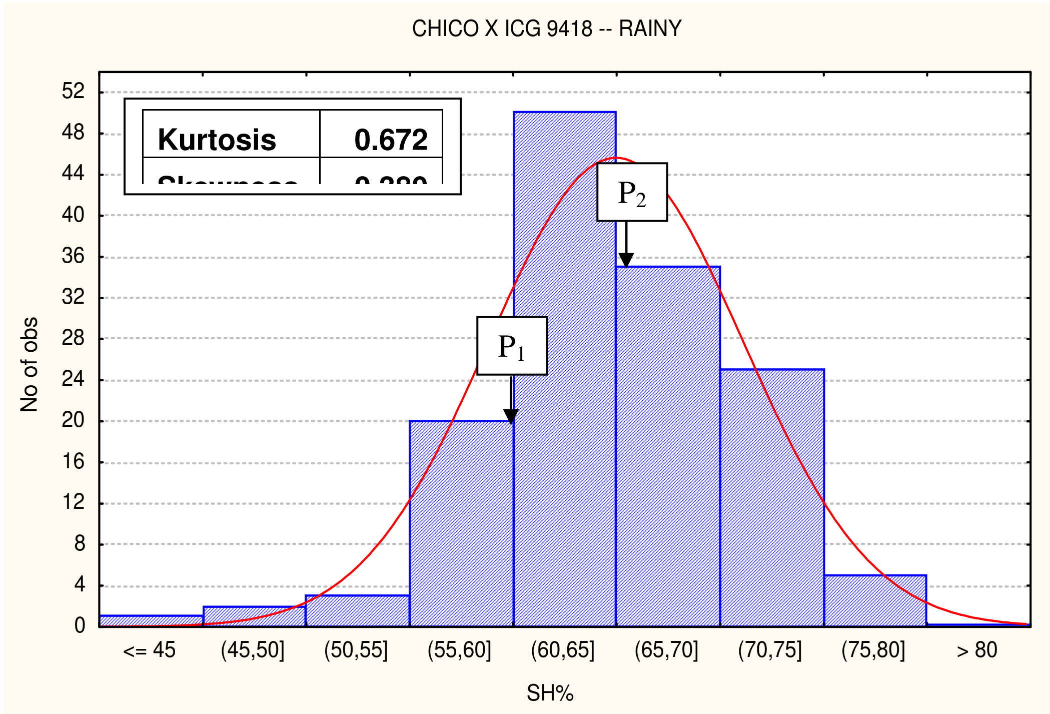

Fig 61: Distribution of F_2 of Chico × ICG 9418 cross for shelling percentage during rainy season

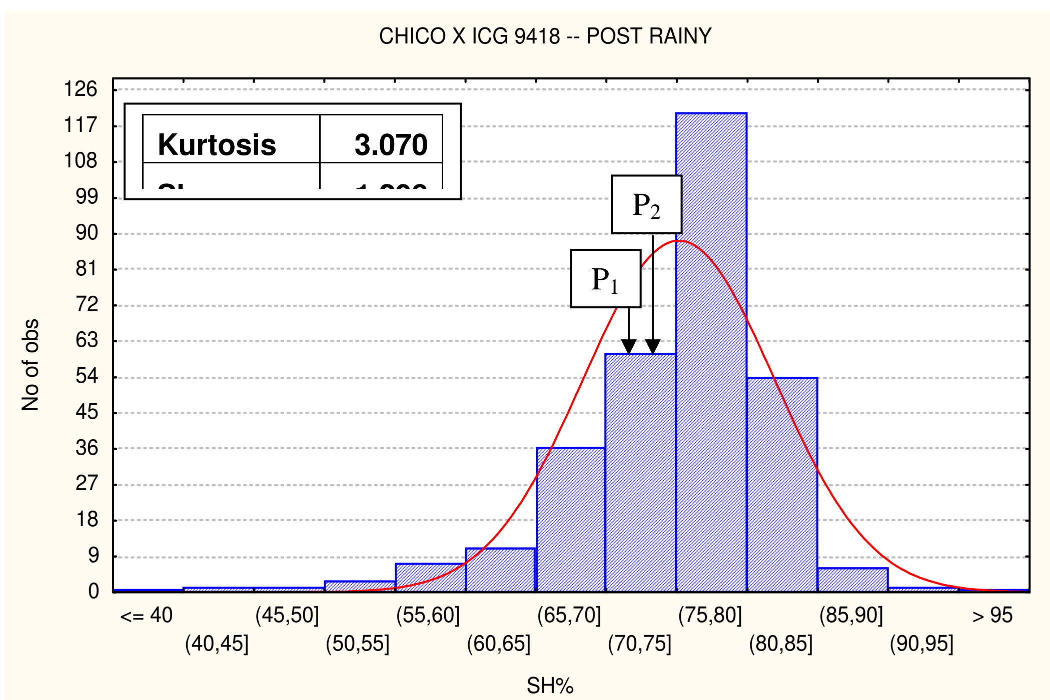

Fig 62: Distribution of F_2 of Chico × ICG 9418 cross for shelling percentage during post rainy season

