Research Project

Improving Heat Tolerance in Chickpea for Enhancing its Productivity in Warm Growing Conditions and Mitigating Impacts of Climate Change

Half-Yearly Technical Report - Year 3

(1 October 2011 to 31 March 2012)

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ICRISAT Science with a human face

International Crops Research Institute for the Semi-Arid Tropics

Patancheru, Hyderabad 502 324, AP

May 2012

Contents

1 Project Profile

1. Project title: Improving Heat Tolerance in Chickpea for Enhancing its Productivity in Warm Growing Conditions and Mitigating Impacts of Climate Change

2. Participating institutes

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- Indian Institute of Pulses Research (IIPR), Kanpur 208 024
- Panjab University, Chandigarh 160 014
- Jawaharlal Nehru Agricultural University, Jabalpur 482 004, MP
- Acharya NG Ranga Agricultural University, RARS-Nandyal, Andhra Pradesh

3. Name and designation of the Executive Authority of the lead institute

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6. Project duration: Four years

7. Total cost of the project: Rs. 329.65 Lakhs

11. Project goal: The overall goal of the project is to enhance chickpea production in warm growing conditions by developing heat tolerant and climate-resilient cultivars.

12. Key objectives:

- Refine techniques for effective screening of heat tolerance at reproductive stage.
- Identify chickpea genotypes with reproductive stage heat tolerance.
- Understand mechanisms and genetics of heat tolerance.
- Identify molecular markers for gene(s) controlling heat tolerance.
- Introgress heat tolerance in selected cultivars/elite breeding lines.
- Evaluate selected heat tolerant lines at farmers' fields.

13. Major activities

- Standardization of techniques for large scale screening of chickpea germplasm for heat stress at reproductive stage. This may involve study of pollen viability and pollen tube growth, pod filling, cell membrane thermo-stability, chlorophyll fluorescence and canopy thermal imagery.
- Screening of a set of genotypes (germplasm, cultivars and breeding lines) at multiple locations for their ability to flower and set pods at high temperatures (March-May).
- Crossing of heat tolerant germplasm with improved cultivars/elite lines for incorporating heat tolerance trait in suitable agronomic background.
- Study genetics of heat tolerance.
- Development of recombinant inbred lines (RILs) from a cross involving the most contrasting heat tolerant and heat sensitive genotypes for mapping heat tolerance gene(s).
- Rapid advancement of RILs and breeding materials by taking 2-3 generations per year.
- Identification of molecular markers for heat tolerance gene(s).
- Screening of segregating material under late sown conditions for establishing lines with enhanced heat tolerance and improved agronomic traits.
- Evaluation of selected heat tolerant lines at farmers' fields.

2 Executive Summary

Chickpea (*Cicer arietinum* L.) is a cool season grain legume grown in the arid and semi-arid regions of the world. It is the most important pulse crop of India and the third most important pulse crop globally. Heat stress (≥ 35oC during flowering and pod development) results in severe yield losses due to the impact of high temperatures on different physiological processes. Therefore, identification and development of heat tolerant genotypes is an important aspect of chickpea breeding, especially in view of the changing global climate scenario.

One of the objectives of this project is to identify genotypes with high level of heat tolerance for use in chickpea breeding programs. The screening for heat tolerance during the past two years of the project revealed high genetic variability for heat tolerance. Based on the results of past two years, a set of 30 germplasm/breeding lines, including both desi and kabuli types, were evaluated during normal-sown conditions during 2011-12 crop season, and are currently being evaluated under late-sown conditions for performance under heat stress at four locations (ICRISAT, Kanpur, Jabalpur and Nandyal). Observations are being recorded on phenological characters, and yield components. The normal-sown trial at all locations had good plant growth. The data from this trials will be used to compare the performance of genotypes under late-sown (heat stress) condition. Variations for pod set ranged between 80 – 100% at all locations in normal-sown trial. At Patancheru and Nandyal locations breeding lines ICCV 07102 and ICCV 07110 showed highest yield compared to existing released varieties, whereas at Jabalpur and Kanpur varieties ICC 4958 and Vishal performed well under normal sown conditions respectively. The results from late-sown trials will be available during June 2012.

