

**Tapping wild *Cicer* species for
enriching variability in cultivated
genepool for chickpea improvement**

THESIS

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**Jawaharlal Nehru Krishi Vishwa Vidyalaya,
Jabalpur**

In partial fulfilment of the required for the

Degree of

MASTER OF SCIENCE

In

AGRICULTURE

(Genetics and Plant Breeding)

By

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2019

CERTIFICATE- I

This is to certify that the thesis entitled, “**Tapping wild *Cicer* species for enriching variability in cultivated genepool for chickpea improvement**” submitted in partial fulfilment of the requirement for the degree of **MASTER OF SCIENCE IN AGRICULTURE (Genetics and Plant Breeding)** of Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur is a record of the bonafide research work carried out by **Mr. Vikas Verma** under my guidance and supervision. The subject of the thesis has been approved by the Student’s Advisory Committee and the Director of Instructions.

All the assistance and help received during the course of the investigation has been acknowledged by him.

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This is to certify that the thesis entitled, “**Tapping wild *Cicer* species for enriching variability in cultivated genepool for chickpea improvement**” submitted by **Mr Vikas Verma** to the Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur in partial fulfilment of the requirements for the degree of **MASTER OF SCIENCE IN AGRICULTURE (Genetics and Plant Breeding)** in the Department of **Plant Breeding and Genetics** has been, after evaluation, approved by the External Examiner and by the Student’s Advisory Committee after an oral examination on the same.

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Declaration and Undertaking by the Candidate

I, **Vikas Verma** S/o Mr.Radheshyam Verma Certify the work embodied in thesis entitled “**Tapping wild *Cicer* species for enriching variability in cultivated genepool for chickpea improvement**” is my own first hand bonafide work carried out by me under the guidance of **Dr. Anita Babbar** at Department of Plant Breeding and Genetics, College of Agriculture, Jabalpur during **2018-2019**.

The matter embodied in the thesis has not been submitted for the award of any other degree/diploma. Due credit has been made to all the assistance and help.

I, undertake the complete responsibility that any act of misinterpretation, mistakes, errors of fact are entirely of my own.

I, also abide myself with the decision taken by my advisor for the publication of material extracted from the thesis work and subsequent improvement, on mutually beneficial basis, provided the due credit is given ,thereof.

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Date: -

Place:-Jabalpur

(**Mr. Vikas Verma**)

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List of symbols

S. No.	Abbreviations		Stand for
1	%	-	Percentage
2	$\sqrt{\quad}$	-	Square root
3	Σ	-	Summation
4	cm	-	Centimeter
5	<i>et al.</i> ,	-	And co-workers
6	g	-	Gram
7	ha	-	Hectare
8	SE	-	Standard error
9	viz.	-	Namely
10	df	-	Degree of freedom
11	DF	-	Days to first flowering
12	DF50	-	Days to 50% flowering
13	DM	-	Days to maturity
14	PH	-	Plant height
15	PPP	-	Number of effective pods per plant
16	PWP	-	Pod weight per plant
17	SPP	-	Number of Seed yield per plant
18	SYP	-	seeds yield per plant
19	BY	-	Biological yield

Sr. No.	Abbreviations		Stand for
20	HSW	-	100-Seed weight
21	HI	-	Harvest index
22	ILs	-	Introgression lines
23	Min.	-	Minimum
24	Max.	-	Maximum
25	PCV	-	Phenotypic coefficient of variation
26	GCV	-	Genotypic coefficient of variation
27	h^2	-	Heritability
28	GAM	-	Genetic advance as percent of mean
29	PCA	-	Principal component analysis
30	SE	-	Semi-erect
31	SS	-	Semi-spreading
32	S	-	Spreading
33	$\pm$	-	Plus or minus
34	>	-	More than
35	<	-	Less than
36	-	-	Hyphen
37	()	-	Parenthesis
38	:	-	Colon
39	;	-	Semicolon

Sr. No.	Abbreviations	Stand for
40	,	- Coma
41	/	- Oblique
42	.	- Full stop
43	Fig.	- Figure
44	<i>i.e.</i>	- That is
45	LSD	- Least significant difference
46	mha	- Million hectare
48	mt	- Million ton

INTRODUCTION

Chickpea [*Cicer arietinum* (L.); $2n = 2x = 16$] belongs to the genus *Cicer*, family Fabaceae (Leguminosae), subfamily Faboideae (Papilionaceae), and tribe *Cicereae* Alef. It is commonly known as gram, bengal gram or garbanzo bean and is the important cool season food grain legume in the world after common bean (*Phaseolus vulgaris* L.) and field pea (*Pisum sativum* L.). Chickpea originated in south-eastern Turkey (Ladizinsky, 1975) and is an annual, self-pollinating, diploid pulse crop with a genome size of ~738 Mbp (Varshney *et al.*, 2013). Based on seed size and colour, cultivated chickpea are of two types: Macrosperma (*Kabuli* type) and Microsperma (*desi* type) (Cubero, 1975).

1. Macrosperma (*Kabuli* type). The seeds of this type are relatively large (100-seed weight >25 g), plump, round-shaped, and with smooth cream-coloured testas. The plants are medium to tall in height with large leaflets and white flowers and don't contain anthocyanin.

2. Microsperma (*desi* type). The seeds of this type are small and angular in shape with rough brown to yellow testas. There are 2-3 ovules per pod but on an average 1-2 seeds per pod are produced. The plants are short with small leaflets and purplish flowers and contain anthocyanin.

Chickpea is cultivated on 14.6 million hectare (m ha) area with 14.8 million metric tonnes (mt) production in over 45 countries of the world. India is the largest chickpea producer accounting for a share of about 67% in global chickpea production with about 9.51 mha area, 9.08 mt production and 951.4 kg/ha productivity (FAOSTAT, 2017-18). Distribution of chickpea in six states viz., Madhya Pradesh, Rajasthan, Maharashtra, Uttar Pradesh, Karnataka and Andhra Pradesh together contribute 91% of the production and 90% of the area of the country. In Madhya Pradesh, chickpea is cultivated on 3.59 m ha area with 4.60 mt production and 1280 kg/ha productivity (PC Annual Report, 2018). As a grain legume, it plays a significant role in the nutrition of

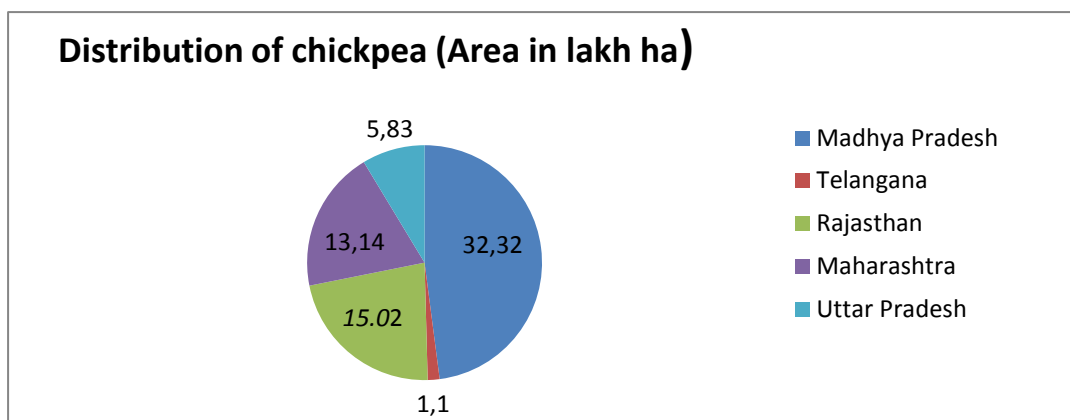


Figure 1.1 Contribution (%) of states in India at national level

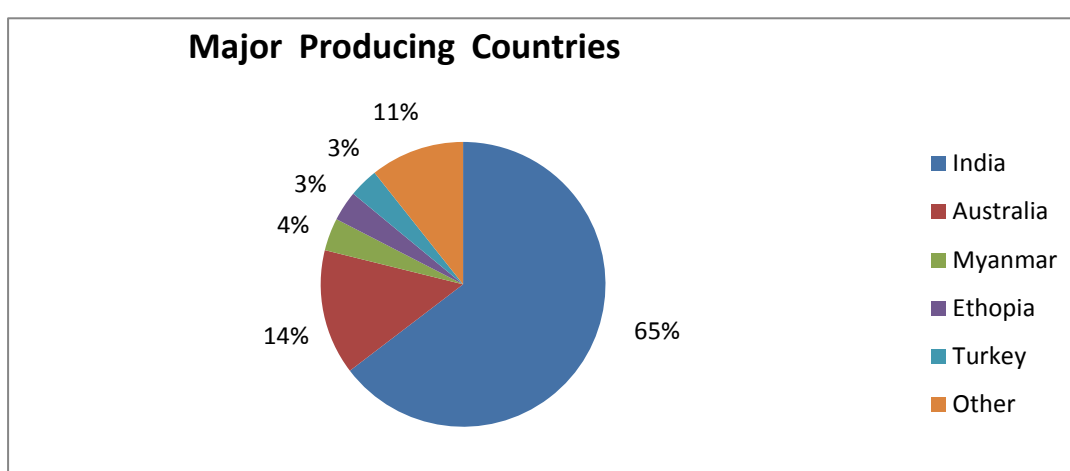


Figure 1.2 Production(%) of chickpea at global level

the rural and urban poor in the eveloping world with providing a protein-rich supplement to cereal-based diets particularly of vegetarians and subsistence farmers who cannot afford meat. The seed is the main edible part of the plant and contains 23% protein, 64% total carbohydrates, 47% starch, 5% fat, 6% crude fibre and 6% soluble sugar. It is rich in essential amino acid lysine and deficient in sulfur-containing amino acids, methionine, and cysteine. Like other legume crops, chickpea can fix atmospheric nitrogen through its symbiotic association with *Rhizobium* species, thus helping in enhancing soil quality for subsequent cereal crop cultivation.

Chickpea is an important grain legume of the semi-arid tropics and warm temperate zones and forms one of the major components of the human diet. However, a narrow genetic base of cultivated chickpea (*Cicer arietinum*

L.) has hindered the progress in realizing high yield gains in breeding programs. Furthermore, various abiotic and biotic stresses are the major bottlenecks for increasing chickpea productivity. Since adequate sources of resistance to abiotic and biotic stresses and productivity traits are often not available within cultivated germplasms, this has stimulated the interest to use wild species for the improvement of chickpea (Mallikarjuna *et al.*, 2007). Ladizinsky and Adler (1976 a,b) exploited the possibilities of introgression of desirable alien genes from wild into cultivated chickpea.

Studies have shown that besides disease resistance and drought tolerance, the wild *Cicer* species possess genes for a higher number of fruiting branches and pods per plant contributing towards higher productivity (Singh *et al.*, 1994). Among the wild species, *C. reticulatum*, the progenitor species of cultivated chickpea, possesses many desirable genes for resistance to various biotic and abiotic stresses like *Fusarium* wilt (Infantino *et al.*, 1996). In addition, it also contains valuable genes that contribute to yield and its component traits (Singh *et al.*, 2005).

The extent of genetic variability has been considered as an important factor, which is an essential pre-requisite for a successful hybridization aimed at producing high yielding progenies. Using two wild *Cicer* species, *C. reticulatum* (ICC 17269) and *C. echinospermum* (IG 69978) and cultivated chickpea (ICC 4958) in crossing program following complex cross approach (3-way cross), new genetic variability has been created for chickpea improvement (Sharma, 2017). The present investigation was undertaken to assess the genetic variability, heritability and association studies among yield-related traits in the selected introgression lines derived from this complex cross.

Realizing the importance of above aspects, the present investigation has been carried out with the following objectives:

Objectives of Investigation

- 1.To estimate the genetic parameters for yield and component traits
- 2.To study the correlation coefficient amongst various characters and measure direct and indirect effects of various components on yield
- 3.To identify the trait-specific promising introgression lines for the use in chickpea improvement programs

REVIEW OF LITERATURE

Chickpea is an important grain legume of the semi-arid tropics and warm temperate zones and forms one of the major components of the human diet. However, a narrow genetic base of cultivated chickpea (*C. arietinum* L.) has hindered the progress in realizing high yield gains in breeding programs. Furthermore, various abiotic and biotic stresses are the major bottlenecks for chickpea productivity. Since adequate sources of resistance to abiotic and biotic stresses and productivity traits are often not available within cultivated germplasms and this has stimulated the interest to use wild species for the improvement of chickpea (Mallikarjuna *et al.*, 2007). On the other hand, the extent of genetic variability has been considered as an important factor, which is an essential prerequisite for a successful hybridization aimed at producing high yielding progenies.

Therefore, tapping wild *Cicer* species for enriching variability in the cultivated genepool is essential, considering this, the present investigation was undertaken to assess the genetic variability, idea of heritability, association of various traits in introgression lines and identification of traits specific promising introgression lines for improvement of chickpea.

Keeping in view the immense value of the above aspects, the relevant literature pertaining to the present investigation has been viewed under the following heads:

2.1 Wild species of chickpea:

2.1.1 Utilization of wild species for chickpea improvement

2.1.2 Importance and use in other legume crops

2.1.3 studies on cereals and oilseed crops

2.2 Genetic variability

2.3 Heritability

2.4 Genetic advance

2.5 Correlation coefficient analysis

2.6 Path coefficient analysis

2.1 Wild species of chickpea

The *Cicer* genus belongs to family Leguminosae, subfamily Papilionaceae and tribe Cicereae Alef. The *Cicer* genus currently comprises 43 species, out of which 9 are annual and 34 are perennial species (Muehlbauer *et al.*, 1994). Most of these species are found in West Asia and North Africa covering Turkey in the north to Ethiopia in the south and Pakistan in the east to Morocco in the west. Of the 9 annual *Cicer* species, *C. arietinum* is the only cultivated species. The eight other annual *Cicer* species are *C. reticulatum*, *C. echinospermum*, *C. pinnatifidum*, *C. judaicum*, *C. bijugum*, *C. cuneatum*, *C. chorassanicum* and *C. yamashitae*.

The wild annual progenitor of chickpea has been identified as *C. reticulatum* L. (Ladizinsky and Adler, 1976), and the perennial progenitor is proposed as *C. anatolicum* (Tayyar and Waines, 1996). The *Cicer* species including cultivated and wild, have been classified into four sections based on their geographical distribution, life cycle and morphological characteristics (vander Maesen, 1987). The 8 annual species, namely, *C. arietinum*, *C. reticulatum*, *C. echinospermum*, *C. pinnatifidum*, *C. bijugum*, *C. judaicum*, *C. yamashitae* and *C. cuneatum*, were grouped in section *Monocicer*, annual species *C. chorassanicum* and perennial species *C. Incisum* in section *Chamaecicer*, 23 perennial species in section *Polycicer* section and the remaining 7 woody perennial species in section *Acanthocicer*.

2.2.1 Utilization of wild species for chickpea improvement

Brinsmead *et al.* (1985) found limited resistance in chickpea germplasm for Phytophthora root rot (*Phytophthora medicaginis*) which is a major disease of chickpea in north-eastern Australia. This necessitates utilization of wild species as the host-plant resistance is the only practicable management option for this disease.

Badami *et al.* (1997) used *C. reticulatum* and *C. echinospermum*, the wild *Cicer* species that are cross-compatible with the cultivated species for chickpea improvement. These species have narrow ecogeographic adaptation and may therefore provide limited array of adaptive alleles. Use of more

distantly related species, those in tertiary gene pool, may offer more allelic diversity.

(Singh and Ocampo, 1997) reported successful utilization of *C. reticulatum* for increasing yield (up to 39%).

Collard *et al.*(2001) identified a number of resistant wild *Cicer* accessions in controlled environment, particularly those belonging to *C. bijugum*. (Collard *et al.*,2003)Quantitative trait loci (QTL) associated with seedling and stem resistance to the fungal disease ascochyta blight were detected in the F₂ population of a cross between a resistant accession of *C. echinospermum* and a susceptible accession of cultivated chickpea.

Berger *et al.*(2005) showed that some annual wild *Cicer* species (including *C. eticulatum* and *C. echinospermum*) were almost insensitive to the temperature range experienced during flowering at a strategically located cool site; interspecific hybrids, despite being selected for an unrelated trait (root-lesion nematode resistance) also showed a significantincrease in chilling tolerance as reflected in a shorter interval from anthesis to pod appearance.

Knights *et al.*(2008)observed wild annual *Cicer* species in during an experiment and found wild relative from both the primary (*C.reticulatum* and *C.echinospermum*) and secondary (*C.bijugum*) genepools of chickpea were generally more resistant than commercial chickpea cultivars to either *Pratylenchus thornei* or *Pratylenchus neglectus* or both .Resistant accessions of *C.reticulatum* and *C.echinospermum* were crossed and topcrossed with desi cultivars and resistant F₄ lines were obtained.

Gaur *et al.*(2009) reviewed that the wild species of grain legumes are valuable gene pools, particularly for resistance to biotic and abiotic stresses. These have largely remained under-utilized due to crossability barriers, but there are some examples of successful introgression of genes into the cultivated species from their wild relatives, particularly those constituting primary and secondary gene pools. In chickpea, two closely related species, *C. reticulatum* and *C. echinospermum*, have been used for widening genetic base of the cultigen and introgressing genes for resistance/tolerance to phytophthora root rot, cyst nematode (*Heterodera ciceri*), root-lesion

nematode (*Pratylenchus* spp.), pod borer (*Helicoverpa armigera*), ascochyta blight, botrytis grey mould and low temperatures.

Sharma *et al.* (2015) observed synergistic effects of vernalization and photoperiod in *C.bijugum*, *C.yamashitae*, *C.chorassanum* and *C.cuneatum*. However, both vernalization and photoperiod treatments had minimal effect on the rate of progress toward flowering in early-maturity and greater effects on medium and late-maturing chickpea varieties. These results would contribute significantly to enhance use of wild *Cicer* species for chickpea improvement through synchronization of flowering facilitating hybridization.

Sharma *et al.* (2016) evaluated a set of two BC₂F₂ populations that resulted in the identification of introgression lines with early flowering (26 days), high number of pods per plant (up to 460 pods), high pod weight per plant (up to 180 g), high number of seeds per plant (up to 460 seeds), and high seed weight per plant (up to 142.0 g).

2.1.2 Importance and use in other legume crops

1.Pigeonpea (*Cajanus cajan* Mill Sp.)

Dodia *et al.* (1996) suggested that resistance to *H. armigera* in cultivated pigeonpea could be improved by transferring genes regulating the production of non-glandular trichomes on pods from *C. scarabaeoides*.

Shanower *et al.* (1997) studied the survival, growth and fecundity of *H.armigera* on pods of *C.cajan* and two wild species and reported that survival on *C.scarabaeoides* was 21% compared to 57% on *C. platycarpus* and 78% on *C. cajan*. The dense covering of non-glandular trichomes on *C. Scarabaeoides* acts as physical barrier and prevents small larvae reaching the surface of the pods .

Sharma *et al.* (2003) identified wild relatives of pigeonpea such as *Cajanus scarabaeoides*, *C. sericeus*, *C. acutifolius*, *C. albicans*, *Rhynchosia aurea*, *R. bracteata* and *Flemingia bracteata* are highly resistant to *H. armigera*. Some of the wild relatives of pigeonpea have also shown resistance to pod fly (*Melanagromyza obtusa*) and pod wasp (*Tanaostigmodes cajaninae*).

Mallikarjuna *et al.*(2006) successfully crossed *Cajanus platycarpus*, a wild species in the tertiary gene pool of pigeonpea, with cultivated pigeonpea by hormone-aided pollinations and the aborting hybrid embryos rescued in vitro. Tetraploids have been obtained by treating the hybrids with colchicine as the F₁ hybrids were 100% pollen sterile. The convertibility of diploids to tetraploids using colchicine treatments was less than 3%. Tetraploids at the F₃ and F₄ generations in pigeonpea were screened for resistance to *H. armigera* under field conditions and pod damage was found to be quite low (<10).

Mallikarjuna *et al.*(2007) developed advanced generation population having resistance to pod borer, variation in seed colour and high seed weight by utilization of *C. acutifolius* as the pollen parent.

2. lentil

Hamdi *et al.*(1996) observed cold tolerance and earliness in *L. culinaris* ssp. *orientalis*.