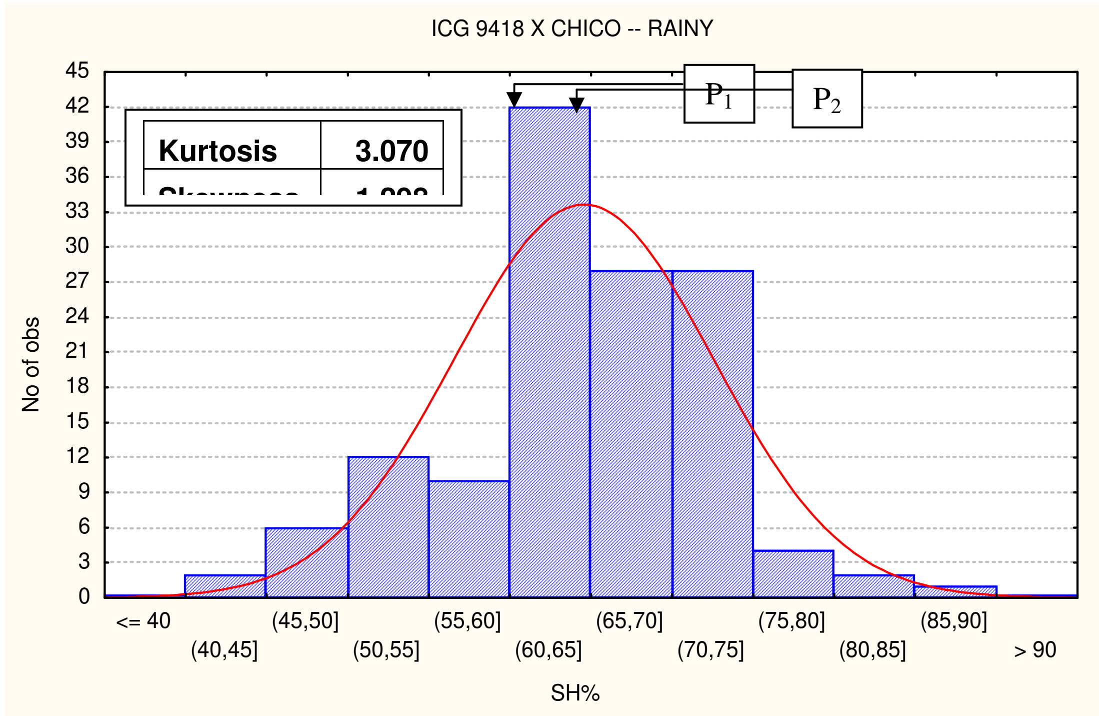

Fig 63: Distribution of F_2 of ICG 9418 × Chico cross for shelling percentage during rainy season