Physiological studies on heat tolerance were carried out at PU- Chandigarh and IIPR-Kanpur to understand the mechanisms of heat tolerance. Four heat tolerant genotypes (ICC 1356, ICC 8950, ICC 15614 and ICCV 92944) and two heat sensitive genotypes (ICC 5912 and ICC 10685) were used in this study. At PU-Chandigarh the experiment was sown in earthen pots on 1st Nov, 2011 (Normal sowing) and 9th Feb, 2012 (late sown sowing for imposing heat stress). The observations were taken at two temperatures i.e. normal temperature (25^{0}C/15^{0}C) and high temperature (above 35^{0}C/20^{0}C) on stress injury in leaves, carbohydrate and nitrogen metabolism, Oxidative metabolism, Enzymatic and non-enzymatic antioxidants, stomatal conductance and other morphological parameters. Results from this experiment are being analysed and will be available in June 2012.

Physiological studies at IIPR-Kanpur showed that chickpea can well tolerate up to 41^{0}C so far pollen germination, and ovule viability is concerned. However, genetic differences exist in percent pollen germination, rate of pollen tube growth, insertion of pollen tubes within the stylar region at higher temperature. Damage of photosynthetic system was assessed in intact leaves of contrasting genotypes. The fluorescence images of heat sensitive line ICC 10685 showed complete inhibition of photosynthesis at temperature 43^{0}C (bottom leaf) while heat tolerant genotype ICCV 92944 showed reduced photosynthesis but leaf remained photo synthetically active even at 43^{0}C. Similarly, the heat tolerant line ICCV 92944 showed the lowest membrane injury when subjected to high temperature and sensitive line ICC 10685 had the maximum injury. However, many heat tolerant genotypes such as ICC 8950 yielding high under warmer environment had higher membrane injury index than poor yielding sensitive line ICC 5912. This shows the existence different types of mechanisms for heat tolerance in chickpea. Except two heat sensitive lines ICC 10685 and ICC 5912, all the other heat tolerant lines showed significant increase in the chlorophyll a/b ratio under late sown condition.

Physiological studies at ICRISAT suggested that chickpea pollen grains were more sensitive to high temperature than the stigma in both the field and controlled environments. The critical temperature for pod set was ≥37 ˚C in heat tolerant genotypes (ICC 1205 and ICC 15614) and ≥33 ˚C for heat sensitive genotypes (ICC 4567; ICC 10685). Overall, pod set showed greater sensitivity in the controlled environments where a 67% reduction was observed at ≥ 34/19 ˚C compared to the control (27/16 ˚C). In the field a pod set reduction of more than 50% occurred at high ambient day temperature (36 ˚C) and, the stigma was still receptive at 40.2/25.5 ˚C. In contrast, under controlled conditions the stigma was still receptive at 35/20 ˚C in four genotypes.

Studies on genetics of heat tolerance are in progress at ICRISAT-Patancheru and IIPR-Kanpur. F3 progenies of two crosses were screened for heat tolerance at ICRISAT. Recombinant inbred lines (RILs) are being developed from two crosses and these are currently at F4. IIPR-Kanpur has made 8 crosses for studying genetics of heat tolerance.

Four participating centers (IIPR-Kanpur, JNKVV-Jabalpur, RARS-Nandyal and ICRISAT-Patancheru) are involved in breeding for heat tolerance. At ICRISAT-Patancheru 4 F2 populations, 140 F3 progenies and 778 advanced breeding lines have been screened under late sown condition (sown on 1 Feb 2012) for developing heat tolerant breeding lines. At Kanpur and Jabalpur 8 and 20 new crosses have been attempted by using heat tolerant and locally adopted cultivars for genetic studies and developing breeding populations respectively.

The heat tolerant cultivar JG 14 (ICCV 92944) released from JNKVV, Jabalpur during 2009 is being evaluated at farmers' fields in late sown conditions in five states (Madhya Pradesh, Uttar Pradesh, Jharkhand, Chhattisgarh and Odisha). More than 200 farmers are evaluated this variety under late sown conditions. Demonstrations on JG 14 are being conducted on fields of 50 farmers in 11 villages of the Jabalpur district of Madhya Pradesh. The total area covered by these demonstrations is about 35 ha.