(Gupta and Sharma, 2006) reported genetic variability for yield attributes and biotic and abiotic stresses among 70 accessions of four wild species/subspecies (*L. culinaris* ssp. *orientalis*, *L. odemensis*, *L. ervoides*, and *L. nigricans*). As the result, donors for resistance to powdery mildew [*L. culinaris* ssp. *orientalis* (ILWL 200), *L. nigricans* (ILWL 37)], rust, and wilt resistance have been found in all above the four species and also for drought tolerance in *L. nigricans* and seeds per plant in *L. culinaris* ssp. *Orientalis* (ILWL 90).

2.1.3 Studies on cereals and oilseed crops

1. Rice

(Jena and Khush, 1990) identified resistance to three biotypes of Brown plant hopper (*Nilaparvata lugens*) in *O. officinalis* and transferred this resistance into *O. sativa*.

Khush *et al.*(1990) and Brar *et al.*(1996) identified a dominant gene for resistance to bacterial blight (*Xanthomonas oryzae* pv. *oryzae*) in *O. longistaminata* and transferred to *O. sativa*. Several introgression lines are resistant to bacterial blight developed by crossing IR 56 with *O. brachyantha*.

Bordeos *et al.*(1992) found resistance to Blast disease (*Magrtaportha grisea*) and Bacterial blight transferred from *O. minuta* to *O. sativa*.

2. Wheat

Cai *et al.*(2005) identified resistance to fusarium head blight (*Fusarium graminearum*) transferred from *T. dicoccoides*, *T. timopheevi*, *T. monococcum*, and *Ae. speltoides* to *T. aestivum*.

Gororo *et al.*(2002) identified traits related to drought tolerance in *T. aestivum*. in a cross with *T. tauschii* contributed.

3.Maize

Goodman *et al.*(1987) found resistance to northern corn leaf blight (*Bipolaris maydis*) transferred from *Tripsacum dactyloides* to maize.

4.Peanut

Stalker *et al.*(2002) observed wild *Arachis* species contributed resistance to nematodes (*Meloidogyne* spp.), Spodoptera (*S. frugiperda* and *S. litura*), corn earworm (*Heliothis zea*), southern corn rootworm (*Diabrotica tica undecimpunctata howardi*), velvet bean caterpillar (*Anticarsia gemmatilis*), and Jassids (*Empoasca* ssp) to *A. hypogaea*.

5.Soybean

Sebolt *et al.*(2000) studied *G. Soja* which contributed 2 major QTL alleles that increased protein content in backcross progenies involving *G. soja* and *G. max*.

Concibido *et al.*(2003) studied *G. Soja* which contributed yield-enhancing QTL alleles that demonstrated 9% yield advantage in backcross progenies.

2.2 Genetic Variability

Variability refers to the presence of differences among the individuals of the plant population. Variability results due to differences either in the genetic constitution of the individuals of a population or in the environment on which they are grown. The literature available on this topic in chickpea is reviewed here:

(Bharadwaj and Singh, 1970) studied the genotypic and phenotypic variability in a collection of 60 indigenous lines of chickpea under irrigated condition. A wider range of phenotypic variability was observed in plant height, a number of branches per plant and number of pods per plant. The three characters viz., 100 seed weight, a number of seeds per pod and seed yield per plant were found to have a high coefficient of variation.

(Mandal and Bahl, 1983) studied 40 local and introduced cultivar of *C. arietinum*. They reported the high genotypic and phenotypic coefficient of variability for biological yield.

(Sandhu and Mandal, 1989) observed a considerable range of variability for plant height, pod number, seed number, seed weight and seed yield in 48 diverse chickpea line grown during rabi 1986-87.

(Rao, 1996) provided information on genetic variability for 10 yield-related traits in 40 chickpea genotypes. Variability was highest for pod weight per plant followed by seed yield and pods per plant.

(Rao and Kumar, 2000) measured genetic variability in 40 short duration desi chickpea genotypes. They observed high variation for biological yield by seed yield and minimum variability for days to maturity followed by days to 50% flowering.

Hedge *et al.* (2003) observed a high and significant coefficient of variability for pods per plant, seed per plant, 100 seed weight and seed yield per plant.

Brar *et al.* (2004) evaluated chickpea genotypes for seed yield and its components viz., days to flowering, days to maturity, plant height, primary branches per plant, pods per plant, 100 seed weight. The genotypes differed significantly for all the characters studied.

Vaghela *et al.* (2008) evaluated fifty genotypes of Kabuli chickpea and estimated the high genotypic coefficient of variation for seed yield per plant and number of pods per plant.

Borate *et al.*(2010) observed population parameters such as range, mean, phenotypic and genotypic variances, PCV and GCV, heritability and genetic advance for 13 agronomic characters in a set of 30 chickpea genotypes. Range of variability was appreciable for days to first flowering, plant height, dry matter and grain yield. Values of genotypic and phenotypic variances were highest for a number of pods, while the lowest for seeds. PCV showed higher values than GCV for all characters.

Babbar *et al.*(2012) studied forty-four promising lines of chickpea under the late sown condition and found the maximum genotypic coefficient of variation for a total number of seeds per plant and the total number of pods per plant.

Rajkumar *et al.*(2014) observed 100 advance breeding lines of chickpea (received from ICRISAT) were sown on 26th January 2012. The analysis of variance revealed the significant differences among the genotypes for all the traits indicating the presence of sufficient variability among the genotypes for various traits.

Desai *et al.*(2015) determine the extent of genetic variability in the indigenous collection of 48 different chickpea genotypes for yield, nutritional quality and other agronomic characters. The analysis of variance revealed the existence of considerable genetic differences among the genotypes for all the characters. The highest genotypic coefficient of variation was observed for the 100-seed weight (22.95) followed by a number of pods per plant (19.41), seed yield per plant (13.63) and a number of seeds per pod (13.18).

Joshi *et al.*(2018) observed 252 intra-specific recombinant inbred lines (RIL) population derived from a cross between desi (ICC 283) and Kabuli (ICC 8261) type of chickpea, received from ICRISAT, Patancheru, India. Traits assessed were days to 50% flowering, maturity, plant height, biological yield, seed yield, harvest index and 100-seed weight. Standard statistical analysis was adopted for calculating the genetic variability. High estimates of GCV and PCV were recorded for seed yield per plant, 100-seed weight, biological yield per plant and harvest index per plant in RILs.

Singh *et al.*(2018) observed 105 genotypes of chickpea during *Rabi* season of 2013-14. The genotypic coefficient of variation was highest for seed yield per plant followed by harvest index, number of pods per plant, 100 seed weight and plant height.

2.3 Heritability

Heritability is the proportion of phenotypic variation in a population that is attributable to genetic variation among individuals. Phenotypic variation among individuals may be due to genetic and/or environmental factors. Heritability analysis estimates the relative contributions of differences in genetic and non-genetic factors to the total phenotypic variance in a population. The estimate of heritability helps the plant breeder in the selection of elite genotypes from a diverse population and as a good index of the transmission of characters from parents to their offspring. The literature available on this topic in chickpea is reviewed here:

Sidramappa *et al.*(2008) found high heritability for pods per plant, seed yield per plant, seed weight, days to 50% flowering, days to pod initiation and plant height.

Vaghela *et al.*(2008) found high heritability for all the traits except plant height in chickpea.

Borate *et al.*(2010) recorded high heritability coupled with high genetic advance for grain yield, plant height, dry matter, days to first flowering and days to maturity indicated high additive gene effects.

Dar *et al.*(2012) reported high heritability for 100-seed weight and seed yield per plant.

Singh *et al.*(2012) found high estimates of heritability for 100-seed weight, number of pods per plant, number of branches per plant, plant height, seed yield and number of seeds per pod

Jain *et al.*(2013) reported that seed yield /plant, harvest index and 100 seed weight exhibited high heritability and moderate to high estimates of genetic advance as percentage of mean.

(Monpara and Dhameliya, 2013) estimated high heritability for flowering periods, followed by days to maturity, plant height and seed yield per plant

2.4 Genetic advance

Improvement in the mean genotypic value of selected plants over the parental population is known as genetic advance. It is the measure of genetic gain under selection. The success of genetic advance under selection depends on three main factors *i.e.* genetic variability, heritability and selection intensity.

Singh *et al.*(2012) observed that pods per plant, 100-seed weight, biological yield per plant and seed yield per plant had high genetic advance.

Vaghela *et al.*(2008) found high genetic advance expressed as a percentage of the mean for seed yield per plant and number of pods per plant.

Babbar *et al.*(2012) found medium genetic advance as a percentage of mean for days to 50% flowering, days to maturity, plant height, 100 seed weight and seed yield per plant, whereas a number of seeds per plant and number of pods per plant showing high genetic advance as a percentage of mean.

Gul *et al.*(2013) observed high genetic advance for pods per plant, seed yield per plant, primary branches per plant and secondary branches per plant.

Kuldeep *et al.*(2014) reported high genetic advance as percentage of mean for seed yield per plant, followed by 100 - seed weight, harvest index, number of effective pods per plant, total number of pods per plant and number of secondary branches, while moderate genetic advance was observed for plant height, seeds per pod and days to flower initiation.

Yadav *et al.*(2015) found moderate genetic advance for a number of primary branches, number of secondary branches, plant height, pod length, and pods/plant, indicating the influence of environment for these traits. Low and moderate genetic advancement has been observed for days to maturity indicated that this trait was greatly influenced by the environment.

2.4 Correlation coefficient analysis

Knowledge about the interrelationship between yield and yield contributing characters facilitates the choice of efficient breeding method to be adopted and the selection of parents for the crop improvement programme. The correlation coefficient is a statistical measure which is used to find out the degree and direction of the relationship between two or more variables. The phenotypic correlation coefficient helps in determining selection index whereas, genotypic correlation coefficient provides a close measure of association between characters which may be useful for the overall improvement of the crop.

(Narayan and Reddy, 2002) observed a significant association between seed yield and harvest index, a number of pods per plant and number of secondary branches per plant both at genotypic and phenotypic levels. It was observed that the number of pods per plant, 100 seeds weight, number of seeds/ pods and harvest index had a high direct effect on seed yield.

Brar *et al.* (2004) observed that seed yield showed a highly significant and positive correlation with pods per plant, plant height and primary branches per plant

(Babbar and Patel, 2005) revealed the positive significant association of seed yield with biological yield, pod weight per plant, number of pods per plant and days to maturity.

(Atta, 2008) reported that grain yield per plant showed a highly significant positive correlation with days to maturity, primary branches, secondary branches, 100 seed weight and pods per plant.

(Thakur and Sirohi, 2009) evaluated 53 chickpea genotypes over two seasons to find out association among characters and found that seed yield per plant exhibited stable positive association with biological yield per plant, pods per plant, primary branches per plant, plant height and harvest index at genotypic and phenotypic levels in individually as well as combined over seasons.

(Tomar and Singh, 2009) reported that the genotypic correlation coefficient was observed to be higher than that of phenotypic correlation coefficient indicating the existence of strong inherent association for various traits and phenotypic selection may be rewarded. Grain yield/plant exhibited a stable positive association with biological yield/plant, followed by seeds/plant, pods/plant and seeds/pod at genotypic and phenotypic levels.

Sreelakshmi *et al.* (2010) exhibited significant positive correlation for days to 50% flowering, days to maturity and number of pods per plant with seed yield.

(Mishra and Babbar, 2011) observed that seed yield per plant was positively and significantly correlated with effective pods per plant, seeds per pod, biological yield per plant, 100 seed weight and harvest index in normal and late sown.

Dar *et al.* (2012) observed that seed yield had a significant positive correlation with pods per plant, branches per plant and seeds per pod.

Devasirvatham *et al.* (2013) found that phenological traits viz., days to first flowering and days to pod maturity showed a significant and negative correlation among themselves. Plant biomass, pod number, filled pod number and seed number per plant were positively correlated with grain yield.

(Monpara and Dhamelia, 2013) revealed that days to flowering, flowering period and days to maturity had significant positive association among themselves.

Tesfamichael *et al.* (2015) found a significant positive correlation of seed yield per ha with biomass yield per ha, pods per plant, plant canopy width and secondary branches per plant

2.5 Path coefficient analysis

The path analysis helps in partitioning the correlation coefficient of yield components into their direct and indirect effects on seed yield to ensure the actual contribution of an attribute as well as its influence through other traits. Therefore, an attempt has been made to review the available literature on these aspects.

Uddin *et al.*(1990) studied 54 chickpea varieties and showed that days to maturity, pods per plant, 100 seed weight, harvest index, plant height and primary branches per plant had a positive direct effect on yield per plant.

Dasgupta *et al.*(1992) studied path analysis on 9 yield components in 28 genotypes of chickpea. They reported that pods per plant, seeds per plant, 100 seed weight and seeds per pod had a highly positive direct effect on yield.

(Ozdemir, 1996) revealed that seed yield perplot had a significant and positive correlation with seed yield per plant, seeds per pod, pods per plant, secondary branches per plant, biological yield, harvest index and plant height but the 100-seed weight was negatively associated with seed yield. Seed yield per plant showed maximum direct contribution towards seed yield followed by plant height, secondarybranches per plant, seeds per plant and harvest index.

Talebi *et al.*(2007) observed that harvest index had a greatest direct effect on seed yield and its indirect effect on seed yield was positive through plant height, a number of seeds per pod and biomass, but negative and low through days to maturity, 100 seed weight and a number of primary branches.

(Borate and Dalvi, 2010) noted that a number of pods per plant and number of primary branches had the highest direct positive effect on grain yield, followed by dry matter per plant.

(Yucel and Anlarsal, 2010) revealed that the harvest index had the greatest direct effect on seed yield (0.4206)

(Hasan and Deb, 2014) revealed that number of seeds per plant had maximum positive direct effect on seed yield, followed by days to first flower and plant height at genotypic level, while at phenotypic level, plant height at maximum flower had the highest positive direct effect on yield, followed by plant weight at harvest and number of pods per plant.

(Monpara and Gaikwad, 2014) confirmed that the number of seeds per plant (0.672 to 0.821) and 100-seed weight (0.441 to 0.501) had the highest positive direct influence on grain yield per plant.

Chandra *et al.*(2015) studied the M3 and M4 generations and found that harvest index and biological yield per plant had a high (maximum) direct effect on seed yield per plant in both generations.

MATERIALS AND METHODS

The present investigation entitled, “**Tapping wild *Cicer* species for enriching variability in cultivated genepool for chickpea improvement**” was conducted at, ICRISAT, Patancheru, Telangana, during 2018-19 *rabi* season. Details of the material used, methods adopted and statistical analysis followed during the investigation are described below.

3.1. Experimental material

The experimental material used for study consisted of 300 Introgression lines derived from three-way cross between ICC 4958 x (ICC 17269 (*Cicer reticulatum*) x IG 69978 (*Cicer echinospermum*)) followed by advanced backcross at **ICRISAT, Patancheru, Hyderabad**. The list of Introgression lines is given in Table 3.1.

3.2The experimental details:

Location	:	ICRISAT
Crop	:	Chickpea
Season	:	<i>rabi</i> (2018-19)
Design	:	Augmented design
Number of blocks	:	6
Number of genotypes	:	300
Number of checks	:	4
Row to Row distance	:	60.0 cm
Row length	:	3.0 m

3.3 Observations:

Data on days to first flowering, days to 50% flowering, growth habit, days to maturity were recorded on plot-basis. For remaining traits, five representative plants were selected randomly from each plot and tagged for recording the observations. Overall, the following observations were recorded:

Plate 1- Field view of the experiment



3.3.1 Days to first flowering (DF)

Number of days from the date of sowing to the day when first flower bloomed in the plot

3.3.2 Days to 50% flowering (DF50)

Number of days from the date of sowing to the day when 50% plants in each plot flowered

3.3.3 Growth habit (GH)

Angle of primary branches, recorded on plot -basis at mid-pod filling stage

3.3.4 Plant height (PH) (in cm)

Height of main stem from the base upto the tip of the stem, recorded on each of 5 randomly selected plants at maturity

3.3.5 Days to maturity (DM)

Number of days from the date of sowing to the stage when over 75% of pods in a plot have attained physiological maturity

3.3.6 Number of effective Pods per plant (PPP)

Total number of pods harvested per plant on each of 5 randomly selected plants

3.3.7 Pod weight per plant (PWP)

Weight of total number of pods harvested per plant on each of 5 randomly selected plants

3.3.8 Number of seeds per plant (SPP)

Total number of seeds harvested per plant on each of 5 randomly selected plants

3.3.9 Seed yield per plant (SYP) (g)

Weight of total number of seeds threshed per plant on each of 5 randomly selected plants

3.3.10 Biological Yield (BY) (g)

The aerial parts of each of 5 randomly selected plants were harvested, air dried at 38⁰ c for 48 hrs and total dry weight of the plant above the ground including pod weight were recorded

3.3.11 100 seed weight (HSW) (g)

Weight of 100 randomly selected seeds was recorded in grams for each genotype.

3.3.12 Harvest index (%)

Harvest index was obtained by dividing the total seed yield per plant by biological yield per plant and expressed in per cent.

$$\text{Harvest index (\%)} = \frac{\text{Seed yield per plant (g)}}{\text{Biological yield per plant (g)}} \times 100$$

Table 3.1:List of 300 Introgression lines used in present study along with four checks

S. No	Identity	S. No	Identity	S. No	Identity	S. No	Identity
1	ICCP 171038	30	ICCP 171452	59	ICCP 171761	88	ICCP 172130
2	ICCP 171040	31	ICCP 171461	60	ICCP 171817	89	ICCP 172132
3	ICCP 171051	32	ICCP 171470	61	ICCP 171837	90	ICCP 172137
4	ICCP 171053	33	ICCP 171473	62	ICCP 171840	91	ICCP 172138
5	ICCP 171054	34	ICCP 171480	63	ICCP 171849	92	ICCP 172146
6	ICCP 171056	35	ICCP 171490	64	ICCP 171850	93	ICCP 172147
7	ICCP 171081	36	ICCP 171491	65	ICCP 171869	94	ICCP 172153
8	ICCP 171092	37	ICCP 171500	66	ICCP 171883	95	ICCP 172226
9	ICCP 171119	38	ICCP 171501	67	ICCP 171892	96	ICCP 172228
10	ICCP 171128	39	ICCP 171509	68	ICCP 171893	97	ICCP 172229
11	ICCP 171129	40	ICCP 171513	69	ICCP 171894	98	ICCP 172230
12	ICCP 171135	41	ICCP 171526	70	ICCP 171908	99	ICCP 172231
13	ICCP 171136	42	ICCP 171547	71	ICCP 171912	100	ICCP 172238
14	ICCP 171169	43	ICCP 171548	72	ICCP 171947	101	ICCP 172244
15	ICCP 171182	44	ICCP 171551	73	ICCP 171952	102	ICCP 172261
16	ICCP 171207	45	ICCP 171557	74	ICCP 171954	103	ICCP 172276
17	ICCP 171230	46	ICCP 171561	75	ICCP 171961	104	ICCP 172281
18	ICCP 171248	47	ICCP 171566	76	ICCP 171968	105	ICCP 172293
19	ICCP 171265	48	ICCP 171567	77	ICCP 171969	106	ICCP 172318
20	ICCP 171271	49	ICCP 171576	78	ICCP 171988	107	ICCP 172325
21	ICCP 171287	50	ICCP 171638	79	ICCP 172027	108	ICCP 172331
22	ICCP 171289	51	ICCP 171667	80	ICCP 172056	109	ICCP 172350
23	ICCP 171306	52	ICCP 171669	81	ICCP 172063	110	ICCP 172352
24	ICCP 171340	53	ICCP 171711	82	ICCP 172071	111	ICCP 172401
25	ICCP 171341	54	ICCP 171712	83	ICCP 172077	112	ICCP 172418
26	ICCP 171343	55	ICCP 171732	84	ICCP 172079	113	ICCP 172429
27	ICCP 171358	56	ICCP 171745	85	ICCP 172118	114	ICCP 172432
28	ICCP 171399	57	ICCP 171750	86	ICCP 172126	115	ICCP 172436
29	ICCP 171443	58	ICCP 171760	87	ICCP 172128	116	ICCP 172483