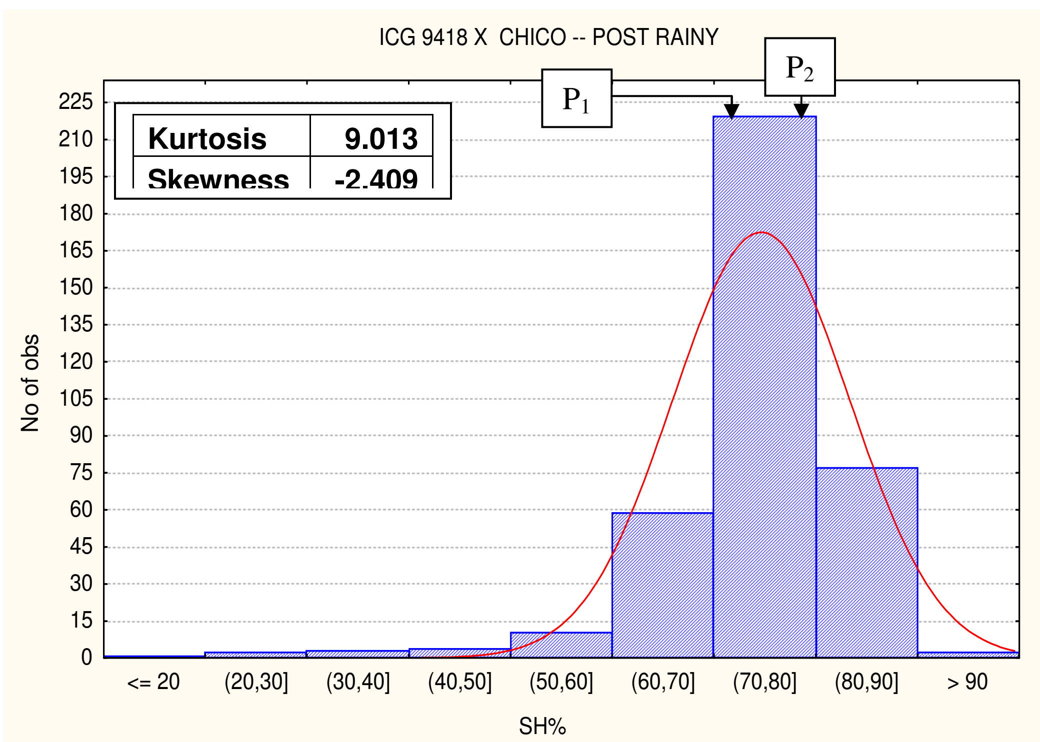

Fig 64: Distribution of F_2 of ICG 9418 × Chico cross for shelling percentage during post rainy season

As true with main gene effects, [d] and [h], the magnitude and direction of di-genic epistatic gene effects varied with the seasons for all the traits in all the crosses. The magnitude of dominance × dominance [l] gene effects were substantially higher than that of other di-genic epistatic gene effects i.e., [i] and [j] for all the characters in all the crosses. Barring seed length (where, additive-dominance model was adequate) duplicate interaction as indicated by opposite signs of [h] and [l] were played a significant role in the expression of all the traits in all the crosses. The net sign of dominance x dominance[l] gene effects were negative in all the crosses for pod yield and in ICG 7243 × ICG 6766 and Chico × ICG 9418 crosses for seed yield during both rainy and post rainy seasons. In ICG 9418 × Chico, the net sign of dominance x dominance gene effects were positive for seed yield during both the seasons. For seed yield, the net sign of additive × additive[i] and dominance × dominance[l] gene effects were positive in ICG 7243 × ICG 6766, and Chico × ICG 9418 crosses while it was negative in ICG 9418 × Chico during both the seasons.

The F_2 distribution for SCMR and SLA at 60 DAS and 80 DAS (Fig 1-32) and for 100-Kernel weight (Fig 49-56) in all the four crosses was near normal distribution.

The F_2 distribution of pod yield (Fig 33-40) and seed yield (41-48) of all the crosses was positively skewed.

The F_2 distribution of shelling percentage in cross, ICG 7243 × ICG 6766 and ICG 12988 × ICG 10890 during post rainy season was negatively skewed whereas in cross ICG 9418 × Chico and ICG 9418 × Chico in post rainy and in all four crosses during rainy season, the distribution was near normal (Fig 57-64).

4.3. Maternal effects

Significant differences were evident between straight cross (Chico × ICG 9418) and its reciprocal cross (ICG 9418 × Chico) for SCMR taken at 60 and 80 DAS during both rainy and post rainy seasons (Table 15). The magnitude of difference between straight and reciprocal crosses for SCMR at 60 and 80 DAS is higher in post rainy season compared to that in rainy season. SCMR at both 60 DAS and 80 DAS was higher in straight cross compared to that in reciprocal cross during both rainy and post rainy seasons. In contrast to SCMR, SLA at 60 DAS and 80 DAS were higher in reciprocal cross than that in straight cross in both rainy and post rainy seasons. The difference between straight and reciprocal cross for SLA at 60 DAS and 80 DAS were significant in both rainy and post rainy seasons. The magnitude of difference was higher in rainy season.

4.4. Carbon isotope discrimination ratio

Among the parents, JUG 26 showed the lowest $\Delta^{13}C$ (17.61) while Chico manifested higher $\Delta^{13}C$ (Average $\Delta^{13}C$ = 20.36). $\Delta^{13}C$ of ICGS 76 × Chico was lower than lower parent, while $\Delta^{13}C$ of JUG 26 × Chico was similar to higher parent. Contrastingly, $\Delta^{13}C$ of JUG 3 × Chico was intermediate to its parents (Table 16).

4.5. Character association

4.5.1. Association of drought tolerance traits with yield and its attributing characters

ICG 7243 × ICG 6766

SCMR at 60 DAS showed negative and highly significant correlation with SLA (-0.524), while its correlation was negative but non significant with pod yield (-0.023) and seed yield (-0.036). Contrastingly, correlation of SCMR was positive and non significant with 100-kernel weight (0.118). Similarly correlation of SLA with pod yield (0.022) and seed yield (0.152) was positive and non significant, while its correlation was negative with 100-kernel weight (0.107) (Table 17).

ICG 12988 × ICG 10890

The association of SCMR with SLA (-0.367) was highly significant and negative. But its correlation with seed yield (-0.020) and 100-kernel weight (-0.149) was negative and non significant. The association of SLA with 100-kernel weight (0.061) was positive and non-significant while its correlation with pod yield (-0.001) was negative and non significant (Table 18).