S. No	Identity	S. No	Identity	S. No	Identity	S. No	Identity
117	ICCP 172495	145	ICCP 172994	173	ICCP 173122	201	ICCP 173234
118	ICCP 172509	146	ICCP 172999	174	ICCP 173124	202	ICCP 173237
119	ICCP 172518	147	ICCP 173003	175	ICCP 173125	203	ICCP 173238
120	ICCP 172519	148	ICCP 173004	176	ICCP 173126	204	ICCP 173239
121	ICCP 172524	149	ICCP 173005	177	ICCP 173129	205	ICCP 173253
122	ICCP 172535	150	ICCP 173007	178	ICCP 173130	206	ICCP 173256
123	ICCP 172553	151	ICCP 173010	179	ICCP 173157	207	ICCP 173271
124	ICCP 172554	152	ICCP 173011	180	ICCP 173159	208	ICCP 173278
125	ICCP 172563	153	ICCP 173012	181	ICCP 173160	209	ICCP 173284
126	ICCP 172569	154	ICCP 173014	182	ICCP 173161	210	ICCP 173287
127	ICCP 172576	155	ICCP 173017	183	ICCP 173163	211	ICCP 173299
128	ICCP 172587	156	ICCP 173019	184	ICCP 173170	212	ICCP 173308
129	ICCP 172727	157	ICCP 173028	185	ICCP 173171	213	ICCP 173312
130	ICCP 172734	158	ICCP 173032	186	ICCP 173174	214	ICCP 173314
131	ICCP 172738	159	ICCP 173034	187	ICCP 173180	215	ICCP 173315
132	ICCP 172765	160	ICCP 173037	188	ICCP 173181	216	ICCP 173320
133	ICCP 172771	161	ICCP 173043	189	ICCP 173189	217	ICCP 173322
134	ICCP 172801	162	ICCP 173057	190	ICCP 173192	218	ICCP 173330
135	ICCP 172857	163	ICCP 173070	191	ICCP 173199	219	ICCP 173334
136	ICCP 172877	164	ICCP 173071	192	ICCP 173205	220	ICCP 173335
137	ICCP 172936	165	ICCP 173085	193	ICCP 173206	221	ICCP 173337
138	ICCP 172938	166	ICCP 173089	194	ICCP 173207	222	ICCP 173341
139	ICCP 172940	167	ICCP 173090	195	ICCP 173209	223	ICCP 173358
140	ICCP 172944	168	ICCP 173091	196	ICCP 173210	224	ICCP 173359
141	ICCP 172949	169	ICCP 173099	197	ICCP 173211	225	ICCP 173362
142	ICCP 172953	170	ICCP 173101	198	ICCP 173212	226	ICCP 173370
143	ICCP 172957	171	ICCP 173104	199	ICCP 173230	227	ICCP 173387
144	ICCP 172979	172	ICCP 173116	200	ICCP 173231	228	ICCP 173396

S. No	Identity	S. No	Identity	S. No	Identity
229	ICCP 173408	256	ICCP 173677	283	ICCP 173805
230	ICCP 173419	257	ICCP 173679	284	ICCP 173806
231	ICCP 173426	258	ICCP 173686	285	ICCP 173807
232	ICCP 173442	259	ICCP 173695	286	ICCP 173808
233	ICCP 173502	260	ICCP 173696	287	ICCP 173809
234	ICCP 173526	261	ICCP 173697	288	ICCP 173811
235	ICCP 173531	262	ICCP 173709	289	ICCP 173817
236	ICCP 173538	263	ICCP 173710	290	ICCP 173818
237	ICCP 173540	264	ICCP 173711	291	ICCP 173819
238	ICCP 173542	265	ICCP 173712	292	ICCP 173826
239	ICCP 173543	266	ICCP 173715	293	ICCP 173842
240	ICCP 173580	267	ICCP 173718	294	ICCP 173843
241	ICCP 173584	268	ICCP 173719	295	ICCP 173844
242	ICCP 173588	269	ICCP 173720	296	ICCP 173845
243	ICCP 173599	270	ICCP 173725	297	ICCP 173847
244	ICCP 173604	271	ICCP 173728	298	ICCP 173856
245	ICCP 173608	272	ICCP 173729	299	ICCP 173859
246	ICCP 173609	273	ICCP 173731	300	ICCP 173863
250	ICCP 173615	277	ICCP 173785	Checks	
252	ICCP 173651	279	ICCP 173797	1	ICC 4958
253	ICCP 173655	280	ICCP 173798	2	JG 14
254	ICCP 173666	281	ICCP 173800	3	JG 130
255	ICCP 173668	282	ICCP 173802	4	ICCV 10

3.4 Statistical methodology

3.4.1 Assessment of variability

a. Analysis of variance

The mean data on five plants were subjected to variance analysis and test of significance as per the method of Sharma (1998).using SAS university edition version 9.4 for individual traits.

The data on quantitative characters were statistically analyzed on the basis of model described for Augmented randomized block design.

$$Y_{ij} = (\mu + b_i + t_j + e_{ij}) n_{ij}$$

Where,

Y_{ij} = Performance of j^{th} genotype in i^{th} block

M = General mean

b_i = i^{th} block effect

t_j = j^{th} treatment effect

e_{ij} = Random errors which are supposed to be identically and independently distributed with normal distribution having mean zero and variance σ^2_e . $i = 1, \dots, r$, $j = 1, \dots, v$, n_{ij} is one if the j^{th} treatment occurs in the i^{th} block and zero otherwise.

ANOVA table for Augmented Experimental Designs

Source of variation	Degrees of freedom	Sum of Square	Mean sum of squares	F-ratio
Blocks	(b-1)	bSS	bMS	bMS/eMS
Entries	(E-1)	ESS	EMS	EMS / eMS
Tests	(T-1)	TSS	TMS	TMS / eMS
Controls	(R-1)	RSS	RMS	RMS / eMS
Test s Vs Controls	1	R vs TSS	R vs TMS	R vs TMS / eMS
Error	(R-1)(b-1)	eSS	eMSS	

Where,

E = Number of entries (introgression lines and checks)

T = Number of unreplicated test entries (introgression lines)

R = Number of blocks

b = Number of replications for controls (checks)

$E = T + R$

The significance of “F” value was tested by comparing the computed value with the table value as given by Fisher. Further, standard error of means (S.E. (m)), critical difference (C.D.) and co-efficient of variations (C.V.) were calculated using appropriate formulae to compare means of the genotypes.

b. Estimation of genetic variability parameters

3.4.1.1 Phenotypic and genotypic variance

Phenotypic and genotypic components of variance were estimated by using the formula given by Cochran and Cox (1957).

Genotypic variance (σ^2_g) = MSS due to genotypes – MSS due to error/No. of blocks

Phenotypic variance (σ^2_p) = Genotypic variance (σ^2_g) + MSS due to error

3.4.1.2 Co-efficient of variability

Both phenotypic and genotypic co-efficient of variability for all the characters were estimated using the formulae of Burton and De Vane (1953).

Genotypic Co-efficient of Variability (GCV):

$$\text{GCV \%} = \frac{\sqrt{\text{Genotypic variance}}}{\text{Grand mean}} \times 100$$

Phenotypic Co- efficient of Variability (PCV):

$$\text{PCV \%} = \frac{\sqrt{\text{Phenotypic variance}}}{\text{Grand mean}} \times 100$$

PCV and GCV were classified as per Shivasubramanian and Menon (1973) as shown below:

0 – 10 %: Low; 10.1 – 20 %: Moderate; >20 %: High

3.4.2 Heritability in Broad sense (h^2)

Heritability (broad sense) was estimated for all the characters as the ratio of total genotypic variance to the total phenotypic variance as suggested by Hanson *et al.* (1956).

$$h^2 (\text{bs}) = \frac{\sigma^2_g}{\sigma^2_p}$$

Where,

$h^2(\text{bs})$ = heritability in broad sense

σ^2_g = Genotypic variance

σ^2_p = Phenotypic variance

The range of heritability was categorized as low (below 50 per cent), moderate (50-70 per cent) and high (above 70 per cent) as followed by Johnson *et al.* (1955).

3.4.3 Genetic Advance (GA)

Genetic advance for each character was estimated by using the following formula of Johnson *et al.* (1955).

$$GA = h^2 \times K \times \sigma_p$$

Where,

h^2 = heritability estimate

K = selection differential which is equal to 2.06 at 5% intensity of selection.

σ_p = phenotypic standard deviation

Further the genetic advance as per cent of mean was computed by using the following formula:

$$\text{GA as per cent of mean} = \frac{\text{GA}}{\text{Grand mean}} \times 100$$

Genetic advance as per cent of mean was categorized according to Johnson *et al.* (1955), as given below. 0 – 10 %: Low; 11 – 20 %: Moderate; ≥ 21 %: High

3.4.4 Correlation studies

Changes in one characteristic accompanied by a change in another variable are referred to as correlation. The coefficient of correlation is the measure of association between two characteristics. Correlations can be either positive,

when an increase in one variable is accompanied by an increase in another one, or negative when an increase in one character is accompanied by a decrease in another (Falconer, 1960).

Genotypic and phenotypic correlations were computed by using the formula given by Weber and Morthy (1952).

$$r = \frac{\text{Cov}(xy)_p}{\sigma_{px} \times \sigma_{py}} \times 100$$

$$r = \frac{\text{Cov}(xy)_g}{\sigma_{gx} \times \sigma_{gy}} \times 100$$

Where, r = Corrélation coefficient

$\text{Cov}(xy)$ = Covariance between the characters 'x' and 'y'

σ_{px} and σ_{py} = Phenotypic variance of the character 'x' and 'y' respectively

σ_{gx} and σ_{gy} = Genotypic variance of the character 'x' and 'y' respectively

Correlation coefficients were compared against 'r' values given in Fisher and Yates (1963) Table at (n-2) degrees of freedom at the probability levels of 0.05 and 0.01 to test their significance.

3.4.5 Path-coefficient analysis

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

Path coefficients were obtained by solving the simultaneous equations, which express the basic relationship between correlations and path coefficients. The equations are as follows:

$$r_{1y} = a + r_{12} b + r_{13} c + \dots + r_{1l} l_i$$

$$r_{2y} = r_{21} a + b + r_{23} c + \dots + r_{2l} l_i$$

$$r_{3y} = r_{31} a + r_{32} b + c + \dots + r_{3l} l$$

$$r_{1y} = r_{11}a + r_{12} b + r_{13} c + \dots + l$$

Where,

r_{1y} to r_{11y} = Coefficient of correlation between causal factors 1 to l with dependent characters 'y'

r_{12} to r_{11} = Coefficient of correlation among causal factors

a, b, c...l = Direct effects of characters 'a' to 'l' on the dependent characters 'y'

Residual effect is computed as follows,

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

3.4.6 Principal component analysis (PCA)

Associations among the traits were also determined by Principal Component Analysis (PCA) using R version 3.6.0 (R Project for Statistical Computing, <http://www.r-project.org/>).

3.4.7 Cluster analysis

Clustering is done by using adjusted means through R version 3.6.0 (R Project for statistical computing, <http://www.r-project.org/>). All the introgression lines are grouped into different cluster groups based on Euclidean distance matrix.

RESULTS

The advanced backcross population in BC₂F₄ generation derived from three way cross ICC 4958 x (ICC 17264 x IG 69978) were evaluated for eleven quantitative traits at International Crop Research Institute for Semi-arid Tropics (ICRISAT), Patancheru, Telangana along with 4 Checks. The results of the present investigation are presented hereunder in the following subheads:

4.1 Genetic variance in advanced backcross (BC₂F₄) population

4.2 Parameter of genetic variability

4.2.1 Range and mean

4.2.2 Genotypic and phenotypic coefficient of variation

4.2.3 Heritability (%)

4.2.4 Genetic advance as percent of mean

4.3 Association studies

4.3.1 Correlation analysis

4.3.2 Path coefficient analysis

4.3.3 Principal component analysis

4.4 Cluster analysis

4.5 Identification of promising introgression lines

4.1 Genetic variance in advanced backcross (BC₂F₄) population:

The analysis of variance of 300 introgression lines along with 4 checks was carried for eleven quantitative traits sown in Augmented design (Table 4.1). While, analyzing through SAS university edition version 9.4, a considerable amount of variability was observed for all traits which account for the genetic variability among the introgression lines derived from three-way crossing between ICC 4958 and {(ICC 17264 x IG 69978)} followed by advanced backcrossing.

Table 4.1 Analysis of variance for eleven quantitative traits of 300 Introgression lines at ICRISAT during post- rainy season 2018-19

	Df	Mean Sums of Square										
		DF	DF50	DM	PH	PPP	PWP	SPP	HSW	BY	HI	SYP
Block	5	4.45	2.57	0.95	4.72	19.76	2.46	17.45	0.46	16.53	15.31	0.89
Treatments	303	27.36*	90.82*	18.52*	23.61*	516.33*	67.27*	652.88*	21.6*	156.84*	59.25*	50.16*
ILs	299	21.04*	86.83*	17.76*	23.42*	497.88*	67.58*	542.99*	17.05*	156.07*	55.52*	50.06*
Controls	3	416.27*	511.67*	42.27*	48.62*	1128.35*	44.43*	5358.66*	240.79*	37.21	264.69*	60.97*
ILs vs Controls	1	749.71*	19.09*	175.27*	5.31	4198.78*	44.4*	19392.45*	725.93*	747.14*	557.03*	47.22*
Error	15	1.67	1.17	2.57	5.99	17.36	2.17	19.89	1.86	15.08	20.1	2.38
Corrected Total	323											

* - Significant at 5 percent ; **df**:Degree of freedom; **ILs**: Introgression lines; **DF**:Days to first flowering; **DF50**: Days to 50% Flowering; **DM**: Days to Maturity; **PH**: Plant height ; **PPP**: Number of effective pods per Plant; **PWP**: Pod weight per plant; **SPP**: Number of seeds per plant ; **HSW**:100 Seed weight; **BY**:Biological yield ; **HI**:Harvest Index; **SYP**: Seed yield per plant ;.

4.2 Parameter of genetic variability:

To predict genetic variability in the population, various parameters *viz.*, range, mean, genotypic and phenotypic coefficient of variance, heritability and genetic advance for yield attributing traits were estimated and are presented in table 4.2

4.2.1 Mean and range

Days to first flowering ranged from 29 to 70 days with a mean of 37 days and days to 50% flowering exhibited an average value of 45 days and varied from 33 to 77 days, whereas, the days to maturity was recorded between 104 days to 119 days with an average performance of 111 days. Plant height varied between 36.47 cm to 60.51 cm with a mean of 49.04 cm. Number of effective pods per plant had a mean of 73 and range from 26 to 138, while a number of seeds per plant ranged from 32 to 154 with mean of 81. Hundred seed weight had a mean of 27.33 g and range between 18.58 to 34.74 g; pod weight per plant ranged from 8.85 g to 55.95 and had a mean of 24.83 g; biological yield had a mean of 37.94 g with a range between 18.11 to 106.26 g. Harvest Index (%) showed a mean value of 57.52%, while it ranged from 40.42 % to 79.29 % and seed yield per plant ranged from 7.52 to 46.44 g with average value of 20.55 g.

4.2.2 Genotypic and phenotypic coefficient of variation

Phenotypic and genotypic coefficient of variation for yield and yield its component traits were summarized in table 4.2. In general, the phenotypic variance must be higher in magnitude than that of genotypic variance. The same trend was observed in the present investigation for all the traits. High estimates of GCV and PCV observed for traits like seed yield per plant, pod weight per plant, biological yield, number of effective pods per plant, number of seed per plant, while characters like days to 50% flowering, 100-seed weight, days to first flowering and harvest index expressed a moderate level of GCV and PCV. Low level of GCV and PCV observed in traits like days to maturity and plant height.

Table 4.2 Genetic parameters of variability among 300 Introgression lines at ICRISAT, Patancheru, during post-rainy season 2018-19

S.No	Traits	Mean	Range		CV		h ² (bs)%	GAM%
			Min.	Max.	GCV%	PCV%		
1	DF	37	29	70	11.96	12.46	92.06	23.63
2	DF50	45	33	77	20.55	20.69	98.65	42.06
3	DM	111	104	119	3.51	3.8	85.53	6.69
4	PH	49.04	36.47	60.51	8.51	9.87	74.42	15.13
5	PPP	73	26	138	30.09	30.63	96.51	60.9
6	PWP	24.83	8.85	55.95	32.58	33.11	96.79	66.02
7	SPP	81	32	154	28.09	28.62	96.34	56.79
8	HSW	27.33	18.58	34.74	14.26	15.11	89.09	27.73
9	BY	37.94	18.11	106.26	31.29	32.93	90.34	61.27
10	HI	57.52	40.42	79.29	10.35	12.95	63.8	17.02
11	SYP	20.55	7.52	46.44	33.6	34.43	95.25	67.56

DF: Days to first flowering; **DF50:** Days to 50% Flowering; **DM:** Days to Maturity; **PH:** Plant height; **PPP:** Number of effective pods per plant; **PWP:** Pod weight per plant ;Plant; **SPP:**Number of seeds per plant; **HSW:**100 Seed weight;;**BY:** Biological yield **HI:** Harvest Index; **SYP:** Seed yield per plant;.

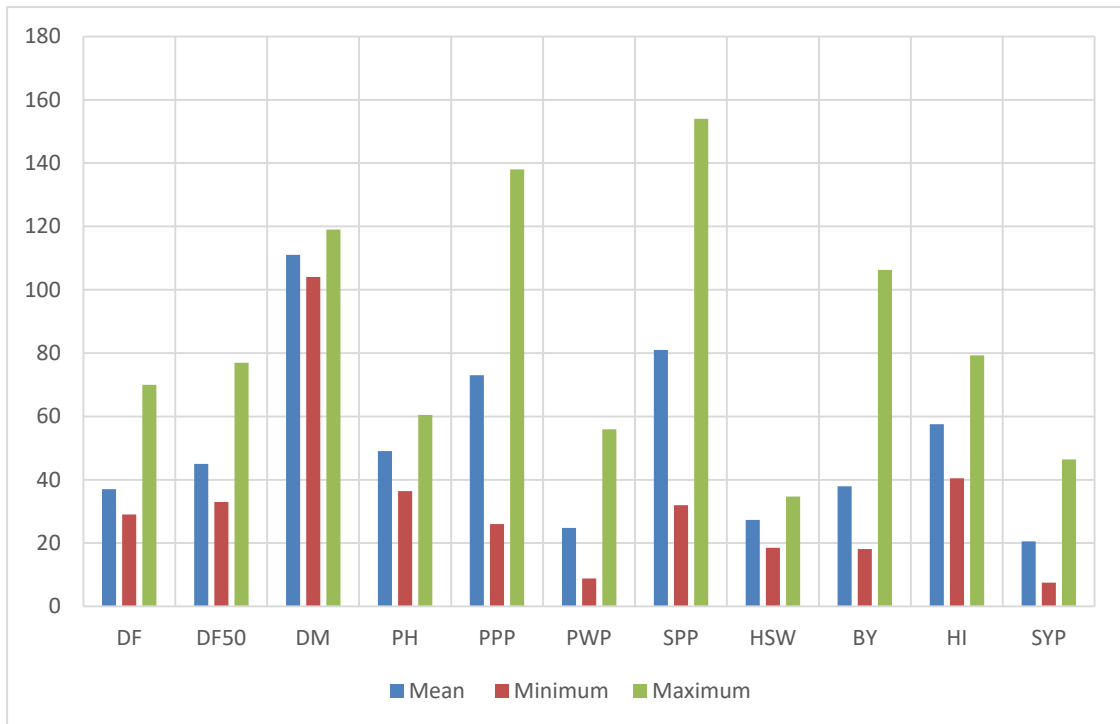


Figure 4.1: Mean and range for eleven quantitative traits studied in 300 introgression lines