Chico × ICG 9418

The association of SCMR with 100-kernel weight (0.016), was positive and non significant, whereas its association was negative and non significant with pod yield (-0.054). The correlation of SCMR with SLA (-0.236) was negative and highly significant. The association of SLA with pod yield (0.051) was positive and non-significant, whereas its association with 100-kernel weight (-0.012) was negative and non- significant (Table 19).

ICG 9418 × Chico.

The association of SCMR with pod yield (0.125) was negative and significant. While its correlation with SLA (0.038) was positive but non significant. The association of SLA was negative and non significant with seed width (-0.060), pod yield (0.054) and 100-kernel weight (Table 20).

Table 15: Descriptive statistics for straight cross (Chico × ICG 9418) and Reciprocal cross (ICG 9418 × Chico) and two sample 't' test for reciprocal cross difference for SCMR and SLA during 2007 rainy season and 2007-08 post rainy season

	Rainy season				Post rainy season			
Descriptive statistics	SCMR 60 DAS		SCMR 80 DAS		SCMR 60 DAS		SCMR 80 DAS	
	SC	RC	SC	RC	SC	RC	SC	RC
Mean	37.75	36.20	36.21	34.82	41.246	39.06	41.8	40.18
Variance	2.00	1.73	1.21	1.89	1.66	2.143	1.71	1.37
Pooled Variance	1.86		1.556		1.94		1.53	
Two-sample t test								
Hypothesized difference between mean of SC and RC	0.00		0.00		0.00		0.00	
Actual mean difference	1.54		1.394		2.17		1.67	
t statistic	2.99		2.499		5.72		4.81	
P(T<=t) two tail	0.00		0.022		5.03167E-07		1.47143E-05	
The critical two tail table 't'value	2.05		2.100		2.00			
	SLA 60 DAS		SLA 80 DAS		SLA 60 DAS		SLA 80 DAS	
Mean	143.87	160.96	154.45	158.02	169.96	177.41	168.39	175.12
Variance	12.35	15.59	7.06	10.75	15.84	13.93	18.38	21.87
Pooled Variance	13.97		8.90		14.91		20.07	
Two-sample t test								
Hypothesized difference between mean of SC and RC	0.00		0.00		0.00		0.00	
Actual mean difference	-17.09		3.57		-7.51		-6.73	
t statistic	-12.09		-2.93		-5.58		-4.69	
P(T<=t) two tail	3.49695E-12		0.01		4.0399E-06		3.65474E-05	
The critical two tail table 't'value	2.05		2.07		2.03		2.02	

SC= Straight Cross, RC= Reciprocal cross, SCMR=Soil Plant Analytical Development Chlorophyll Meter Reading;
SLA= Specific Leaf Area (cm^2/g)

Table 16: Carbon isotope discrimination ability of parents and their F_1's in groundnut

PARENTAGE	MEAN ± S.E	VARIANCE
ICGS 76	19.58 ± 0.1995	0.3185
Chico	20.19 ± 0.5508	1.9271
F_1	18.98 ± 0.2900	1.4298
JUG 3	18.98 ± 0.3608	1.1719
Chico	20.07 ± 0.5553	2.1587
F_1	19.70 ± 0.3576	1.4071
JUG 26	17.61 ± 0.3283	0.9705
Chico	20.83 ± 0.4011	1.4485
F_1	20.13 ± 0.3022	1.9180

Table 17: Estimates of phenotypic correlation coefficients among the traits related to drought tolerance and yield and its component traits in F_2 of ICG7243 × ICG6766 groundnut cross

	SCMR	SLA	SL	SW	PY	SY	100-KW	SH%
SCMR	1.00							
SLA	-0.54**	1.00						
SL	0.034	0.057	1.00					
SW	-0.170	0.054	0.284**	1.00				
PY	-0.023	0.022	0.346**	0.196*	1.00			
SY	-0.036	0.015	0.355**	0.250**	0.958**	1.00		
100KW	0.118	-0.107	0.462**	0.257**	0.350**	0.368**	1.00	
SH%	-0.020	-0.053	0.054	0.254**	0.044	0.259**	0.280**	1.00

* Significance at P=0.05 ** Significance at P=0.01

SCMR=Soil Plant Analytical Development (SPAD) Chlorophyll Meter Reading
SLA=Specific Leaf Area (cm^2/g)
SL=Seed Length (mm)
SW=Seed Width (mm)
PY=Pod yield (g)
SY=Seed yield (g)
100-KW=100-Kernel Weight (g)
SHP=Shelling percentage (%)

Table 18: Estimates of phenotypic correlation coefficients among the traits related to drought tolerance and yield and its component traits in F_2 of ICG 12988 × ICG 10890 groundnut cross

	SCMR	SLA	SL	SW	PY	SY	100KW	SH%
SCMR	1.00							
SLA	-0.367**	1.00						
SL	0.086	-0.139	1.00					
SW	-0.020	0.003	0.452**	1.00				
PY	0.008	-0.001	0.241**	0.342**	1.00			
SY	-0.020	0.021	0.186*	0.374**	0.905**	1.00		
100KW	-0.149	0.061	0.591**	0.560**	0.357**	0.348**	1.00	
SH%	0.018	0.114	-0.042	0.014	-0.057	0.249**	0.005	1.00

* Significance at P=0.05 ** Significance at P=0.01

SCMR=Soil Plant Analytical Development (SPAD) Chlorophyll Meter Reading
SLA=Specific Leaf Area (cm^2/g)
SL=Seed Length (mm)
SW=Seed Width (mm)
PY=Pod yield (g)
SY=Seed yield (g)
100-KW=100-Kernel Weight (g)
SHP=Shelling percentage (%)

Table 19: Estimates of phenotypic correlation coefficients among the traits related to drought tolerance and yield and its component traits in F_2 of Chico × ICG 9418 groundnut cross

	SCMR	SLA	SL	SW	PY	SY	100KW	SH%
SCMR	1.000							
SLA	-0.236**	1.000						
SL	0.001	-0.020	1.000					
SW	0.025	0.011	0.262**	1.000				
PY	-0.054	0.051	0.371**	0.081	1.000			
SY	-0.043	0.055	0.383**	0.094	0.985**	1.000		
100KW	0.016	-0.012	0.428**	0.236**	0.258**	0.284**	1.000	
SH%	0.006	0.022	0.125*	0.122*	0.016	0.147*	0.187**	1.000

* Significance at P=0.05 ** Significance at P=0.01

SCMR=Soil Plant Analytical Development (SPAD) Chlorophyll Meter Reading
SLA=Specific Leaf Area (cm^2/g)
SL=Seed Length (mm)
SW=Seed Width (mm)
PY=Pod yield (g)
SY=Seed yield (g)
100-KW=100-Kernel Weight (g)
SHP=Shelling percentage (%)

Table 20: Estimates of phenotypic correlation coefficients among the traits related to drought tolerance and yield and its component traits in F_2 of ICG 9418 × Chico groundnut cross

	SCMR	SLA	SL	SW	PY	SY	100KW	SH%
SCMR	1.00							
SLA	-0.038	1.00						
SL	-0.036	-0.106*	1.00					
SW	0.021	-0.056	0.584**	1.00				
PY	-0.125	-0.054	0.269**	0.295**	1.00			
SY	-0.088	-0.028	0.266**	0.310**	0.965**	1.00		
100KW	0.004	-0.069	0.482**	0.458**	0.228**	0.267**	1.00	
SH%	0.102*	0.093	0.067	0.166**	-0.014	0.201**	0.240**	1.00

* Significance at P=0.05 ** Significance at P=0.01

SCMR=Soil Plant Analytical Development (SPAD) Chlorophyll Meter Reading
SLA=Specific Leaf Area (cm^2/g)
SL=Seed Length (mm)
SW=Seed Width (mm)
PY=Pod yield (g)
SY=Seed yield (g)
100-KW=100-Kernel Weight (g)
SHP=Shelling percentage (%)

V. DISCUSSION

The results obtained in the experiment are discussed under the following heads.

1. Mean performance
2. Gene effects
3. Maternal effects
4. Carbon isotope discrimination ratio
5. Character association

5.1 Mean performance

5.1.1 Surrogate traits of drought tolerance (SCMR and SLA)

The mean of both non-segregating (P_1, P_2 and F_1) and segregating generations (F_2, B_1 and B_2) for SCMR and SLA at 60 and 80 DAS were higher in the post rainy season than those in rainy season (Table 3-6). These results are similar to those reported by Upadhyaya (2005). Higher performance of the generations could be due to higher radiation and lower temperatures in the post rainy season. Bell *et al*. (1992) have clearly demonstrated the effect of temperature on the production and utilization of photosynthates in groundnut leaves.

In Chico × ICG 9418 and ICG 9418 × Chico crosses, the similarity of B_1 mean with P_1 mean and that of B_2 mean with P_2 mean during both rainy and post rainy seasons suggested influence of maternal parent in the expression of SCMR at 60 and 80 DAS.

The F_1 mean was intermediate to their parental means for SCMR at 80 DAS in all the crosses except Chico × ICG 9418 during post rainy where F_1 mean was higher than its higher parent. Contrastingly, the F_1 mean of ICG 9418 × Chico during rainy season was lower than the lower parent. Surpassing of F_1 mean of the crosses Chico × ICG 9418 and its reciprocal ICG 9418 × Chico out of parental means clearly suggest possible involvement of overdominance in the expression of SCMR at 80 DAS in these crosses.

The similarity of B_1 mean was towards P_1 mean and B_2 mean towards P_2 mean in Chico×ICG 9418 and ICG 9418 × Chico crosses during both rainy and post rainy seasons suggested the influence of maternal parent in the expression of SLA at 60 and 80 DAS.