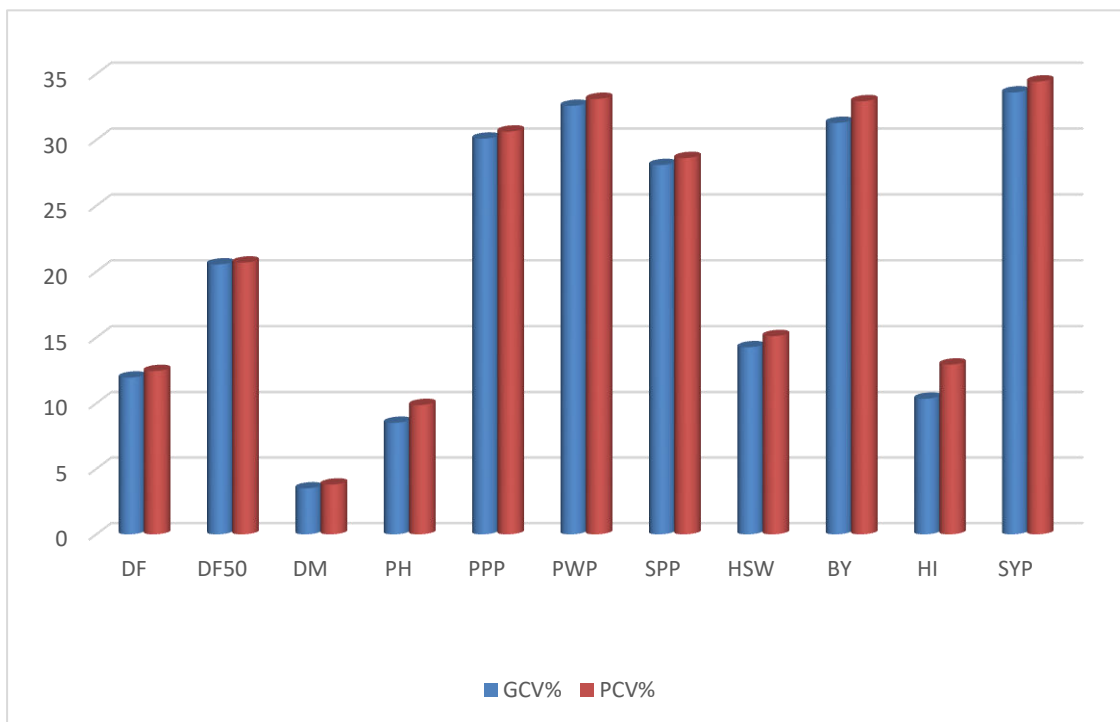


Figure 4.2: GCV% and PCV% for eleven quantitative traits studied in 300 introgression lines

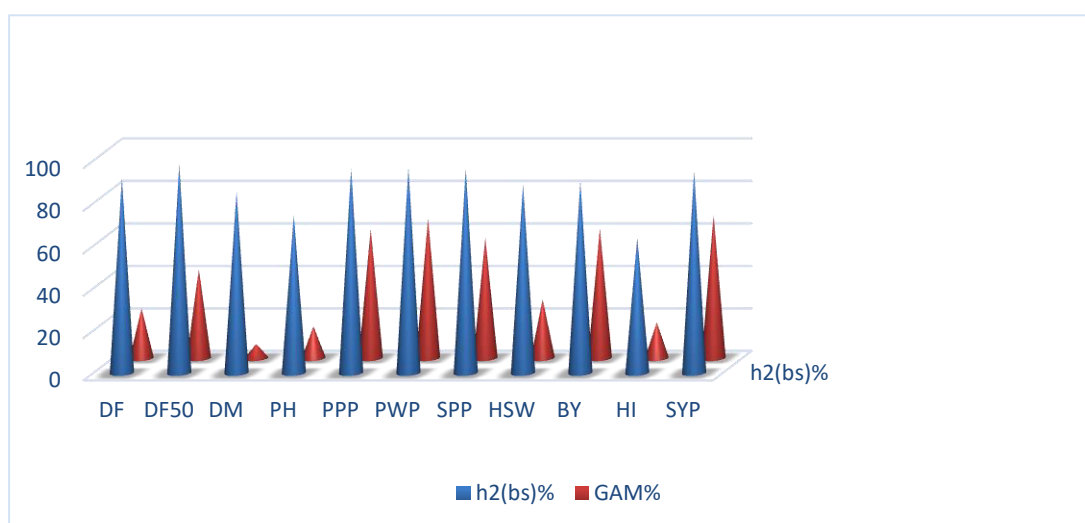


Figure 4.3: $h^2(bs)\%$ and GAM %for eleven quantitative traits studied in 300 introgression lines

4.2.3 Heritability (%)

Broad-sense heritability was computed for each of the characters by the variance components for estimating their relative magnitude of genotypic and phenotypic variability contributed through environmental factors. It was classified as very high (>90%), high (70-90%), moderate (50 -70%) and low (<50%). The estimates of heritability in a broad sense for yield and its components traits characters presented in Table 4.2.

High heritability estimate was noted for days to 50% flowering (98.65%), followed by pod weight per plant (96.79%), number of effective pods per plant (96.51%), number seed per plant (96.34%), seed yield per plant (95.25%), days to flowering (92.06%) and biological yield (90.34%), 100-seed weight (89.09%), days to maturity (85.53%) and plant height (74.42%). Moderate heritability was recorded for harvest index (63.80%).

4.2.4 Genetic advance as percent of mean(%)

Estimates of genetic advance as percent of mean ranged from 6.69% to 67.56 %. The highest genetic advance as percent of mean was recorded for seed yield per plant (67.56%), followed by pod weight per plant (66.02%), number of effective pods per plant (60.90%), number of seed per plant (56.79%), days to 50% flowering (42.06%). Low genetic advance as percent

of mean was recorded for the 100-seed weight (27.73%), days to first flowering (23.63 %), harvest index (17.02%), plant height (15.13%) and days to maturity (6.69%).

4.3 Association studies

4.3.1 Correlation analysis

The usefulness of independent secondary traits in the selection process can be assumed by their significant association with dependent traits like seed yield. As expected, pod weight per plant (0.98), biological yield (0.90) had a highly strong association with seed yield per plant. Number of seeds per plant (0.86) and number of effective pods per plant (0.87) had strong association with seed yield per plant, while plant height (0.50), 100-seed weight (0.26) and harvest index (0.21) was positively correlated with seed yield (Table 4.3). Days to flowering, days to 50% flowering and days to maturity showed non significant correlation with seed yield.

Likewise, biological yield (0.90) had a highly strong association with pod weight per plant, while number of seeds per plant (0.87) and number of effective pods per plant (0.87) were found strongly associated with pod weight per plant. A significant positive association was observed in case of plant height (0.52) and 100-seed weight (0.24) with pod weight per plant, while there was non significant and positive at par association of harvest index (0.14) with pod weight per plant (Table 4.3).

Number of effective pods per plant (0.83) and seeds per plant (0.83) had a strong association with biological yield. A significant and positive association was found in plant height (0.53) with biological yield, while 100-seed weight (0.17) had a positive association with biological yield. There was a negative association between harvest index (-0.21) and biological yield. Days to first flowering, days to 50% flowering and days to maturity follow the similar trend as observed in seed yield per plant and pod weight per plant, with biological yield.

100-seed weight (0.22) was positively associated with harvest index, while biological yield (-0.21), days to maturity (-0.14) and plant height (-0.11) had a negative association with harvest index. No significant association was

observed in days to first flowering, days to 50% flowering, plant height, number of effective pod per plant and number seeds per plant with harvest index.

Days to first flowering, days to 50% flowering, days to maturity, plant height, number of effective pods per plant and number of seeds per plant had no significant association with 100-seed weight. As expected highly strong positive association was observed in between number of effective pods per plant (0.97) and number of seeds per plant. There was a significant positive association in between plant height (0.35) and number of seeds per plant, while non significant association was found with days to first flowering, days to 50% flowering and days to maturity.

Plant height (0.45) had a significant and positive association with number of effective pods per plant, while days to maturity had a negative association with number of effective pods per plant. There was no significant association was observed amongst days to first flowering and days to 50% flowering with number of effective pods per plant. Days to first flowering, days to 50% flowering and days to maturity had non significant correlation with plant height. Days to 50 % flowering has a positive association with days to maturity, while the non significant association was observed with days to first flowering. As expected days to first flowering had a significant positive association with days to 50% flowering.

Table 4.3 Correlation coefficient analysis for yield and its contributing traits among 300 Introgression lines at ICRISAT during post rainy season 2018-19

Traits	DF	DF50	DM	PH	PPP	PWP	SPP	HSW	BY	HI	SYP
DF	1	0.61**	0.1	-0.01	0	-0.03	0.02	-0.1	-0.01	-0.06	-0.03
DF50		1	0.14*	0.06	0.07	0.04	0.09	-0.07	0.09	-0.09	0.06
DM			1	0.09	-0.1	-0.05	-0.1	0.04	0	-0.14*	-0.07
PH				1	0.45**	0.52**	0.45**	0.15**	0.53**	-0.11*	0.50**
PPP					1	0.87**	0.98**	-0.01	0.83**	0.06	0.87**
PWP						1	0.87**	0.24**	0.90**	0.14*	0.98**
SPP							1	-0.03	0.83**	0.04	0.86**
HSW								1	0.17**	0.22**	0.26**
BY									1	-0.21**	0.90**
HI										1	0.21**
SYP											1

DF: Days to first flowering; **DF50:** Days to 50% Flowering; **DM:** Days to Maturity; **PH:** Plant height; **PPP:** Number of effective pods per Plant;**SPP:** Number of seeds per plant; **HSW:**100 Seed weight; **PWP:** Pod weight per plant; **BY:** Biological yield; **HI:** Harvest Index; **SYP:** Seed yield per plant.

4.3.2 Path coefficient analysis

Path coefficient analysis is simply a standardized partial regression coefficient which splits the correlation coefficient into the measure of direct and indirect effects. The relationship determined by path coefficient analysis among the examined traits in the research is given in Table 4.4. Results from path analysis showed that biological yield was the major direct contributor to seed yield (0.5798) followed by pod weight per plant (0.4149) and harvest index (0.2759). Number of effective pods per plant, pod weight per plant and number seeds per plant found to have the highest positive indirect effect on grain yield via biological yield (0.4812, 0.5218, 0.4812 respectively). On the other side, pod weight per plant showed a positive direct effect on seed yield (0.4149), while pod per plants showed a negative direct effect on seed yield (-0.1351). Days to first flowering had a low negative direct effect in seed yield (-0.0086). However, its contribution towards seed yield was via biological yield with positive indirect effect. It was a positive direct effect of days to 50% flowering, plant height and 100-seed weight on seed yield per plant while days to maturity and number of effective pods per plants had the negative direct effect on grain yield (-0.0138 and -0.1315 respectively).

4.3.3 Principal component analysis

Principal component analysis (PCA) was performed based on the predicted means (BLUPs) obtained through R version 3.6.0 (R Project for statistical computing, <http://www.r-project.org/>). Proper values measure the importance and contribution of each component to total variance whereas each coefficient of the proper vector indicates the degree of contribution of every original variable with which each principal component is associated. The higher the coefficients, regardless of sign, the more effective they will be in discriminating between the genotypes. PCA revealed that the first four principal components in the experiment explained 81.89 % (Table 4.5). The percentage variation of PC 1, PC 2, PC 3, PC 4 and was 44.57 % , 15.71% , 11.15% and 10.45.% respectively. Five traits, seed yield per plant, pod weight per plant, biological yield, number of seeds per plant and number of effective pods per plant were the major contributing traits and had an almost

equal contribution (-0.42 to -0.43) for PC 1, followed by plant height (-0.27). On the other side, 100-seed weight contributed (-0.08) to PC 1, while days to 50% flowering (-0.038) and harvest index (-0.024) contributed to PC 1 and days to first flowering (0.0032) and days to maturity (0.0282) had contributed to PC 1.

The second principal component accounted for 15.71% of the total variance. Traits highly and positively correlated were days to first flowering and days to 50% flowering. The third component accounted for 11.15 % and was positively associated with days to first flowering, days to 50% flowering, pod weight per plant, 100-seed weight, harvest index and seed yield per plant. This third component is negatively associated with days to maturity, plant height, number of effective pods per plant and biological yield per plant while the fourth principal component accounted for 10.45% of the total variance and was positively associated with days to first flowering, days to 50% flowering, number of effective pod per plant, number of seeds per plant and harvest index.

From PCA biplot (Fig.4.5), it was evident that seed yield per plant, pod weight per plant, number of effective pods per plant, number of seeds per plants and biological yield traits were clustered together and contributed to maximum variability, which was in accordance with the high correlation values between these traits ($r=0.86$ to 0.98).

Table 4.4 Path coefficient analysis for yield and its component traits in 300 Introgression lines at ICRISAT during post-rain season 2018-19

Traits	DF	DF50	DM	PH	PPP	PWP	SPP	HSW	BY	HI	SYP
DF	-0.0086	0.0126	-0.0014	-1.00E-04	0	-0.0125	0.0027	-0.0004	-0.0058	-0.0166	-0.03
DF50	-0.0053	0.0206	-0.002	0.0005	-0.0095	0.0166	0.012	-0.0003	0.0522	-0.0249	0.06
DM	-0.0009	0.0029	-0.0138	0.0007	0.0136	-0.0208	-0.0133	0.0002	0	-0.0387	-0.07
PH	1.00E-04	0.0013	-0.0013	0.0077	-0.0608	0.2158	0.0598	0.0006	0.3073	-0.0304	0.5
PPP	0	0.0015	0.0014	0.0035	-0.1351	0.361	0.1302	-1.00E-04	0.4812	0.0166	0.86
PWP	0.0003	0.0009	0.0007	0.0041	-0.1175	0.4149	0.1155	0.001	0.5218	0.0387	0.98
SPP	-0.0002	0.0019	0.0014	0.0035	-0.1324	0.361	0.1328	-0.0002	0.4812	0.0111	0.86
HSW	0.0008	-0.0015	-0.0006	0.0012	0.0014	0.0996	-0.004	0.0039	0.0986	0.0607	0.26
BY	1.00E-04	0.0019	0	0.0041	-0.1121	0.3735	0.1102	0.0007	0.5798	-0.058	0.9
HI	0.0006	-0.0019	0.002	-0.0009	-0.0082	0.0581	0.0054	0.0009	-0.1218	0.2759	0.21

DF: Days to first flowering; **DF50**: Days to 50% Flowering; **DM**: Days to Maturity; **PH**: Plant height; **PPP**: Number of effective pods per Plant; **SPP**: Number of seeds per plant; **HSW**:100 Seed weight; **PWP**: Pod weight per plant; **BY**: Biological yield; **HI**:HarvestIndex; **SYP**:Seed yield perplant

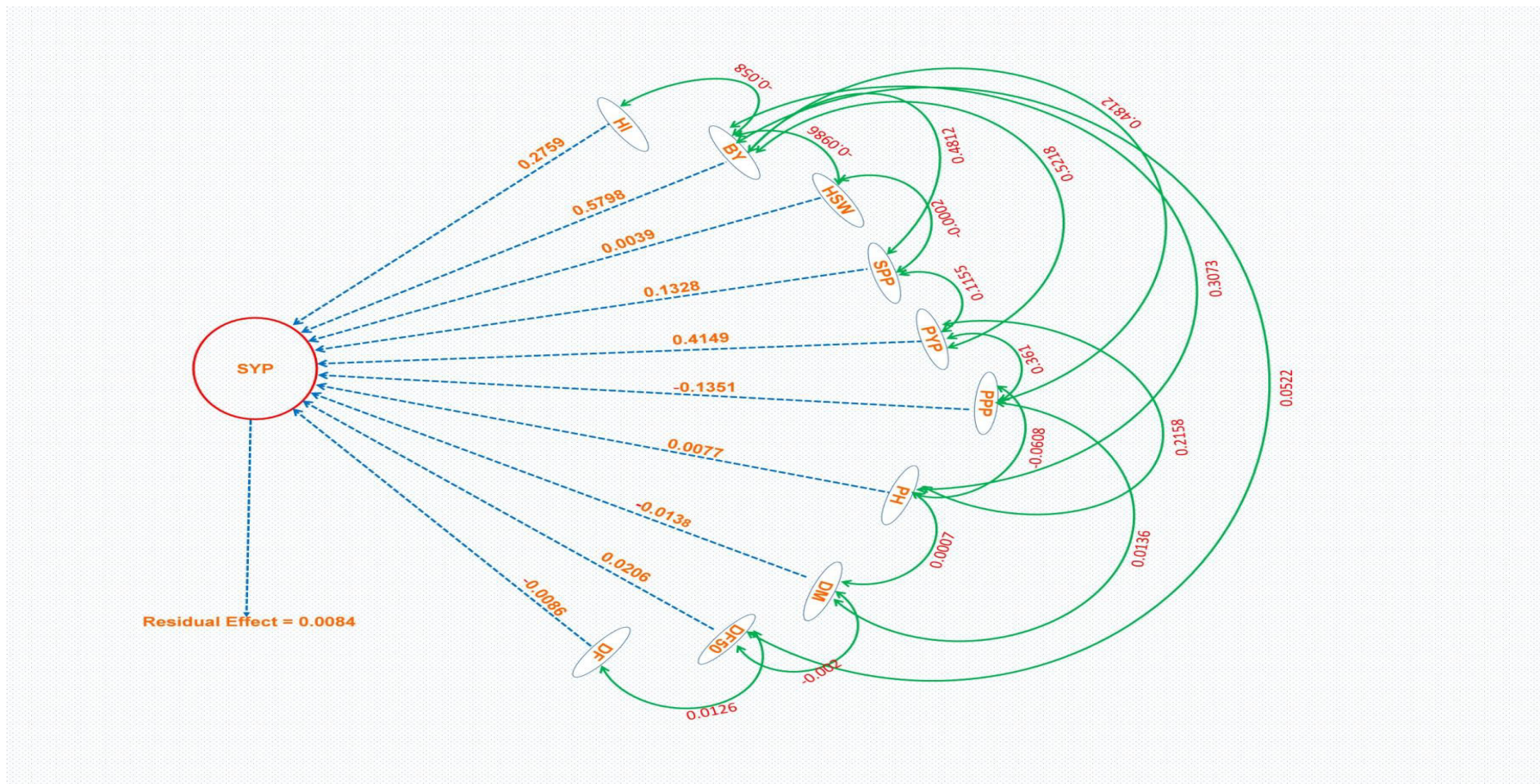


Fig.4.4 Path diagram showing direct and indirect effects of various traits on grain yield per plant in 300 Introgression lines

Table 4.5 Eigen values, the proportion of variability and traits that contributed to the principal components in chickpea ILs

Traits	PC1	PC2	PC3	PC4
DF	0.0032	0.6173	0.3136	0.1391
DF50	-0.0385	0.6309	0.2787	0.0636
DM	0.0282	0.2565	-0.0525	-0.6598
PH	-0.2702	0.0631	-0.1207	-0.3485
PPP	-0.4232	0.0177	-0.0716	0.1874
PWP	-0.438	-0.0566	0.079	-0.018
SPP	-0.4233	0.0341	-0.0834	0.1934
HSW	-0.0802	-0.2313	0.5116	-0.5377
BY	-0.4215	0.0578	-0.1574	-0.0969
HI	-0.0245	-0.2928	0.6948	0.2205
SYP	-0.4362	-0.064	0.1392	-0.0027
Eigen value	4.9032	1.7288	1.2272	1.15
Variance percent	44.5738	15.7164	11.1555	10.4541
Cumulative variance percent	44.5738	60.2901	71.4456	81.8997

DF: Days to first flowering; **DF50:** Days to 50% Flowering; **DM:** Days to Maturity; **PH:** Plant height; **PPP:** Number of effective pods per plant; **SPP:** Number of seeds per plant; **HSW:**100 Seed weight; **PWP:** Pod weight per plant; **BY:** Biological yield; **HI:** Harvest Index; **SYP:** Seed yield per plant;

PCA Biplot

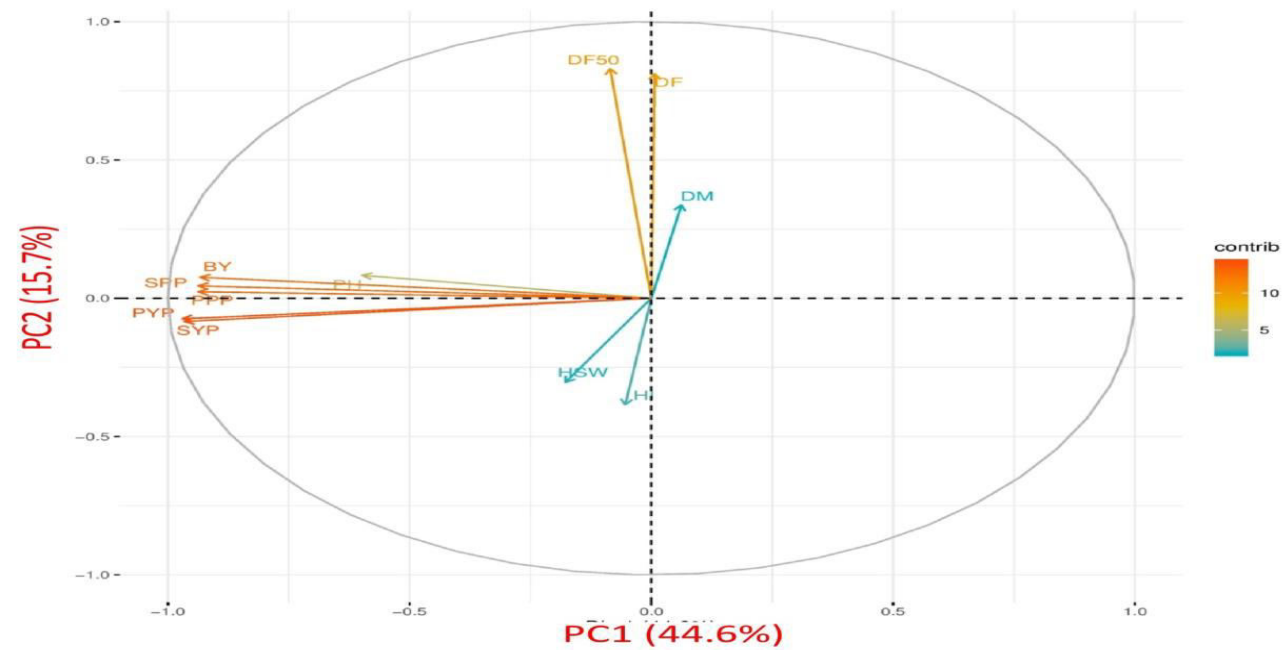


Figure 4.5. The plot of the first two PCA showing relation among various traits in chickpea Introgression lines in yield trial at ICRISAT during post –rainy season 2018-19

4.3.3 Cluster analysis:

Cluster analysis or clustering helps in grouping the genotype based on various traits in such a way that genotype in the same group (called a cluster) are more similar (in some sense) to each other than to those in other groups (clusters). At different distances, different clusters will form, which can be represented using a dendrogram, which explains where the common genotype "hierarchical clustering" comes from these algorithms do not provide a single partitioning of the data set, but instead provide an extensive hierarchy of clusters that merge with each other at certain distances. In a dendrogram, the y-axis marks the distance at which the clusters merge, while the genotypes are placed along the x-axis such that the clusters don't mix.

In the present study, clustering is done by using adjusted means through R version 3.6.0 (R Project for statistical computing, <http://www.r-project.org/>). All the introgression lines are grouped into ten cluster groups based on Euclidean distance matrix. Cluster one consisted of 49 ILs, cluster II consisted of 47 ILs, cluster III consisted of 46, cluster IV consisted of 25 and cluster V(13), VI(15) , VII(10), IX(48), and X consisted of 11 ILs respectively.

Out of four checks, two checks ICCV10 and JG130 clustered in cluster II and cluster VII, respectively, while ICC 4958 (high yielding, large seeded, drought-resistant donor) and JG 14 (high yielding, medium bold seeded, heat tolerant and widely adapted cultivar) clustered separately (cluster I and cluster IX respectively).

4.3.3.1 Cluster mean for yield and yield contributing traits of introgression lines

The cluster mean for different traits are presented in Table 4.6. In case of days to first flowering cluster VII showed maximum 40.8 days and cluster I and III showed minimum 35.71 days, while, for days to 50% flowering, cluster VII showed maximum and cluster I had minimum cluster mean values of 51.11 days and 40.95 days, respectively. Days to maturity was found maximum in cluster IX i.e. 112.99 days and minimum cluster mean values was observed for cluster VIII i.e. 109.1days. Plant height (51.37cm) recorded maximum value in cluster V, whereas minimum in cluster X (45.12cm).

Number of effective pods per plant (96.88) found maximum in cluster V, followed by cluster VI (96.08), while, minimum in cluster X (48.98).

Similar trend was observed for pod weight per plant and number of seeds per plant where cluster V found to have maximum mean values (33.62 and 107.6), followed by cluster VI (33.44 and 106.2) and minimum in cluster X (16.38 and 56) respectively. 100-seed weight was recorded maximum in cluster I (29.46g). Biological yield (54.94g) recorded maximum value in cluster V, while harvest index (58.59%) and seed yield per plant (28.28g) was recorded maximum values in cluster I and VI respectively.

Table 4.6 Cluster mean for quantitative traits of 300 Introgression lines at ICRISAT during post-rainy season 2018-19

S.No	Traits	Cluster I	Cluster II	Cluster III	Cluster IV	Cluster V	Cluster VI	Cluster VII	Cluster VIII	Cluster IX	Cluster X
1	DF	35.71	37.06	35.71	36.27	36.38	36.15	40.80	37.23	37.12	37.09
2	DF50	40.95	49.13	44.61	46.72	47.90	46.14	51.11	41.33	48.05	47.83
3	DM	111.36	110.15	111.24	110.38	111.06	111.51	112.32	109.10	112.99	111.30
4	PH	51.24	50.01	48.18	50.72	51.37	50.89	50.37	48.95	45.63	45.12
5	PPP	71.99	89.47	69.01	93.22	96.88	96.08	83.90	62.49	49.91	48.98
6	PWP	26.36	29.65	21.68	31.81	33.62	33.44	28.52	21.01	17.28	16.38
7	SPP	80.30	98.68	77.80	102.92	107.60	106.20	93.33	70.78	57.03	56.00
8	HSW	29.46	25.99	23.21	26.28	27.60	28.80	28.04	28.40	28.88	27.14
9	BY	38.68	43.73	33.64	48.46	54.94	52.53	45.13	32.34	27.68	26.31
10	HI	58.29	57.76	56.75	56.47	53.15	56.17	56.15	58.08	58.05	58.60
11	SYP	21.56	24.54	17.62	26.34	27.90	28.28	24.10	17.43	14.46	13.75

DF: Degree of freedom; **DF50:** Days to 50% Flowering; **DM:** Days to Maturity; **PH:** Plant height; **PPP:** Number of effective pods per Plant; **SPP:** Number of seeds per plant; **HSW:**100 Seed weight; **PWP:** Pod weight per plant; **BY:** Biological yield; **HI:** Harvest Index; **SYP:** Seed yield per plant.

4.5 Identification of promising introgression lines

Days to 50% flowering, 100-seed weight and seed yield per plant are considered few most important economic traits by the breeders in Chickpea improvement.

For days to 50% flowering, none of the ILs were found extra early than the extra early flowering check, ICC 4958(37 days); however, 121 ILs were at par with this check. Eighty-one ILs have 100-seed weight ranging from (30.02-34.74g) out of which 58 ILs were at par than the popular cultivar ICC 4958(34.27g) (Fig 7). Based upon the *per se* performance 24 ILs produced significantly higher seed yield per plant compared with the best check, ICC 4958 (25.81g). (Table 4.7) .

Beside this for days to 50% flowering, none of the ILs were found earlier than the earliest flowering check, JG 14 (41 days); however, 66 ILs were at par with this check., while two ILs ICC 172079 and ICC 171491 were found significantly earlier than ICCV 10 (50days) and 44 ILs were at par with this check . With compare to JG 130 (57 days), 45 ILs were found at par and the remaining 23 ILs were found medium over all checks(Table 4.7).

On the basis of 100-seed weight, forty ILs were found significantly medium than the popular cultivar JG 14(25.78g) ,while 152 ILs were at par with this check. Whereas fifty ILs were found at par with the best check,.ICCV 10 (19.79g), small seeded. Based upon mean *per se* performance 99 ILs produced at par seed yield per plant compared with the best check, ICC 4958 (25.81 g), while, 177 ILs were found below at par for seed yield per plant compared with best check ICC 4958(Table 4.8).

Among 24 promising lines (Table 4.10) for seed yield per plant over superior check-ICC 4958, seven ILs ICCP 171119, ICCP 171500, ICCP 173211, ICCP 173170, ICCP 173181, ICCP172429 and ICCP 172350 were found at par extra early than ICC 4958. On the basis of 100-seed weight, only ICCP 171119 and ICCP 173181 were at par large seeded than ICC 4958, while ICCP 172429 was significantly medium seeded then JG 14 and remaining four ILs were found at par medium with JG 14. Five ILs ICCP 173668, ICCP 171182, ICCP 171340, ICCP 172331 and ICCP 173210 were

found at par early than JG 14. Only ICCP 173210 was at par large seeded than ICC 4958, while ICCP 173668 and ICCP 171340 were at par medium seeded than popular check JG 14, whereas, ICCP 171182 and ICCP 172331 were significantly medium seeded than JG 14.

Two ILs ICCP 172079 and ICCP 173284 were found significantly better for seed yield per plant and at par large seeded than ICC 4958, were significantly early than ICCV 10. While, ICCP 173004, ICCP 172738, ICCP 172147, ICCP 173159 and ICCP 172325 were at par early than ICCV 10. On the basis of 100-seed weight ICCP 173004, ICCP 172147 were at par large seeded than ICC 4958. While ICCP 172738 was found at par medium seeded than JG 14.

ICCP 173159 and ICCP 172325 were found significantly medium seeded than popular check JG 14. On further evaluation, ICCP 173334 and ICCP 173278 were found significantly better than popular cultivar ICC 4958. These lines were also found at par early than JG 130 had at par medium seed size than JG 14. Out of 24 high yielding ILs three ILs, ICCP 173651, ICCP 171053 and ICCP 171081 were found medium over all checks based on days to 50% flowering.

While ICCP 171081 was found significantly medium seeded than JG 14, ICCP 173651 and ICCP 171053 were found at par large seeded than ICC 4

Table 4.7 List of promising introgression lines identified based on earliness for use in chickpea improvement

Category	Promising ILs (ICCP No.)	Total ILs
1.Extra early (At par than ICC 4958)	173686,173695,172244,173719,173802,171119,173396,173728,173785,173805,173842,171136,171230,171289,171343,171358,171461,171470,171473,171490,171500,171526,171551,171566,173014,173089,173090,173129,173211,173234,173312,173540,173542,173599,173604,173610,173611,172281,172518,172519,172524,171711,171712,171750,172077,171271,171443,171547,171548,171557,173043,173071,173116,173122,173124,173126,173170,173180,173181,173538,173613,172261,172318,172432,172509,172553,172576,172765,172877,172938,172949,173005,173007,171761,171837,171849,171869,171952,171961,171969,172128,172132,171341,171399,171561,173171,173174,173205,172276,172350,172401,172429,172436,172483,172535,172734,172857,172936,172940,172944,171667,171669,171732,171745,171850,171892,171893,171954,171988,172138,172146,172230,171265,173034,173335,171287,171306,173099,173101,173104	120
2.Early (At par early than JG14)	173584,173794,171760,171840,171968,172130,171207,173308,173622,173655,173666,173668,173677,173697,173712,173715,173729,173797,173843,171128,171182,171340,171501,171576,173019,173256,173608,173679,173710,172331,172352,172569,172587,172801,172953,172957,172994,171883,171908,171947,172071,172126,172137,172228,173057,173125,173157,173192,173209,173253,173287,173299,173314,173322,173359,173387,173502,173609,173856,172063,	66

	172153,172226,173199,173206,173210,173230	
Significantly early than ICCV 10	172079, 171491	02
At par early than ICCV 10	173284,173010,173085,173130,172495,172554,172563,172738,172771,172979,172999,173003,173004,171912,172147,172229,173798,173800,173826,ICCV10,171567,173320,173543,173159,173163,173207,173212,173696,173819,173844,173845,173847,172325,172231,173271,173811,172118,171040,171054,171129,173237,173239,173330,173358,173419	44
At par early than JG 130	173718,171638,173028,173070,173091,173161,173231,173334,173362,173711,173720,173725,173743,173806,172293,173011,173037,173278,173615,173744,172727,173315,173341,173709,173773,173807,173808,173012,173017,173032,JG130,173238,171817,171894,172027,172238,173160,173337,173408,173426,173442,173531,171248,171509,171513,172418	45
3.Medium than all popular checks	173651,173731,173817,173818,173859,173863,173580,173588,171051,171053,171056,171081,171092,171480,173809,172056,171038,171135,173526,171169,173370,171452,173189	23

4.8 List of promising introgression lines identified based on seed size for use in chickpea improvement

Category	Promising ILs (ICCP No.)	Total ILs
1.Small (At par than ICCV 10)	171638,172765,172994,171399,171343,171509,173206,172519,171849,171745,173126,172293,173697,172877,173817,172801,173731,172137,173609,173613,171443,173071,171968,173231,173845,173809,173085,173847,172231,173844,173710,173543,171817,173718,173238,173610,173099,173599,172027,173070,17305,173709,171576,173157,173396,173712,172128,173608,172063,173209	50
2.medium (At par than JG 14)	172576,171341,172738,171969,171040,173189,173743,173604,171952,172132,172509,173125,173842,171567,173711,173651,173160,173531,171711,173615,173696,173012,173234,172979,171490,173237,171551,172228,171761,173010,173174,173502,173655,173043,173863,173856,172230,173278,,171340,171912,171092,171480,171840,171947,173686,173695,173728,173370,171501,173003,173089,171056,173611,173859,171461,173129,173540,173256,173192,173170,173130,173199,173230,171452,171561,171669,172118,172281,171712,171760,171129,171893,173205,171135,172229,172056,173442,172771,173588,171500,173007,171850,173362,171207,	152

	171837,173122,173806,172352,173028,171491,173584,173322,172153,172350,172276,172518,172936,171750,171908,172401,172734,172857,172944,173011,173720,171054,173622,173091,172436,173668,173818,171513,172563,173034,173358,171732,173330,173320,173337,173538,171306,171869,173239,173299,172495,172553,173308,173211,172418,171988,171136,171954,172535,172146,171547,172587,173032,173819,172727,173005,172238,171289,171894,173315,172483,173334,173387,172138,173843,171470,173271,171038	
Significantly medium than JG 14	171169,173171,173159,172261,172432,172940,172331,173101,173116,171667,173017,173180,171883,173090,173677,172325,173314,173798,171265,171081,171271,173408,173526,173785,173419,172130,173426,171287,172953,171557,173341,173104,173163,171182,172429,172244,172524,172569,171566,173800	40
3.Large (At par large than ICC 4958)	173773,173715,172226,171230,171053,171119,172071,173826,171051,173037,173019,173807,172318,172949,172999,173207,173161,171128,173004,173210,173014,173719,173808,173797,172554,173725,171548,173359,173542,173284,173335,173580,173287,173124,171892,173794,172938,173802,172077,173805,172957,171961,171473,173666,173679,171526,173253,173212,173744,171358,173729,173811,172126,173312,173181,171248,ICC4958,172079,172147	58

4.9 List of promising introgression lines identified based on seed yield per plant for use in chickpea improvement

Category	Promising ILs (ICCP No.)	Total ILs
1. Significantly better than ICC 4958	173278,172331,172429,173334,172147,171053,172350,173170,172079,173210,173668,173284,171182,173004,171340,173651,173211,172325,171119,172738,171500,173159,171081,173181	24
2. At par than ICC 4958	173287,171038,171750,171128,173426,173797,173604,173014,173599,171136,171883,173230,171547,172281,173019,173677,171265,171968,171271,172938,173160,173845,173540,173408,171513,173807,171051,173800,171480,173802,173335,172027,173359,172146,173130,173719,173615,171248,173171,173809,172524,173362,173157,173538,173728,172126,171056,173442,173315,171954,173655,172137,173844,171399,172483,173715,173819,173207,173526,173794,171207,172318,173003,172953,173234,173129,171169,173859,173806,171129,172936,172230,171869,171341,172734,172077,171837,172228,172071,173808,171817,171306,172238,173037,173314,172554,173007,171567,172563,173308,172231,173253,171893,173531,173032,171491,173099,173312,171509	99

3.Below at par than ICC 4958	171912,171557,171287,171947,173613,173330,172801,173743,171230,172432,171135,173010, 173043,173847,171490,171054,173104,173299,171908,171892,173089,171732,173584,172495, 173122,173005,172352,173811,173237,173341,173696,172293,173017,171711,172130,173542, 171040,171961,173622,172771,173125,171840,172226,171988,173161,172519,172765,173729, 171561,171669,173731,173209,172261,173320,173718,171092,173843,173124,172957,172118, 172994,173611,171461,171712,173502,173205,173588,171548,173192,173090,173126,173116, 173711,171576,173163,173744,173387,173070,173180,173785,173071,173239,171289,173856, 173720,173817,171761,173012,173370,173212,172587,172244,173709,171894,173826,173773, 173028,173666,173725,173679,171849,171850,173818,172128,172877,173710,171358,172553, 173322,171551,173805,171667,173238,171501,173609,173580,172509,171969,171760,171452, 172940,172138,173337,172999,171566,173206,172436,173011,173863,172063,173712,173271, 172944,172727,173101,171470,173842,173174,171526,173091,173686,172569,172276,173034, 172056,173189,173419,173057,173610,172535,173798,172518,172418,171473,172949,171952, 173396,171443,173695,173085,172979,171638,173358,172153,171745,173199,173231,172229, 173256,173697,171343,172132,172857,173608,173543,172401,172576	177
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Table 4.10 List of 24 Promising ILs that were either similar or showed significant superiority over respective checks for days to 50% flowering, 100-seed weight and seed yield per plant for use in chickpea improvement.

S.No	Entry	GH	DF50	HSW	SYP
1	ICCP173278	SE	55	25.71	46.44
2	ICCP172331	SE	43	29.59	43.45
3	ICCP172429	SE	38	30.46	42.93
4	ICCP173334	SE	54	29.09	42.31
5	ICCP172147	SE	47	34.74	41.40
6	ICCP171053	SE	63	30.89	39.44
7	ICCP172350	SS	38	27.65	37.66
8	ICCP173170	SS	36	26.73	37.46
9	ICCP172079	SS	45	34.74	37.33
10	ICCP173210	SS	44	31.42	36.93
11	ICCP173668	SS	42	28.06	36.02
12	ICCP173284	SE	46	31.88	34.28
13	ICCP171182	SE	42	30.44	34.18
14	ICCP173004	SS	47	31.39	33.97
15	ICCP171340	S	42	25.81	33.90
16	ICCP173651	SS	61	24.45	33.01
17	ICCP173211	SE	35	28.54	32.48
18	ICCP172325	SS	52	29.85	32.35
19	ICCP171119	SE	34	30.89	32.28
20	ICCP172738	SS	47	23.58	31.57
21	ICCP171500	SE	35	27.17	31.57

22	ICCP173159	SE	51	29.54	31.45
23	ICCP171081	SE	63	30.03	31.28
24	ICCP173181	SE	36	33.99	31.16
Check	ICC 4958	SE	37	34.27	25.81
Check	JG 14	SE	41	25.78	18.90
Check	JG 130	SE	57	22.48	20.22
Check	ICCV 10	SE	50	19.79	22.85
LSD			3.94	3.58	4.46

Plate- 2 Promising Introgression lines



DISCUSSION

Chickpea (*Cicer arietinum* L.) is an important protein-rich foodgrain legume crop of the semi- arid and warm temperate zones and forms one of the major components of human diet. The narrow genetic base of cultivated chickpea (*Cicer arietinum* L.) has hindered the progress in realizing high yield gains in breeding programs. Since it is an annual crop, the genetic variability present in eight annual wild *Cicer* species will play an important role for chickpea improvement. Of the eight annual wild *Cicer* species, only *C. reticulatum* is readily crossable with cultivated chickpea, resulting in fertile hybrid (Singh *et al.*,2005). Although *C. echinospermum* is also crossable with cultivated chickpea, the resulting hybrids are mostly sterile (Pundir and Menhgesha, 1995).