In ICG 12988 × ICG 10890, Chico × ICG 9418, ICG 9418 × Chico crosses the difference between their parental means was comparatively narrow while it was wider in ICG 7243 × ICG 6766. The frequency of transgressive seggregants would be higher in ICG 7243 × ICG 6766 compared to other crosses for SLA at 60 and 80 DAS.

ICG 6766, one of the parents of the cross ICG 7243 × ICG 6766 produced highest pod yield and seed yield during post rainy season. Interestingly, 1CG6766 also had the highest SPAD reading with lowest SLA during rainy and post rainy seasons. Thus, ICG 6766 has ideal combination of drought tolerance traits and thus higher pod yield and seed yield indicating its potentiality for use as one of the parents in crossing programmes.

In contrast to *per se* performance of various generations, the variability (as indicated by the range and variance) was higher in rainy season compared to that in post rainy season for SCMR and SLA at 60 and 80 DAS. The comparatively unfavorable environment in terms of radiation and temperature during rainy season *vis-a-vis* post rainy season (Upadhyaya 2005) could be attributed to the better discrimination of progeny among various generations resulting in higher variability. The favorable and less variable weather parameters during post rainy season are likely to have contributed to better expressions of progeny within each generation, thus resulting in lower discrimination among the progeny during post rainy season.

As is true with surrogate traits of drought tolerance, *per se* performance of various generations was higher during post rainy season than during rainy season for seed yield and its attributing traits reverse being true with respect to range and the variance. These results indicate significant influence of weather variables on the expression of traits irrespective of whether they are physiological (SCMR and SLA) or economic traits (pod yield, seed yield and 100-kernel weight). Consistent (less variable) weather variables during post rainy season favor better expression of the crop growth, contributing to lower discrimination among the individuals in each generation resulting in lower variability.

5.2 Gene effects

5.2.1 Surrogate traits of drought tolerance (SCMR and SLA)

Additive-dominance model was not sufficient to explain the expression of SCMR and SLA at 60 and 80 DAS during both the seasons in all the crosses with only two exceptions (for SCMR at 60 DAS in ICG 9418 × Chico during rainy season and for SLA at 80 DAS in Chico × ICG 9418 during rainy season) as indicated by significance of chi-square statistic in joint scaling test (Table 13). The inadequacy of additive-dominance model suggested the possible involvement of di-genic / higher order epistatic gene action in the expression of SCMR and SLA at 60 and 80 DAS. Both additive and dominance main gene effects {[d] and [h]} were significant with predominance of dominance gene effects in the expression of SCMR and SLA at 60 and 80 DAS in all the crosses with only a few exceptions. Predominance of dominance gene effects reflected in dominance × dominance di-genic epistatic gene effects [l] aswell. The magnitude of dominance × dominance gene effects were substantially higher compared to that of other di-genic epistatic effects {[i] and [j]} and main gene effects {[d] and [h]}. These results are in confirmity with those repored by Babitha *et al*. (2006) for SCMR. Whereas, Chuni Lal e*t al.* (2006) for SCMR, Nigam *et al*. (2001) for SLA, Venkateswarlu *et al*. 2007) for SCMR and SLA, have reported predominance of additive gene effects for expression of SCMR and SLA in a few groundnut crosses. These differential results are expected given that SLA and SCMR (more so SLA) is highly sensitive to season, position of the leaf, stage of the crop (Nageshwara Rao *et al*., 2001 and Upadhyaya, 2005) and material used for the study. Predominance of dominance genes controlling the expression of SCMR and SLA is also reflected by negatively skewed distribution of individuals of F_2 generation in all the crosses during both the seasons (Fig 1-32). The negatively skewed distribution of F_2 individuals indicated higher frequency of increasing alleles with dominance property for the expression of SCMR at 60 and 80 DAS(Fig 1-16). On the other hand, positively skewed distribution of F_2 individuals in all the crosses during both the seasons suggested higher frequency of decreasing alleles with dominance property in the expression of SLA at 60 and 80 DAS(Fig 17-32). Deliberate selection of the parents for higher SCMR and lower SLA could be attributed to the higher frequency of increasing alleles and decreasing alleles respectively with dominance gene action in F_2 generation of all the crosses. The skewed distribution of F_2 individuals reinforces the predominant role of dominance gene action in expression of SCMR and SLA in all the crosses.

The results indicate that selection for SCMR and SLA in early generations may not be effective. It is, therefore, to advisable to defer selection to advanced segregating generations to improve these traits. Alternatively, two or more cycles of biparental mating of superior individuals in segregating generation is likely to result in constellation of superior genes coupled with enhanced additive variance (Salimath *et al.,* 2003). Further, considering that SLA and SCMR are sensitive to environment, breeding groundnut for drought tolerance based on these surrogate traits should be in specific drought-prone environment to which final products are targeted. The opposite signs of dominance gene effects [h] and dominance × dominance gene effects [l] indicated duplicate type of epitasis in the expression of both SCMR and SLA at 60 and 80 DAS in most of the crosses. Duplicate epistasis is not likely to result in higher expression of SCMR and SLA. However, according to Mather, (1974) a population undergoing continuous directional selection develops complementary epitasis. Under such circumstances, true breeding lines derived in advanced segregating generations will have desirable expression of SCMR (towards higher side) and SLA (towards lower side).