Extensive screening of wild *Cicer* accessions belonging to eight annual wild *Cicer* species has led to the identification of accession with a high level of resistance to *Aschocyta* blight, bacterial grey mould, dry root rot, *fusarium* wilt and pod borer. These promising accessions are being used as donors as to introgress useful genes and alleles into popular chickpea cultivars after backcrossing. For introgressing resistance into susceptible cultivars, the complex three-way cross could be better than the simple crosses due to the involvement of two parents contributing resistance to three-way cross progenies. This approach was useful in wheat, where in leaf rust severity of three-way cross progenies was lower than that of simple cross progenies (Singh *et al.*,1998). Further, complex (three and four-way) crosses allow to increase in the range of traits that can be simultaneously incorporated into the elite progeny, However, the frequency of elite progeny from this type of cross is usually very low due to insufficient population sizes (Langridge and Chalmers,2005; Velu and Singh, 2013). Hence, in complex three-way crosses, the large-sized populations are required to recover the plants with a desirable combination of genes compared to simple crosses.

Following simple or complex crosses, large-sized advanced backcross populations was produced using cultivated chickpea as a recipient with the objective to recover the maximum genetic background of the cultivated types

with small desirable segments introgressed from the wild species. These populations are in different stages of development. Following complex crosses, advanced backcross populations have been developed using desi landrace ICC 4958 as recipient and *C. reticulatum* accession ICC 17264 and *C. echinospermum* accession IG 69978 as donors. In segregating populations (BC₂F₂ generation) derived from three-way F₁ crosses {[ICC 4958 x (ICC 17264 x IG 69978)]} considerable variability was observed for morpho-agronomic traits (Sharma, 2017).

Evaluation of a set of these BC₂F₂ populations has resulted in the identification of introgression lines (ILs) with early flowering (26 days), high number of pods per plant (up to 460 pods), high pod weight per plant (up to 180 g), high number of seeds per plant (up to 460 seeds) and high seed weight per plant (up to 142.0 g). Besides this, preliminary screening of a few plants in different segregating generations (BC₂F₁, BC₁F₂, and 3- F₂) derived from two crosses for AB and BGM following the cut-twig method (Sharma *et al.*, 1995) under controlled environment conditions has identified ILs with high levels of resistance to these diseases (Sharma *et al.*, 2016). These promising ILs will be rescreened further to confirm the resistance. At present, an advanced backcross population derived from an ICC 4958 x (ICC 17264 x IG 69978) cross in BC₂F₄ generation exhibiting enormous variability is available for high-throughput phenotyping across locations for important biotic and abiotic stresses and morpho-agronomic traits.

The present study was initiated to provide sufficient genetic variability for use in chickpea improvement. Three hundred ILs derived from complex cross were evaluated for various quantitative traits and an effort has been made to analyze the total variability with the help of suitable genetic parameters under the following heads :

5.1 Genetic variability

5.1.1 Phenotypic and genotypic coefficient of variation

5.1.2 Heritability (Broad sense) and genetic advance as per cent of mean

5.2 Association studies

5.3 Cluster analysis

5.3 Identification of promising ILs

Plate-3 Parental lines seed samples



ICC 4958

ICC 17264

IG 69978

Plate-4 Progeny of BC₂F₄ population showing phenotypic variation for seed traits



5.1 Genetic variability

Variability refers to the presence of difference among the individuals of the plant population. Variability results due to the difference in the genetic constitution of the individuals of a population or in the environment in which they are grown. The existence of variability is essential for resistance to biotic and abiotic factors as well as for the wide adaptability. Selection is also effective when there is genetic variability among the individuals in a population. Hence, the presence of large genetic variation in all the experimental materials validates the purpose of the study in the first stage.

The range of gross variability observed in eleven quantitative traits revealed that almost every trait had wide range of variability. Amongst the traits studied, number of seeds per plant (19-145), number of effective pods per plant (19-135), biological yield (12.69g-110.67g), seed yield per plant (6.75g-47.17g), pod weight per plant (8.57g-56g), days to first flowering (29-70), days to 50% flowering (33-77), plant height (36.47cm -60.51cm) and harvest index (40.42%-79.29%) had a wider range compared to 100-seed weight (18.58g-34.47g) and days to maturity (104-119). These findings are in accordance with Bharadwaj and Singh (1970), Sandhu and Mandal (1989), Brar *et al.* (2004), and Desai *et al.* (2015). Thus, it may be assumed that the exploitation of these traits for chickpea improvement could be rewarding.

5.1.1 Phenotypic and genotypic coefficient of variation

Estimation of the GCV% and PCV% components helps to assess the magnitude of genetic variation present in the population for the trait per se. In general, the PCV% was higher than GCV % for all the traits as which is in agreement with the findings of Borate *et al.* (2010), which indicated that the environment influenced considerably in the expression of these characters. The high magnitude of coefficient of variation at phenotypic as well as genotypic level were observed for seed yield per plant which follows the findings of Joshi *et al.* (2018) and Singh *et al.* (2018) followed by pod weight per plant, biological yield per plant, number of effective pod per plant and number of seeds per plant which almost follows the findings of Vaghela *et al.* (2008), Rajkumar *et al.* (2014), whereas lowest for days to maturity which

follows the findings of Rao and Kumar (2000). Days to first flowering, days to 50% flowering, plant height, 100-seed weight, and harvest index have moderate values of PCV % and GCV%. Bharadwaj and Singh (1970), Mandal and Bahl (1983), Hedge *et al.* (2003), Brar *et al.* (2004) and Babbar *et al.* (2012) also find almost similar results for GCV% and PCV% for the traits studied in the present investigation.

5.1.2 Heritability (Broad sense) and Genetic advance as percent of mean

It is not possible to determine the amount of heritable variation with the help of genetic coefficient of variation alone. Burton (1952) suggested that genetic coefficient of variation along with the heritability estimate would provide a better picture of the extent of heritable variation. The importance of heritability estimates of character has been pointed out by Lush (1940) in animal and supported by Johanson *et al.* (1955) in plants.

In the present study, most of the characters exhibited high heritability estimates. All the traits have a high heritability, except harvest index. The almost similar result was reported by Sidramappa *et al.* (2008), Dar *et al.* (2012) and Singh *et al.* (2012). All of them have reported high heritability values in a broad sense for days to 50% flowering, number of effective pod per plant, number of seeds per plant, seed yield per plant, biological yield, 100-seed weight, days to maturity and plant height. The major function of heritability estimates is to provide information on the transmission of character from parent to progeny, but the estimates of heritability alone are not so much useful in predicting the resultant effect for selecting the best individuals (Johanson *et al.*, 1955). They suggested that heritability estimates along with the genetic gain would be more useful than the heritability value alone. Panse (1957) suggested that if the heritability is mainly due to non-additive genetic effect, the genetic gain would be low whereas if the heritability is chiefly due to the additive effect of a gene, a high genetic advance may be expected.

High heritability estimates have been found to be helpful in making a selection of superior genotype on the basis of superior phenotypic performance of economic traits. Heritability in a broad sense includes both additive and epistatic gene effect. High heritability associated with higher genetic advance is expected due to additive gene action.

In the present investigation, estimates of genetic advance expressed as a percent of mean revealed considerable differences among the traits studied. The highest genetic advance as percent of mean was observed for seed yield per plant (67.56%), whereas days to maturity had the lowest value (6.69%) of genetic advance as percent of the mean. The genetic advance as percent of mean has found to be moderate for the 100-seed weight (27.73).

High genetic advance for seed yield per plant, pod weight per plant, biological yield, number of effective pods per plant, number of seeds per plant and days to 50% flowering were also reported by Vaghela *et al.* (2008), Singh *et al.* (2012) and Gul *et al.* (2013). Low genetic advance for days to maturity is in agreement with findings of Yadav *et al.* (2015) indicating that this trait was greatly influenced by the environment. Thus considering the three important genetic parameters viz., genotypic coefficient of variation, heritability (broad sense) and genetic advance as percent of mean, it appears that seed yield per plant, pod weight per plant, biological yield, number of effective pods per plant and number of seeds per plant had higher values for all the three components. Therefore, these five traits may be effective for the practical identification of promising lines along with 100-seed weight in chickpea directly from BC₂F₄ population for efficient expression of the trait. These five traits may be under the control of additive gene effects and further genetic improvement in chickpea may be possible by simple selection for these traits.

5.2 Association studies

The positive and strong association between pod weight per plant, biological yield, number of seeds per plant and pods per plant with seed yield revealed the importance of these traits in improving yield. These findings are almost in agreement with Babbar and Patel (2005), Atta (2008), Thakur and Sirohi (2009), Tomar and Singh (2009), Mishra and Babbar (2011), Dar *et al.* (2012) and Tesfamichael *et al.* (2015). Correlation study showed a non-significant association of days to first flowering, days to 50% flowering and days to maturity with seed yield, these results showed contradictory with the findings of Sreelakshmi *et al.* (2010). Thus, it can be assumed that the yield is the outcome of an increased number of filled pods and seeds rather than the

duration of flowering and maturity. Since both are influenced by environmental fluctuation like excess of irrigation or rainfall enhance the vegetative growth and depresses yield, as observed in the present experiment. In addition, the path analysis result showed that biological yield (0.5798) had a maximum direct effect on grain yield followed by pod weight per plant (0.4149) and harvest index (0.2759). On the other hand, pods per plant had a negative direct effect on grain yield, but high positive correlation with grain yield which is in contrast to the findings of Dasgupta *et al.* (1992) and Borate and Dalvi (2010). Thus, it may be assumed that increased in a number of the pod may increase the number of seeds per plant, but the direct selection of promising lines based on these traits would not be rewarding for yield improvement.

Days to first flowering and days to maturity showed negative direct effect and their contribution through indirect effect via biological yield was also low. This finding is in contrast with the findings of Uddin *et al.* (1990) and Hasan and Deb (2014). Days to 50% flowering, plant height, seeds per plant and 100 seed weight contributed positively and indirectly towards seed yield through biological yield. Thus, the combination of these traits is important to create a selection index for promising introgression lines in chickpea improvement.

To know the exact trait combination which would manage high seed yield, PCA was performed. In the present study, seed yield per plant, pod weight per plant, number of effective pod per plant, number of seeds per plant, biological yield and plant height clustered together and contributed to maximum variability for yield. Hence, phenotypic selection for these traits will be successful for the screening of introgression lines under different agro-ecological conditions. Like other analysis in this study, in PCA analysis too, the contribution of days to first flowering towards the main principal component (PC1) is zero, while days to 50% flowering, days to maturity, 100-seed weight and harvest index have negligible response towards PC1. This is also evident from the PCA bi-plot since the vector corresponding to these traits is of the shortest magnitude.

Cluster analysis:

Cluster I had high mean value for 100-seed weight and plant height, number of effective pods per plant, pod weight per plant, number of seeds per plant and biological yield. Cluster VI had a high mean value for seed yield per plant. Cluster I and III had low mean value for days to first flowering and Cluster I had low mean value for days to 50% flowering. Cluster VIII had low mean value for days to maturity and cluster X had high mean value for harvest index. Therefore, the intercrossing of ILs involved in these clusters could be practiced for enriching variability in the respective traits and their rationale improvement for increasing seed yield. Based on cluster means, Rao and Singh (1994) also reported a wide range of variation for days to maturity, pods per plant and 100 -seed weight. On the basis of these traits, superior introgression lines may be selected and used in hybridization program as a donor parent for developing new chickpea cultivars with a broad genetic base.

5.3 Identification of promising ILs

Chickpea is largely grown on residual soil moisture after rains. Abiotic stress such as terminal drought and heat stresses are the major abiotic constraints in semi-arid tropics, Mediterranean environment (Australia) and cold/frost stress in temperate environment where crops often encounter end season frost. Therefore, to enable the crop to escape stress at the end of the season, it is important to cultivate extra-early maturing varieties for these areas. In this study, 120 ILs were found at par with ICC 4958 based on days to 50% flowering ,which can be exploited for developing such cultivar due to presence of high heritability coupled with high genetic advance . Though, this trait not found to have a significant association with grain yield per plant but due to the presence of wild allele in the genetic background of these ILs may provide tolerance to various biotic and abiotic stresses as observed by Berger *et al.* (2005).

Mallikarjuna *et al.* (2007) observed advanced generation population in pigeonpea having resistance to pod borer, variation in seed color and high seed weight by utilization of *C. acutifolius* as the pollen parent. As chickpea is

valued for its nutritive seed composition which is high protein content, this crop is being used increasingly as a substitute for animal protein. High-quality seed has the potential to attract the best price. Hence, the breeding of desirable quality traits, including seed size is of major importance. In present study, fifty-eight ILs were found large-seeded than ICC 4958 and 40 ILs were found medium-seeded than JG 14. High heritability (89.09%) of 100-seed weight also provides good opportunity for its utilization in chickpea breeding / improvement programme .

Finally the ultimate aim of any breeding programme is to produce high yielding varieties. Singh and Ocampo (1997) reported successful utilization of *C. reticulatum* for increasing yield (up to 39%). In present study, of the 300 ILs, 24 ILs were found significantly high yielding and 99 were at par with the best check, ICC 4958. Similar result were also observed in soybean, wherein, Concibido *et al.* (2003) studied *G. soja* which contributed yield-enhancing QTL alleles that demonstrated 9% yield advantage in backcross progenies.

Based on days to 50% flowering, ILs are classified into different maturity duration groups such as extra-early (less than 40 days), early (40-60 days), medium (61-80 days) and late (>80 days) maturity groups. Seven high-yielding ILs, ICCP 171119, ICCP 171500, ICCP 173211, ICCP 173170, ICCP 173181, ICCP172429 and ICCP 172350 were extra-early (34-38 days) and found similar when compared with best Check ICC 4958 in respective category. Five early ILs viz., ICCP 173668, ICCP 171182, ICCP 171340, ICCP 172331 and ICCP 173210 were at par with the best check JG 14. Two ILs, ICCP 172079 and ICCP 173284 were significantly early than check ICCV 10, while, ICCP 173004, ICCP 172738, ICCP 172147, ICCP 173159 and ICCP 172325 were at par when compared with ICCV 10. Two ILs, ICCP 173334 and ICCP 173278 were early (54-55 days) and at par with check JG 130. Based on days to 50% flowering three ILs, ICCP 173651, ICCP 171053 and ICCP 171081(61-63 days) were found medium over all checks. Of the 24 ILs, 8 ILs were large seeded and were better than best check ICC 4958, whereas 6ILs were significantly better than medium seeded variety JG 14. These 24 promising ILs having good combination of traits may provide good opportunity to develop excellent varieties with broad genetic base.

These selected ILs also exhibited different growth habits like semi-erect, semi-spreading and spreading types. Based on plant type suitability in different agro-climatic zone in India like in NEPZ (North East Plain Zone), where high humidity and bushy plants (semi-spreading and spreading plant type) provides an opportunity for disease aschocyta blight. Thus, semi erect growth habit ILs provides an opportunity for better yield in rice fellow condition in NEPZ. Similarly, short duration, semi-spreading and spreading plant type have large canopy area which reduces the evaporation and provides an opportunity to produce high yield. These types of promising ILs may be utilized for better yield in CZ and SZ of India.

SUMMARY, CONCLUSIONS, AND SUGGESTIONS

FOR FURTHER WORK

6.1.Summary

The cultivation the of a few genetically uniform cultivars has resulted in the vulnerability of the crops to pests and diseases, which causes a huge yield gap between the actual and potential yields due to narrow genetic base in cultivated the agricultural crops which is the major factor limiting the genetic improvement of cultivars. The present research entitled “**Tapping wild *Cicer* species for enriching variability in cultivated gene pool for chickpea improvement**” was aimed at (a) To estimate the genetic parameters for yield and component traits (b)To study the correlation coefficient amongst various characters and measure the direct and indirect effects of various components on yield (c) To identify the trait-specific promising introgression lines for the use in chickpea improvement programs. The research was carried out using 300 Introgression lines developed by complex three-way cross ICC 4958 x (ICC 17264 x IG 69978) in augmented randomized block design at ICRISAT, Patancheru, Hyderabad during post-rainy season 2018-19. This study provides an insight into the genetic variability, heritability, associations between different traits and identification of promising lines which in the future may help in developing new chickpea cultivars with a broad genetic base. The key findings from this research are summarized below:

The highest value of the phenotypic coefficient of variation was recorded for seed yield per plant followed by pod weight per plant, biological yield, number of effective pods per plant and number of seeds per plant. High heritability estimates coupled with high genetic advance as a per cent of mean were recorded for seed yield per plant, pod weight per plant, biological yield, number of effective pod per plant, number of seeds per plant and days to 50% flowering.

Seed yield per plant shared a strong significant and positive association with pod weight per plant (0.98), biological yield per plant (0.90), number of effective pod per plant (0.87), number of seeds per plant (0.86),

plant height (0.50), 100 seed weight (0.26) and harvest index (0.21). The path analysis revealed that biological yield (0.579) showed the highest positive direct effect on seed yield per plant, followed by pod weight per plant (0.414) and harvest index (0.275). The highest negative direct effect exhibited by number of effective pods per plant (-0.135).

On the basis of PCA analysis, four principal components PC1, PC2, PC3, and PC4 were the major contributing components with cumulative variance (%) of 44.57%, 60.29%, 71.44%, and 81.89%. Five traits, seed yield per plant, pod weight per plant, biological yield, number of seed per plant and number of effective pods per plant were the major contributing traits clustered together and contributed to maximum variability, which was in accordance with the high correlation values between these traits ($r=0.86$ to 0.98)

On the basis of cluster analysis, all the introgression lines are grouped into ten cluster groups based on Euclidean distance matrix. Cluster I consisted of 49 ILs, cluster II 47 ILs, cluster III 46 ILs, cluster IV 25 ILs and cluster V 13 ILs, cluster VI 15 ILs, cluster VII 10 ILs, cluster VIII 36 ILs, cluster IX 48 ILs and cluster X 11 ILs.

6.2 Conclusions

High genotypic and phenotypic coefficient of variation was recorded for the traits viz., seed yield per plant, pod weight per plant followed by biological yield, number of effective pods per plant, number of seeds per plant. Thus, it may be assumed that the exploitation of these traits for crop improvement, could be rewarding.

High heritability coupled with genetic advance as per cent of mean was recorded for seed yield per plant, followed by pod weight per plant, biological yield per plant, number of effective pods per plant, number of seeds per plant and days to 50% flowering indicating that predominance of additive gene action. Selection based on these traits may be effective.

Seed yield per plant exhibited significant and positive correlation with pod weight per plant, biological yield, number of effective pods per plant, number of seeds per plant, plant height, 100-seed weight and harvest index. Hence, these traits should be given prime importance for genetic improvement.

Path analysis revealed that biological yield, pod weight per plant, harvest index, number of seeds per plant exerted a maximum positive direct effect on seed yield per plant. Hence, for enhancement of yield, these traits can be selected directly.

PCA analysis revealed that Seed yield per plant, pod weight per plant, number of effective pods per plant, number of seeds per plant, biological yield and plant height clustered together and contributed to maximum variability for yield. Hence phenotypic selection for these traits will be successful for the screening of introgression lines.

Cluster analysis grouped 300 ILs into 10 clusters based on Euclidean distance between ILs. The intercrossing of ILs involved in these clusters could be practised for enriching variability in the respective traits and their rationale improvement for increasing seed yield.

The identified 24 promising introgression lines

ICCP 173278, ICCP 172331, ICCP 172429, ICCP 173334, ICCP 172147, ICCP 171053, ICCP 172350, ICCP 173170, ICCP172079, ICCP173210, ICCP 173668, ICCP 173284, ICCP 171182, ICCP 173004, ICCP 171340, ICCP 173651, ICCP 173211, ICCP 172325, ICCP 171119, ICCP 172738, ICCP 171500, ICCP 173159, ICCP 171081, and ICCP 173181 will play an important role in chickpea improvement.

6.3 Suggestions for Future Work

1. Advanced backcross population used in this study were evaluated in one location in a single season only. This population should be further tested in the multi-location and season to identify stable promising introgression lines.
2. As the population is derived from wild Cicer species, this population may provide novel variability such as new and diverse sources of resistance/tolerance to biotic/abiotic stresses as well as for nutrition-related traits.
3. Molecular markers can be deployed to assess the genetic variability at the molecular level and to identify genomic regions /QTL for various morpho-agronomic traits.

4. Gene tagging for novel alleles for different traits can be done to pinpoint the wild gene for various abiotic and biotic constraints.