5.2.2 Seed yield and its attributing traits

Additive-dominance model was not sufficient to explain the expression of pod yield and seed yield during both the seasons in all the crosses with the exception of ICG 7243 × ICG 6766 during post rainy season for seed yield as indicated by significance of chi-square statistic in joint scaling test (Table 13).

Additive, dominance, additive × additive, dominance gene effects were important in all the crosses, barring ICG 9418 × Chico in which additive gene effects was non-significant for the expression of seed yield with the predominance of dominance and dominance × dominance gene effects. These results are in accordance with the findings of Jagannadha Reddy and Raja Reddy (1987); Upadhayaya *et al*. (1992); Sateera Banu (1992); Nisar Ahmed (1995); Francies and Ramalingam (1999) and Venkateswaralu *et al*. (2007).

Additive, dominance, additive × additive, and dominance × dominance gene effects were seemed to be important in all the crosses, except in ICG 7243 × ICG 6766 during rainy season and in the cross ICG9148 × Chico during post rainy season in which additive gene effects were non significant. Dominance and dominance × dominance gene effects played a significant role in the expression of pod yield in all the crosses. Similar observations were also made by Sangha and Labana (1982); Jagannadha Reddy and Raja Reddy (1987); Dwivedi *et al.* (1989);

Reddi *et al.* (1989); Makne and Bale (1989); Halward and Wynne (1991); Sateera Banu (1992); Vindhiya Varman and Raveendran (1994); Nisar Ahmed (1995); Francies and Ramalingam (1999); Mather *et al*. (2001) and Parameshwarappa (2007). However, Vindhiya varman and Parama Sivam (1992), and Kalaimani and Thangavelu (1996) have reported predominance of additive gene action for the expression of pod yield per plant in ground nut. Predominance of dominance gene effects for the expression of pod yield and seed yield is also reflected by skewed distribution of individuals of F_2 generation in all the crosses during both the seasons. The positively skewed distribution of F_2 individuals (Fig 33-40) indicated an overall excess of decreasing alleles with dominance property in the expression of pod yield and seed yield. Such results are expected given that selection has not favored seed yield and pod yield while selecting the parents for SCMR and SLA.

Selection for seed yield should be deffered to advanced segregating generations as it is predominantly under the control of dominance and dominance-based gene action. Perhaps, one or two cycles of biparental mating in early segregating generations are useful to break conserved linkage blocks which are considered to be causes for non-additive gene action (Salimath *et al.,* 2003).

Both additive and dominant gene effects were important with the predominance of dominance gene effects in all the crosses during both the seasons for the expression of 100-kernel weight. These results are in conformity with those of Sudheer Kumar and Patel (1999). However, the results are contradictory to the findings of Kuchanur *et al*. (1997) and Hariprasanna *et al.* (2008) who reported predominance of additive gene action in the expression of 100-kernel weight. Near normal distribution of F_2 population (Fig 49-56) in all the crosses during both the seasons suggested equal frequency of increasing and decreasing alleles irrespective of whether they are dominant or recessive in the parents of the four crosses under study. Of late, bolder seeds (high 100-kernel weight) fetch premium price in the market. Hence, the varieties with bolder seeds becoming popular in all parts of India and elsewhere. Developing bold seeded cultivars is one of the most important objective of breeding programmes in India and elsewhere. Constelling genes for higher 100-kernel weight by repeated biparental mating preceding selection would be highly effective in genetic enhancement of groundnut for 100-kernel weight. Although, generation mean analysis is valuable for detection and estimation of additive, dominance and epistatic gene effects, it does have limitations. Linkage affects epistatic gene effects and causes more serious bias to the estimates of additive × additive and dominance × dominance gene effects. Inferences based on the magnitudes of additive effects are not advisable, because the distribution of positive and negative gene effects in the parents may result in different degrees of cancellation of effects in the expression of the generation means. For the same reason, the magnitudes of additive gene effects do not necessarily reflect the magnitude of additive variance. However, dominance [h] and dominance × dominance [l] are independent of the degree of gene distribution due to which the combined estimates of dominance [h] and dominance × dominance [l] could be considered to be the best representative of sign and magnitude of individual h's and i's respectively. So, practically these are the only components which can safely be used to determine the type of epistasis may have influence on the observed performance of generations (Mather and Jinks, 1982). For the same reason, emphasis has been given to the characters which are governed by such gene effects for suggesting appropriate breeding method that should be followed to achieve higher expression of such characters.