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APPENDICES

Appendix I. Metrological data

Weekly meteorological data at ICRISAT ,Patancheru, during post-rainy season ,2018-19

Month/date	Weeks	Temperature(⁰ C)		Rainfall(mm)	Relative Humidity(in%)
		Min Temp	Max Temp		
15 to 21 Oct	1	20.65	31.59	24.5	51.28
22 to 28 Oct	2	17.22	32.62	0.6	39.85
29 to 4 Nov	3	16.28	30.8	0	47.42
5 to 11 Nov	4	17.4	32.82	0	44.28
12 to18 Nov	5	14.91	32.45	0	31
19 to 25Nov	6	17.97	31.62	0	47.28
26 to 2 Dec	7	11.88	30.11	0	39.28
3 to 9 Dec	8	19.17	29.8	0	53.42
10 to 16 Dec	9	18.25	29.08	51.6	60.85
17 to 23Dec	10	15.4	25.11	0.7	61.57
24 to 31 Dec	11	12.07	28.27	0	40.62
1 to 7 Jan	12	9.54	29.14	0	33.42
8 to14 Jan	13	12.35	29.31	0	37.42
15 to 21 Jan	14	11.17	30.22	0	39
22 to 28 Jan	15	17.42	29.08	8.89	51.42
29 to 4 Feb	16	13.11	27.34	0	45.57
5 to 11 Feb	17	16.4	30.62	0	42.71
12 to18 Feb	18	17.59	32.57	2.5	42.57
19 to25 Feb	19	19.85	35.14	0	44.28

Appendix II- Mean table of yield and related traits of 300 Introgression lines along with four checks

S.No	Identity	GH	DF	DF50	DM	PH	PPP	PWP	SPP	HSW	BY	HI	SYP
1	ICCP171038	SE	43	71	110	50.47	89.70	33.97	106.27	29.36	48.86	59.60	29.51
2	ICCP171040	SE	35	53	108	46.80	64.99	23.72	80.79	23.67	34.00	58.80	19.38
3	ICCP171051	SS	36	63	110	55.06	74.45	29.97	86.19	30.98	43.11	60.23	26.14
4	ICCP171053	SE	36	63	110	51.84	119.63	43.84	128.50	30.89	65.03	58.93	39.44
5	ICCP171054	SE	37	53	110	51.54	64.03	22.87	73.28	27.85	31.88	63.94	20.35
6	ICCP171056	SS	37	63	109	46.65	77.40	27.61	84.12	26.41	40.14	60.34	24.23
7	ICCP171081	SE	39	63	109	54.29	96.85	34.92	106.61	30.03	49.52	61.39	31.28
8	ICCP171092	SE	36	63	112	49.24	60.55	20.82	68.08	25.88	43.45	47.47	18.15
9	ICCP171119	SE	32	34	116	42.67	112.87	35.58	128.18	30.89	47.07	65.19	32.28
10	ICCP171128	SS	35	42	108	53.68	102.49	32.31	109.16	31.24	46.26	61.81	29.34
11	ICCP171129	SE	43	53	108	48.48	81.74	25.35	88.93	26.92	36.51	62.65	23.04
12	ICCP171135	SS	44	71	112	51.84	72.52	23.26	80.02	27.01	33.32	62.02	20.48
13	ICCP171136	SS	34	35	110	50.47	98.78	31.01	108.15	28.64	43.97	62.35	28.10
14	ICCP171169	SE	61	72	111	46.34	62.68	26.45	76.17	29.45	40.38	58.56	23.34
15	ICCP171182	SE	38	42	108	49.55	92.12	37.67	104.82	30.44	53.12	61.94	34.18
16	ICCP171207	SS	39	41	110	47.41	89.95	26.40	99.29	27.28	40.08	59.38	23.63
17	ICCP171230	SE	34	35	110	42.67	61.90	23.82	73.67	30.88	32.38	63.64	20.58
18	ICCP171248	SE	37	59	113	42.21	75.03	27.84	81.76	34.02	39.25	63.07	25.21

S.No	Identity	GH	DF	DF50	DM	PH	PPP	PWP	SPP	HSW	BY	HI	SYP
19	ICCP171265	SE	38	38	107	52.30	111.67	37.47	126.25	30.02	44.47	60.22	27.05
20	ICCP171271	SE	35	36	113	47.10	86.49	31.89	95.11	30.03	38.57	66.54	26.69
21	ICCP171287	SS	35	40	108	50.01	67.74	30.79	75.93	30.26	38.26	56.79	21.00
22	ICCP171289	SS	34	35	110	49.86	53.99	20.06	66.06	29.00	28.06	62.48	17.01
23	ICCP171306	SE	38	40	113	50.47	67.70	25.98	75.59	28.29	36.74	61.03	22.33
24	ICCP171340	S	37	42	107	47.87	111.18	38.42	123.85	25.81	52.04	62.53	33.90
25	ICCP171341	SS	37	37	113	47.72	122.77	33.74	130.35	23.56	50.90	49.25	22.91
26	ICCP171343	SS	35	35	108	46.49	47.23	11.43	54.74	19.06	20.17	54.98	9.50
27	ICCP171358	SS	34	35	107	50.93	51.82	20.17	63.65	33.42	31.84	53.75	15.71
28	ICCP171399	SE	37	37	105	48.63	101.29	30.05	108.92	18.98	44.85	54.98	23.80
29	ICCP171443	SE	35	36	116	49.09	52.44	14.85	59.22	20.49	25.96	52.04	11.81
30	ICCP171452	SE	35	77	118	53.53	57.85	18.67	64.61	26.80	33.63	49.55	14.68
31	ICCP171461	SE	34	35	111	49.09	60.55	23.37	67.50	26.54	35.40	54.02	17.84
32	ICCP171470	SE	33	35	116	43.13	45.11	16.22	52.48	29.27	24.72	59.04	13.51
33	ICCP171473	SE	34	35	113	47.41	40.67	15.36	47.66	32.67	25.97	54.16	12.57
34	ICCP171480	SE	37	63	114	49.70	104.51	31.22	119.19	25.89	43.23	59.53	25.78
35	ICCP171490	SE	34	35	111	54.44	75.03	26.37	81.76	24.95	41.55	52.52	20.38
36	ICCP171491	SS	37	45	113	53.98	71.12	27.25	79.06	27.43	40.14	55.86	21.59
37	ICCP171500	SE	35	35	116	56.58	90.67	40.16	117.35	27.17	61.92	52.74	31.57

S.No	Identity	GH	DF	DF50	DM	PH	PPP	PWP	SPP	HSW	BY	HI	SYP
38	ICCP171501	SE	38	42	116	45.73	56.50	20.22	65.19	26.36	31.45	53.04	15.17
39	ICCP171509	SE	39	59	118	51.08	88.50	28.00	99.53	19.08	43.19	52.65	21.35
40	ICCP171513	S	37	59	117	48.79	96.94	26.43	105.07	28.08	57.71	49.33	26.30
41	ICCP171526	SE	34	35	117	45.12	44.91	16.77	54.40	32.92	28.00	53.17	13.33
42	ICCP171547	SE	35	36	112	52.46	88.26	34.01	96.16	28.73	49.44	56.79	27.81
43	ICCP171548	SE	34	36	112	50.62	63.40	21.57	71.11	31.71	30.38	60.22	17.67
44	ICCP171551	SE	33	35	112	49.86	59.78	19.13	66.54	25.03	29.43	56.42	15.47
45	ICCP171557	SS	35	36	108	50.77	70.16	26.03	79.54	30.31	37.61	57.75	21.13
46	ICCP171561	SE	35	37	105	47.41	67.74	22.58	75.45	26.82	32.80	58.47	18.46
47	ICCP171566	SE	35	35	110	47.41	50.51	17.64	58.26	30.53	26.17	58.88	14.38
48	ICCP171567	SE	35	50	116	48.33	73.54	27.40	82.67	24.40	40.95	55.69	21.97
49	ICCP171576	SS	39	42	112	50.16	73.29	24.17	84.60	22.73	34.94	54.02	17.58
50	ICCP171638	SE	38	54	107	46.49	54.95	14.46	62.11	18.58	22.92	53.99	10.79
51	ICCP171667	SS	37	38	106	51.31	55.74	19.60	61.23	29.69	31.31	54.49	15.24
52	ICCP171669	SE	36	38	115	49.32	64.42	22.85	69.90	26.84	33.20	59.30	18.43
53	ICCP171711	SE	35	36	110	45.19	82.12	24.86	88.52	24.59	38.29	54.81	19.52
54	ICCP171712	SE	34	36	113	50.69	69.89	24.00	75.36	26.89	36.29	53.70	17.79
55	ICCP171732	SE	36	38	110	49.78	71.95	25.28	78.18	28.20	39.07	55.02	20.09
56	ICCP171745	SE	34	38	105	36.47	48.98	13.22	55.21	19.65	18.85	67.67	10.48

S.No	Identity	GH	DF	DF50	DM	PH	PPP	PWP	SPP	HSW	BY	HI	SYP
57	ICCP171750	SE	35	36	108	51.00	114.86	37.86	123.59	27.70	53.59	55.87	29.43
58	ICCP171760	SE	36	41	110	49.62	56.89	18.49	64.89	26.92	29.33	56.20	14.70
59	ICCP171761	SE	36	37	110	45.34	69.97	21.44	75.68	25.18	31.86	57.36	16.74
60	ICCP171817	SS	37	58	117	53.91	127.17	26.16	136.03	21.84	42.45	55.42	22.35
61	ICCP171837	SE	36	37	115	52.38	88.31	29.64	94.46	27.30	57.18	45.02	22.66
62	ICCP171840	SE	36	41	112	49.47	61.53	22.02	75.68	26.17	36.98	55.85	19.25
63	ICCP171849	SS	36	37	108	49.32	71.95	20.27	83.86	19.65	33.31	53.15	15.83
64	ICCP171850	SE	37	38	108	47.94	66.35	20.73	73.75	27.20	34.14	52.00	15.78
65	ICCP171869	SE	34	37	110	50.08	77.62	28.81	83.70	28.33	38.48	61.14	22.91
66	ICCP171883	SS	38	43	108	54.82	92.42	34.96	99.11	29.72	54.16	53.55	27.98
67	ICCP171892	SE	36	38	110	46.41	69.44	24.31	81.70	32.28	38.96	55.41	20.23
68	ICCP171893	SE	37	38	116	51.31	75.62	27.69	87.43	26.93	41.22	55.58	21.69
69	ICCP171894	SE	38	58	116	49.47	58.39	20.20	64.36	29.01	34.21	53.35	16.43
70	ICCP171908	SE	37	43	108	51.31	75.77	25.65	83.62	27.77	40.71	53.53	20.24
71	ICCP171912	SE	38	47	115	50.54	69.57	27.02	75.68	25.81	36.76	60.15	21.23
72	ICCP171947	SE	37	43	110	53.75	72.15	25.04	78.09	26.17	39.49	56.21	20.98
73	ICCP171952	SE	36	37	117	44.73	54.13	16.69	59.62	24.18	26.70	53.35	12.14
74	ICCP171954	SS	37	38	110	50.39	90.49	28.07	96.63	28.65	42.63	58.09	24.03
75	ICCP171961	SE	36	37	108	45.04	61.72	23.18	69.32	32.63	32.42	62.80	19.38

S.No	Identity	GH	DF	DF50	DM	PH	PPP	PWP	SPP	HSW	BY	HI	SYP
76	ICCP171968	SE	36	41	115	50.39	66.84	31.38	75.20	20.56	41.97	63.95	26.98
77	ICCP171969	SE	35	37	112	47.33	54.38	19.11	60.84	23.61	28.76	57.58	14.84
78	ICCP171988	SS	35	38	110	49.32	66.59	23.71	72.79	28.60	31.00	64.93	19.19
79	ICCP172027	SE	39	58	110	46.72	111.72	32.99	118.54	22.38	41.36	62.52	25.72
80	ICCP172056	SE	66	71	117	46.87	56.38	15.89	61.87	27.07	26.61	56.47	13.10
81	ICCP172063	SE	36	44	112	56.05	69.89	18.61	76.64	23.28	26.16	59.88	13.90
82	ICCP172071	SE	36	43	112	50.54	76.97	26.74	84.59	30.95	38.40	60.72	22.64
83	ICCP172077	SE	35	36	113	51.15	105.29	34.93	111.96	32.46	35.39	65.33	22.72
84	ICCP172079	SS	36	45	112	56.35	105.29	38.72	113.24	34.74	62.53	58.52	37.33
85	ICCP172118	SE	35	53	108	49.93	67.56	21.53	75.20	26.86	32.86	58.93	18.04
86	ICCP172126	SE	37	43	106	51.15	75.68	27.34	83.06	33.66	39.07	62.99	24.31
87	ICCP172128	SS	35	37	104	45.80	67.32	19.96	76.16	23.10	31.00	56.22	15.74
88	ICCP172130	SE	37	41	104	44.43	66.68	22.66	74.07	30.14	27.31	74.08	19.45
89	ICCP172132	SE	36	37	104	42.90	39.32	11.76	46.21	24.18	20.24	57.53	9.37
90	ICCP172137	SS	37	43	106	52.22	85.42	26.98	95.90	20.15	46.24	54.22	23.87
91	ICCP172138	SE	36	38	118	44.27	52.52	17.78	59.06	29.11	31.27	53.05	14.63
92	ICCP172146	SE	37	38	108	49.78	80.83	29.60	90.45	28.68	43.22	59.94	25.52
93	ICCP172147	SE	36	47	110	56.51	102.07	47.35	113.56	34.74	63.00	62.58	41.40
94	ICCP172153	SE	37	44	108	44.73	46.08	12.92	52.18	27.62	22.14	57.97	10.70

S.No	Identity	GH	DF	DF50	DM	PH	PPP	PWP	SPP	HSW	BY	HI	SYP
95	ICCP172226	SE	38	44	106	50.39	57.67	22.02	79.77	30.84	32.57	62.17	19.22
96	ICCP172228	SE	37	43	113	53.14	83.01	28.17	94.22	25.08	51.20	48.58	22.66
97	ICCP172229	SE	38	47	112	44.27	41.26	12.66	51.12	27.04	21.31	55.83	9.65
98	ICCP172230	SE	37	38	106	49.32	76.73	29.05	93.98	25.54	41.68	57.26	22.93
99	ICCP172231	SE	36	52	110	52.22	73.75	27.19	93.74	21.66	40.10	57.04	21.81
100	ICCP172238	SE	37	58	110	50.69	90.16	28.77	97.83	28.96	41.54	56.28	22.29
101	ICCP172244	SE	29	33	119	58.78	48.86	29.15	57.90	30.49	31.22	57.96	16.53
102	ICCP172261	SE	36	37	108	51.28	61.98	22.93	69.17	29.58	37.92	53.31	18.37
103	ICCP172276	SE	36	38	106	43.33	54.65	16.69	60.95	27.69	26.55	56.63	13.15
104	ICCP172281	SS	35	36	108	50.67	96.88	32.61	105.09	26.87	49.57	57.51	27.79
105	ICCP172293	SE	37	55	106	47.61	71.70	22.94	95.94	19.80	37.73	55.93	19.60
106	ICCP172318	SE	36	37	117	50.82	74.68	28.24	80.77	31.21	38.65	62.47	23.58
107	ICCP172325	SS	36	52	111	55.72	103.88	46.55	109.43	29.85	66.30	51.52	32.35
108	ICCP172331	SE	38	43	111	55.72	137.99	51.95	147.63	29.59	56.06	71.83	43.45
109	ICCP172350	SS	37	38	111	47.15	91.01	43.58	97.23	27.65	43.99	79.29	37.66
110	ICCP172352	SE	39	43	112	50.21	61.16	23.60	69.46	27.38	36.67	57.71	19.84
111	ICCP172401	SE	37	38	117	39.51	25.69	8.98	31.73	27.78	19.48	53.03	8.09
112	ICCP172418	SE	38	60	109	45.93	44.03	14.71	49.95	28.59	25.14	57.66	12.60
113	ICCP172429	SE	36	38	106	55.56	125.12	52.23	138.32	30.46	76.41	56.12	42.93

S.No	Identity	GH	DF	DF50	DM	PH	PPP	PWP	SPP	HSW	BY	HI	SYP
114	ICCP172432	SE	36	37	106	51.89	65.02	23.94	72.83	29.58	36.65	59.12	20.52
115	ICCP172436	SE	37	38	111	49.30	48.86	17.20	56.94	28.05	28.02	57.58	14.38
116	ICCP172483	SE	36	38	115	47.46	81.03	31.39	87.60	29.09	41.88	58.86	23.77
117	ICCP172495	SS	38	47	117	43.64	57.87	28.19	75.48	28.50	41.70	52.62	20.07
118	ICCP172509	SE	35	37	115	46.08	57.54	18.14	66.57	24.19	29.18	57.11	14.92
119	ICCP172518	SE	35	36	113	50.52	43.31	15.18	50.19	27.69	25.11	57.77	12.61
120	ICCP172519	SE	34	36	115	47.31	78.78	21.18	91.37	19.55	33.31	60.30	18.87
121	ICCP172524	SE	36	36	113	49.14	76.37	29.80	84.63	30.51	42.44	59.41	24.45
122	ICCP172535	SE	36	38	117	48.68	49.58	15.44	56.70	28.66	24.25	60.13	12.76
123	ICCP172553	SE	35	37	115	48.07	53.49	18.37	59.92	28.50	29.08	59.28	15.66
124	ICCP172554	SE	38	47	108	54.34	76.13	25.97	81.98	31.66	39.00	59.10	22.05
125	ICCP172563	SE	36	47	111	52.81	69.32	25.63	78.99	28.09	38.79	59.18	21.95
126	ICCP172569	SE	37	43	117	44.40	40.17	15.57	48.11	30.52	25.36	59.02	13.15
127	ICCP172576	SE	35	37	104	38.90	31.24	8.85	36.95	23.45	18.11	53.98	7.52
128	ICCP172587	SE	37	43	109	48.22	58.03	19.92	64.40	28.77	39.76	48.11	16.57
129	ICCP172727	SE	39	56	109	50.21	42.82	17.70	50.92	28.95	24.80	61.69	13.59
130	ICCP172734	SE	36	38	116	55.26	84.33	31.66	94.26	27.78	45.96	53.28	22.81
131	ICCP172738	SS	37	47	111	54.80	119.32	36.86	133.19	23.58	53.93	58.89	31.57
132	ICCP172765	SE	35	37	117	50.37	94.23	24.47	101.48	18.76	35.44	56.95	18.71

S.No	Identity	GH	DF	DF50	DM	PH	PPP	PWP	SPP	HSW	BY	HI	SYP
133	ICCP172771	SE	37	47	111	50.82	64.62	23.15	70.90	27.15	36.01	57.54	19.35
134	ICCP172801	SE	37	43	111	46.70	103.40	25.24	109.67	20.11	39.42	55.93	20.61
135	ICCP172857	SE	37	38	106	43.48	36.79	10.60	44.90	27.82	19.87	56.54	9.06
136	ICCP172877	SE	36	37	111	41.65	58.99	18.23	65.85	19.93	28.64	60.28	15.73
137	ICCP172936	SE	37	38	112	54.19	79.99	28.03	86.07	27.69	44.02	55.35	23.00
138	ICCP172938	SE	35	37	108	52.35	89.40	29.07	95.46	32.38	41.60	64.17	26.64
139	ICCP172940	SE	35	38	109	50.21	46.93	20.08	53.24	29.58	31.07	53.53	14.66
140	ICCP172944	SE	36	38	111	47.92	45.38	15.29	51.83	27.82	25.76	59.70	13.63
141	ICCP172949	SE	36	37	111	52.81	45.64	15.10	51.64	31.21	29.63	49.13	12.20
142	ICCP172953	SE	36	43	111	52.51	77.49	29.76	87.60	30.31	47.95	52.64	23.48
143	ICCP172957	SE	37	43	109	52.51	68.16	22.83	74.75	32.56	39.43	51.18	18.06
144	ICCP172979	SE	36	47	108	40.12	54.65	12.89	65.12	24.89	35.19	40.79	10.99
145	ICCP172994	SS	39	43	106	43.48	90.69	22.54	96.59	18.76	31.78	60.78	18.04
146	ICCP172999	SE	38	47	109	45.17	50.46	17.63	56.78	31.21	26.97	59.64	14.41
147	ICCP173003	SE	36	47	108	44.10	82.40	29.65	88.96	26.37	41.28	59.15	23.55
148	ICCP173004	SS	37	47	106	47.00	110.96	41.37	125.48	31.39	56.79	59.55	33.97
149	ICCP173005	SE	35	37	109	43.48	67.52	23.45	73.55	28.95	34.82	60.25	19.85
150	ICCP173007	SE	36	37	109	46.54	80.71	26.13	88.88	27.18	39.75	58.14	22.01
151	ICCP173010	SE	37	46	104	42.69	87.01	25.14	94.95	25.20	31.78	67.11	20.46

S.No	Identity	GH	DF	DF50	DM	PH	PPP	PWP	SPP	HSW	BY	HI	SYP
152	ICCP173011	SE	38	55	111	44.98	54.51	17.04	62.84	27.82	27.40	58.11	14.04
153	ICCP173012	SE	38	57	109	48.81	80.89	23.80	88.85	24.76	35.28	52.84	16.67
154	ICCP173014	SE	34	35	111	52.32	96.66	31.04	104.58	31.51	42.12	66.78	28.43
155	ICCP173017	SS	38	57	111	50.49	53.38	23.01	82.83	29.71	37.01	56.74	19.53
156	ICCP173019	SS	37	42	107	50.95	90.30	35.59	101.37	31.06	48.46	58.19	27.59
157	ICCP173028	SE	38	54	107	44.37	60.62	20.94	72.16	27.43	33.40	54.50	16.34
158	ICCP173032	SS	38	57	111	50.18	74.78	25.57	83.39	28.78	48.01	49.66	21.60
159	ICCP173034	SS	37	38	111	48.19	50.00	16.50	60.60	28.10	27.62	54.90	13.10
160	ICCP173037	SS	36	55	107	50.95	87.01	30.52	96.23	31.05	45.45	52.51	22.10
161	ICCP173043	SS	35	36	106	46.21	65.77	26.12	76.33	25.33	60.93	40.97	20.43
162	ICCP173057	SS	38	43	106	46.82	50.00	14.05	61.24	22.54	23.90	61.80	12.79
163	ICCP173070	SE	38	54	114	46.97	67.70	19.38	77.29	22.49	31.27	60.31	17.38
164	ICCP173071	SS	35	36	107	45.29	67.38	20.64	75.69	20.55	31.43	59.19	17.05
165	ICCP173085	SE	38	46	113	44.37	40.99	13.05	51.93	21.14	23.75	55.74	11.06
166	ICCP173089	SE	34	35	109	51.10	72.53	24.10	81.79	26.41	34.85	61.19	20.21
167	ICCP173090	SE	35	35	107	49.57	59.01	20.15	67.66	29.76	30.33	62.68	17.64
168	ICCP173091	SE	37	54	109	51.10	47.11	15.36	55.14	27.96	25.96	58.56	13.25
169	ICCP173099	SE	35	40	106	50.95	84.75	25.56	93.02	22.22	41.57	55.28	21.53
170	ICCP173101	SS	38	40	114	44.07	48.39	15.66	56.75	29.62	27.17	56.93	13.51

S.No	Identity	GH	DF	DF50	DM	PH	PPP	PWP	SPP	HSW	BY	HI	SYP
171	ICCP173104	SE	35	40	113	51.25	63.52	23.94	72.48	30.37	37.48	57.74	20.32
172	ICCP173116	S	34	36	109	48.81	68.02	20.81	76.01	29.65	32.73	58.47	17.60
173	ICCP173122	SE	35	36	109	48.19	68.02	23.21	78.90	27.36	35.43	60.00	20.05
174	ICCP173124	SE	34	36	111	45.60	63.84	20.01	71.83	32.26	32.24	60.38	18.07
175	ICCP173125	SS	37	43	111	44.68	80.89	22.68	90.78	24.30	38.44	54.50	19.27
176	ICCP173126	SE	35	36	118	50.03	64.80	19.84	72.80	19.72	30.66	61.98	17.61
177	ICCP173129	SS	30	35	118	44.52	84.43	28.80	92.38	26.58	40.98	59.24	23.37
178	ICCP173130	SE	37	46	113	50.95	122.72	30.94	130.59	26.76	49.87	53.85	25.46
179	ICCP173157	SE	38	43	113	49.72	113.07	27.27	120.95	22.76	41.64	60.23	24.36
180	ICCP173159	SE	37	51	109	50.34	92.48	34.90	101.69	29.54	45.74	67.07	31.45
181	ICCP173160	SS	36	58	109	55.69	84.99	32.46	93.42	24.48	49.60	55.61	26.53
182	ICCP173161	SE	41	54	113	44.22	59.33	21.97	68.62	31.24	32.08	63.34	19.16
183	ICCP173163	SE	36	51	113	44.98	54.19	19.99	63.49	30.38	35.68	54.20	17.52
184	ICCP173170	SS	38	36	106	53.85	103.74	41.26	116.78	26.73	58.30	62.42	37.46
185	ICCP173171	SE	37	37	107	50.95	78.96	29.56	87.89	29.53	44.36	58.48	25.13
186	ICCP173174	SE	35	37	118	47.43	63.84	17.50	73.44	25.20	30.78	50.70	13.35
187	ICCP173180	SS	35	36	111	50.95	74.46	19.10	83.71	29.71	30.82	60.92	17.31
188	ICCP173181	SE	34	36	111	53.39	96.66	33.86	106.19	33.99	51.13	60.77	31.16
189	ICCP173189	SE	70	77	119	50.64	45.18	15.19	53.21	23.85	30.82	49.90	13.06

S.No	Identity	GH	DF	DF50	DM	PH	PPP	PWP	SPP	HSW	BY	HI	SYP
190	ICCP173192	SE	35	43	107	51.56	69.63	20.12	79.54	26.71	32.09	59.65	17.67
191	ICCP173199	SE	38	44	118	46.67	34.56	11.42	43.58	26.77	20.41	61.37	10.25
192	ICCP173205	SS	36	37	109	52.32	58.05	20.46	66.38	26.94	34.42	56.26	17.71
193	ICCP173206	SE	37	44	114	53.70	56.76	17.71	66.70	19.55	31.34	52.57	14.38
194	ICCP173207	SE	37	51	114	51.10	95.37	27.56	105.54	31.22	56.77	46.88	23.74
195	ICCP173209	S	37	43	114	53.85	70.66	21.42	90.78	23.30	37.05	54.40	18.41
196	ICCP173210	SS	37	44	114	49.42	102.77	43.69	121.28	31.42	61.88	58.99	36.93
197	ICCP173211	SE	35	35	118	53.24	89.26	39.33	106.51	28.54	58.30	56.48	32.48
198	ICCP173212	SE	37	51	114	45.60	49.28	19.00	57.31	33.08	32.84	55.92	16.60
199	ICCP173230	SS	38	44	106	50.18	113.07	33.04	122.88	26.77	49.51	57.63	27.88
200	ICCP173231	SE	38	54	109	42.84	43.05	11.48	51.09	20.69	21.56	57.53	10.16
201	ICCP173234	S	34	36	110	52.51	93.75	28.07	100.36	24.80	41.39	58.55	23.38
202	ICCP173237	SS	36	53	118	48.53	77.34	24.52	83.35	24.95	37.02	56.85	19.76
203	ICCP173238	SE	38	57	115	48.53	67.68	19.39	72.11	22.01	31.79	53.52	15.22
204	ICCP173239	SE	37	53	108	44.25	66.07	20.74	71.15	28.41	29.22	62.39	17.03
205	ICCP173253	SS	37	44	110	49.45	76.37	24.88	80.78	32.97	40.64	56.42	21.73
206	ICCP173256	SE	36	43	115	42.42	35.51	11.74	40.00	26.64	20.80	55.63	9.60
207	ICCP173271	SE	37	52	111	48.84	51.59	16.86	56.06	29.35	26.21	58.35	13.65
208	ICCP173278	SE	38	55	115	55.72	132.04	55.95	141.13	25.71	106.26	47.35	46.44

S.No	Identity	GH	DF	DF50	DM	PH	PPP	PWP	SPP	HSW	BY	HI	SYP
209	ICCP173284	SE	36	46	111	51.74	97.61	43.72	101.97	31.88	61.32	56.53	34.28
210	ICCP173287	SE	36	44	110	50.98	96.96	36.59	101.64	32.11	51.34	59.05	30.09
211	ICCP173299	SE	36	44	106	47.16	70.90	24.68	75.96	28.45	37.95	56.68	20.24
212	ICCP173308	SE	37	42	111	47.31	65.75	27.83	75.96	28.50	37.41	60.48	21.81
213	ICCP173312	SE	34	36	108	51.90	71.87	25.81	76.60	33.95	37.08	60.28	21.49
214	ICCP173314	SE	36	44	110	47.92	73.80	27.23	78.53	29.86	37.77	60.47	22.05
215	ICCP173315	SE	37	56	111	47.62	78.62	27.81	85.27	29.04	41.36	59.82	24.08
216	ICCP173320	SS	38	50	106	47.62	59.00	19.06	66.33	28.23	31.53	61.38	18.24
217	ICCP173322	SE	37	44	111	47.62	60.28	19.06	65.37	27.51	28.36	59.77	15.51
218	ICCP173330	SS	38	53	111	47.00	82.81	25.47	87.52	28.21	37.98	57.45	20.65
219	ICCP173334	SE	35	54	108	50.22	138.23	50.63	154.30	29.09	74.02	56.86	42.31
220	ICCP173335	SE	34	40	106	49.60	86.02	30.79	90.41	31.88	42.17	61.74	25.73
221	ICCP173337	SE	41	58	118	43.03	52.56	17.58	57.02	28.27	27.22	59.01	14.51
222	ICCP173341	SS	42	56	111	46.09	57.39	23.05	62.80	30.31	30.99	66.07	19.72
223	ICCP173358	SE	41	53	115	44.86	30.94	12.41	35.44	28.11	20.01	63.00	10.71
224	ICCP173359	SE	36	44	115	51.90	80.55	31.02	85.27	31.81	35.65	71.18	25.67
225	ICCP173362	SE	37	54	115	52.51	87.95	30.18	92.66	27.28	44.02	57.49	24.42
226	ICCP173370	SS	62	76	111	50.52	72.51	22.21	78.85	26.31	41.09	46.85	16.64
227	ICCP173387	SS	37	44	110	51.13	62.86	22.23	78.53	29.10	32.27	58.16	17.41

S.No	Identity	GH	DF	DF50	DM	PH	PPP	PWP	SPP	HSW	BY	HI	SYP
228	ICCP173396	SE	34	35	106	46.55	64.14	15.13	71.79	22.80	26.06	52.99	11.88
229	ICCP173408	SE	46	58	110	51.13	97.61	36.68	102.29	30.03	47.55	57.05	26.31
230	ICCP173419	SE	37	53	113	43.49	43.23	15.43	47.71	30.07	23.40	62.57	13.00
231	ICCP173426	SS	36	58	108	52.55	128.18	32.46	132.47	30.25	69.57	46.87	29.33
232	ICCP173442	SE	38	58	110	55.57	84.74	29.42	90.73	27.12	46.05	55.06	24.11
233	ICCP173502	SE	36	44	108	47.00	66.72	21.60	71.15	25.29	34.48	55.74	17.72
234	ICCP173526	SE	41	71	118	49.30	85.38	29.38	91.37	30.03	46.41	54.10	23.70
235	ICCP173531	SE	37	58	111	48.38	77.34	26.47	81.74	24.53	41.98	54.93	21.69
236	ICCP173538	SE	36	37	111	47.92	93.10	29.92	97.79	28.27	43.45	57.98	24.35
237	ICCP173540	SS	37	36	105	46.55	93.59	32.33	98.76	26.62	46.26	58.52	26.46
238	ICCP173542	SS	36	36	105	48.69	64.79	23.03	72.11	31.84	34.54	59.49	19.45
239	ICCP173543	SE	36	50	115	46.70	35.67	10.13	41.85	21.83	19.09	55.90	8.65
240	ICCP173580	SS	38	62	107	49.91	55.46	18.19	61.19	31.97	29.70	56.04	15.00
241	ICCP173584	SE	37	41	115	49.76	70.90	23.84	83.99	27.47	35.83	59.06	20.08
242	ICCP173588	SS	37	62	110	51.44	68.97	21.42	96.83	27.15	45.87	45.18	17.70
243	ICCP173599	SS	34	36	105	49.30	113.37	34.97	119.94	22.23	50.92	56.78	28.18
244	ICCP173604	SS	36	36	109	46.70	88.28	35.30	94.58	24.04	49.60	58.60	28.66
245	ICCP173608	SS	37	43	108	40.74	43.10	10.74	48.93	23.14	18.89	57.01	8.74
246	ICCP173609	SE	38	44	105	47.77	70.26	18.52	75.00	20.33	30.81	54.76	15.16

S.No	Identity	GH	DF	DF50	DM	PH	PPP	PWP	SPP	HSW	BY	HI	SYP
247	ICCP173610	SS	36	36	108	43.03	46.45	15.93	51.24	22.19	24.53	59.02	12.78
248	ICCP173611	SS	34	36	115	51.29	95.03	23.03	103.57	26.46	36.37	54.06	18.02
249	ICCP173613	SS	34	37	115	56.03	89.24	26.58	101.00	20.42	62.87	40.91	20.87
250	ICCP173615	SS	37	55	113	56.33	80.07	31.14	86.40	24.66	47.30	55.78	25.32
251	ICCP173622	SE	34	42	111	45.68	73.51	23.26	80.34	27.90	36.97	55.82	19.35
252	ICCP173651	SS	42	61	113	49.65	131.75	38.59	147.76	24.45	56.69	58.17	33.01
253	ICCP173655	SS	33	42	111	47.51	79.62	29.23	85.16	25.32	42.26	58.28	23.95
254	ICCP173666	SS	35	42	110	49.65	49.06	19.23	54.66	32.81	30.12	58.43	16.33
255	ICCP173668	SS	36	42	111	56.99	129.18	41.98	136.52	28.06	63.68	56.70	36.02
256	ICCP173677	SS	35	42	104	56.69	96.36	32.42	109.88	29.83	51.19	55.38	27.45
257	ICCP173679	SE	34	43	106	52.10	41.57	19.71	55.30	32.85	29.62	58.44	16.01
258	ICCP173686	SS	33	33	111	49.50	50.66	15.51	56.26	26.21	27.11	54.82	13.16
259	ICCP173695	SS	32	33	109	50.57	49.70	14.39	55.94	26.26	25.73	52.87	11.73
260	ICCP173696	SS	36	52	106	47.67	82.84	23.58	88.37	24.73	35.00	58.93	19.67
261	ICCP173697	SE	34	42	109	45.07	46.16	12.45	51.77	19.82	20.47	55.87	9.58
262	ICCP173709	SE	38	57	112	46.44	61.60	19.06	70.71	22.61	27.76	63.08	16.51
263	ICCP173710	SS	36	43	107	47.05	66.75	18.26	73.28	21.80	25.49	65.64	15.71
264	ICCP173711	SE	36	55	109	47.21	72.22	22.29	83.55	24.42	33.50	56.50	17.60
265	ICCP173712	SS	36	42	114	53.02	56.13	15.84	62.36	22.88	27.02	56.66	13.74

S.No	Identity	GH	DF	DF50	DM	PH	PPP	PWP	SPP	HSW	BY	HI	SYP
266	ICCP173715	SS	36	42	107	48.58	74.80	27.10	83.23	30.77	39.76	60.78	23.77
267	ICCP173718	SE	35	54	106	47.82	66.75	21.81	74.88	21.85	34.34	56.78	18.24
268	ICCP173719	SE	35	34	111	52.71	80.27	29.23	87.40	31.53	41.67	61.31	25.37
269	ICCP173720	SE	35	55	111	41.70	50.99	19.55	57.22	27.84	28.99	61.74	16.87
270	ICCP173725	SS	42	55	116	47.82	49.70	18.58	55.62	31.67	28.87	60.54	16.33
271	ICCP173728	SE	34	35	112	52.86	74.15	27.62	80.66	26.26	40.55	60.80	24.31
272	ICCP173729	SE	35	42	114	53.78	55.81	22.13	66.21	33.47	34.13	57.73	18.56
273	ICCP173731	SS	45	61	114	60.51	84.13	20.84	90.93	20.15	34.97	56.35	18.42
274	ICCP173743	SE	35	55	111	49.81	70.94	24.39	76.49	23.95	36.43	58.95	20.60
275	ICCP173744	SE	35	56	112	48.28	54.20	20.36	59.79	33.35	27.41	66.67	17.52
276	ICCP173773	SE	35	57	119	47.67	51.31	19.71	56.90	30.70	30.07	58.63	16.37
277	ICCP173785	SE	34	35	117	47.05	50.02	19.71	58.51	30.05	53.61	40.42	17.13
278	ICCP173794	SE	34	41	117	49.50	65.22	29.71	80.98	32.33	46.62	53.68	23.64
279	ICCP173797	SS	34	42	114	52.10	94.10	32.30	100.89	31.63	46.17	62.61	29.31
280	ICCP173798	SE	35	48	111	48.58	41.33	14.55	47.59	29.87	22.95	61.65	12.68
281	ICCP173800	SE	34	48	114	48.89	73.51	29.71	86.12	30.64	43.30	60.46	25.96
282	ICCP173802	SE	33	34	114	51.34	76.41	29.55	82.91	32.41	43.78	59.66	25.78
283	ICCP173805	SE	33	35	114	44.30	56.13	18.26	61.72	32.51	27.35	60.38	15.26
284	ICCP173806	SE	36	55	111	51.64	93.78	27.13	99.60	27.37	42.56	56.68	23.18

S.No	Identity	GH	DF	DF50	DM	PH	PPP	PWP	SPP	HSW	BY	HI	SYP
285	ICCP173807	SE	35	57	113	49.65	88.31	31.99	94.14	31.07	46.60	57.61	26.26
286	ICCP173808	SE	36	57	113	50.42	68.68	27.46	75.52	31.54	38.91	59.55	22.53
287	ICCP173809	SS	57	67	112	52.56	97.32	30.84	110.52	20.81	44.74	57.06	24.75
288	ICCP173811	SE	43	53	114	49.65	60.32	23.79	68.14	33.62	35.95	58.00	19.83
289	ICCP173817	SE	36	61	113	50.88	60.32	19.56	66.21	20.09	31.44	57.46	16.76
290	ICCP173818	SS	48	61	112	53.17	52.14	19.29	62.36	28.06	28.84	59.12	15.78
291	ICCP173819	SE	36	52	113	47.82	73.51	28.07	80.98	28.84	39.96	60.54	23.76
292	ICCP173826	SE	40	49	114	42.62	46.16	18.35	54.33	30.97	30.44	58.09	16.40
293	ICCP173842	SS	34	35	114	42.16	53.56	17.00	59.15	24.39	28.45	53.69	13.51
294	ICCP173843	SE	34	42	106	43.69	62.89	21.65	68.78	29.17	32.91	58.37	18.08
295	ICCP173844	SS	36	52	113	49.35	92.82	29.38	112.44	21.68	48.05	52.83	23.84
296	ICCP173845	SS	34	52	111	48.89	105.37	32.94	114.37	20.80	49.86	55.14	26.50
297	ICCP173847	SE	35	52	107	47.51	90.24	25.66	96.71	21.62	41.14	53.40	20.41
298	ICCP173856	SE	35	44	109	43.84	67.72	20.68	74.24	25.36	33.23	55.24	16.87
299	ICCP173859	SS	56	61	107	44.30	100.86	28.26	108.59	26.49	42.48	56.99	23.32
300	ICCP173863	SE	38	61	107	47.67	43.75	16.32	57.22	25.35	28.04	55.52	13.95
1	ICC4958	SE	33	37	112	52.65	74.92	29.51	71.47	34.27	39.75	60.71	25.81
2	JG14	SE	33	41	109	50.01	61.99	24.00	64.95	25.78	38.89	47.07	18.90
3	JG130	SE	50	57	113	47.90	73.84	24.26	88.54	22.48	36.73	54.75	20.22

S.No	Identity	GH	DF	DF50	DM	PH	PPP	PWP	SPP	HSW	BY	HI	SYP
4	ICCV10	SE	44	50	108	47.27	94.58	26.91	131.11	19.79	37.33	59.31	22.85

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