5.3 Maternal effects

Knowledge of reciprocal cross differences would help and guide the breeder in choosing parents for the hybridization programme. Marked reciprocal differences were observed for SCMR and SLA at 60 and 80 DAS. These results are in accordance with those of Chuni Lal *et al*. (2006) who reported significant maternal effects for SLA. These results suggest critical role of maternal parent in the expression of F_1 hybrid. It is advisable to use donor parent as maternal parent during crossing programme to generate useful variability for improvement of these traits of selection.

5.4 Carbon isotope discrimination

Among the parents, JUG 26 showed the lowest $\Delta^{13}C$ (17.61) while Chico manifested higher $\Delta^{13}C$ (Average $\Delta^{13}C$ = 20.36). On contrary, $\Delta^{13}C$ of ICGS 76 × Chico was lower than lower parent, while $\Delta^{13}C$ of JUG 26 × Chico was similar to higher parent. Contrastingly, $\Delta^{13}C$ of JUG 3 × Chico was intermediate to its parents (Table 16). It appears that mostly over-dominance playing a significant role in $\Delta^{13}C$ ability of the genotypes in groundnut. However, it should be noted that present study is only preliminary and need systematic investigation to unravel inheritance of $\Delta^{13}C$.

5.5 Character Association

In all the crosses barring ICG 9418 × Chico, correlation between SCMR and SLA was negative and highly significant. These results are in accordance with those of Nageshwara Rao *et al*. (2001); Upadhyaya (2005) and Nigam and Aruna (2008). Such strong inverse relationship is advantageous for genetic enhancement of groundnut for drought tolerance through SCMR and SLA.

The weak association of SCMR and SLA with seed yield indicated that independent genetic control for their expression such weak relationship indicate possibility of simultaneous improvement of drought tolerance and economic yield. In all the four crosses, seed yield was highly significant and positively correlated with, 100-kernel weight, seed length and seed width. The results are in accordance with Abraham (1990); Reddi *et al*. (1991); Vasanthi *et al*. (1998); Roy *et al*.

(2003) and Kavani *et al*. (2004). Such relationship would be advantageous for improving seed yield without compromising seed size.

Future line of work

1. Considering high water–use efficiency coupled with good yield potential of ICG 6766 and JUG 26, it is desirable to involve these genotypes in crop improvement programme for developing high–yielding and drought tolerant groundnut cultivars.

2. ICG 6766 and Chico and JUG 26 and Chico being contrasting pairs of genotypes for SCMR and SLA and $\Delta^{13}C$, respectively, are the best candidate parents for developing mapping population for tagging difficult-to- breed traits.

VI. SUMMARY

An investigation was carried out with the objectives, i) to unravel the nature of gene action for SCMR and SLA, the surrogate traits of drought tolerance and for yield and its contributing traits, ii) to assess the maternal effects for SCMR and SLA in selected parents and their F_1 crosses and iii) to assess the carbon isotope discrimination (another surrogate of drought tolerance) among the parental genotypes. The investigation was carried out in alfisols of International Crops Research Institute for Semi-Arid Tropics (ICRISAT) during 2007 rainy season and 2007-08 post rainy season. The experimental material consisted of six-generations (P_1, P_2, F_1, F_2, B_1, and B_2) which were evaluated in randomized complete block design. The salient findings summarized hereunder.

The genotype ICG6766 Showed contrasting expression for SCMR and SLA in the desired direction i.e. highest SCMR and lowest SLA, indicating its drought tolerance interestingly the genotype was the best for seed yield and its attributes.

In F_2 generation of all the 4 crosses, association of seed yield with pod yield, 100-Kernel weight, seed length and seed width was highly significant.

Significant additive gene effects were evident in the expression of all the characters in all the crosses during both rainy and post rainy season.

Both additive and non-additive gene actions were found to be operative for SCMR at 60 DAS and 80 DAS, SLA at 60 DAS and 80 DAS, pod yield, seed yield, seed length, and seed width. Therefore, biparental or reciprocal recurrent selection would be appropriate breeding method to improve these traits.

Additive gene action was predominant the expression of 100-Kernel weight and shelling percentage. Simple selection by following pedigree method would be appropriate breeding method to improve these traits.

Marked reciprocal differences were observed for SCMR and SLA at 60 DAS and 80 DAS during both rainy and post rainy seasons, suggesting the need for using donor parent as the maternal parent in crossing programme to recover higher frequency of superior lines in advanced generations.

JUG 26 with lowest $\Delta^{13}C$ value coupled with higher SCMR and lower SLA was identified as the most water use efficient genotype.

In F_2 generation of all the 4 crosses, highly significant and negative association was observed between SCMR and SLA.

Significant positive association between SCMR and shelling percentage was observed in the cross ICG 9418 x Chico.

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Plate-1: Overview of experimental plot

Plate 2: Nine genotypes used in the study