3 Objective-wise Technical Report (1 October 2011 to 31 March 2012)

3.1 Introduction

This project was undertaken with an overall goal of enhancing chickpea production in warm growing conditions by developing heat tolerant and climate-resilient cultivars. The major objectives of the project are as follows:

1. Refine techniques for effective screening of heat tolerance at reproductive stage.

2. Identify chickpea genotypes with reproductive stage heat tolerance.

3. Understand mechanisms and genetics of heat tolerance.

4. Identify molecular markers for gene(s) controlling heat tolerance.

5. Introgress heat tolerance in selected cultivars/elite breeding lines.

6. Evaluate selected heat tolerant lines at farmers' fields.

The objective-wise research progress made during the first six months of third year is presented here.

3.2 Objective 1: Refine techniques for effective screening of heat tolerance at reproductive stage

The work on this objective was completed during 2009-10.

3.3 Objective 2: Identify chickpea genotypes with reproductive stage heat tolerance

Based on the results of multi-location and multi-season evaluation for heat tolerance with 80 genotypes from 2008 to 2011, we selected 30 promising genotypes, including both desi and kabuli types. These 30 genotypes have been sent to four partner locations (ICRISAT-Patancheru, IIPR-Kanpur, JNKVV Jabalpur, RARS-Nandyal) for screening under both normal and late sowing conditions during 2011-12. Planting dates of normal sown and late sown trials at different locations are given in Table 1. The experiment was sown in randomized block design with three replications. Plot size was 2 rows of 4 m (50 seeds per row or 100 seeds per plot). Yield data was recorded in a single row of 2 m length plot. Top 10 genotypes selected in each location based on plot yield to compare the performance of tolerant genotypes at different location (Table 2)

Table 1: Time of sowing of chickpea heat tolerant lines at normal and late sown conditions at partner locations

Location	Date of normal sowing	Date of late sowing
ICRISAT-Patancheru	12 Oct 2011	1 Feb 2012
IIPR-Kanpur	22 Nov 2011	17 Jan 2012
JNKVV-Jabalpur	22 Nov 2011	31 Jan 2012
RARS-Nandyal	15 Oct 2011	26 Dec 2011

Table 2: Top 10 high yielding genotypes identified during normal growing season at partner locations.

Entry name	Days to first flower	Days to physio-logical maturity	% of number of filled pods	Data on 2 meter row length			
				Plant count at harvest	Biomass (g)	Grain yield (g)	100 seed weight
Jabalpur							
ICC 4958	56	120	94	20	803	**412**	30.2
KAK 2 (ICC 92311)	50	119	91	21	877	**398**	39.7
Vishal (ICCL 87207)	52	120	93	19	717	**387**	25.3
ICCC 37	54	121	96	19	623	**366**	21.5
NBeG 3	56	120	91	19	737	**358**	25.9
JGK 2 (ICCV 95332)	52	116	93	19	547	**343**	39.1
ICCV 07102	53	117	94	21	603	**338**	19.7
Vihar (ICCV 95311)	56	119	92	21	627	**327**	30.4
JG 11 (ICCV 93954)	54	117	93	21	583	**319**	21.5
ICCV 07118	55	118	94	21	663	**318**	29.1
Patancheru							
ICCV 07102	42	104	87	22	455	**357**	16.8
JG 11 (ICCV 93954)	35	103	81	23	496	**356**	21.4
ICCV 07117	39	105	82	24	502	**356**	21.4
Vishal (ICCL 87207)	39	104	74	23	477	**349**	24.3
ICCV 07105	40	103	86	25	525	**336**	16.1
JG 14 (ICCV 92944)	33	106	71	24	437	**332**	22.2
JGK 2 (ICCV 95332)	32	103	80	24	419	**331**	31.1
ICCV 07118	37	105	76	24	537	**327**	25.6
JG 130 (ICCV 94954)	44	105	74	24	408	**320**	22.0
Vaibhav	42	103	87	26	483	**316**	21.7

Entry name	Days to first flower	Days to physio-logical maturity	% of number of filled pods	Data on 2 meter row length			
				Plant count at harvest	Biomass (g)	Grain yield (g)	100 seed weight
Nandyal							
ICCV 07110	32	80	92	19	161	**99**	26.2
JG 11 (ICCV 93954)	33	75	90	21	152	**97**	21.6
ICCV 07118	33	80	94	20	142	**90**	31.1
Vishal (ICCL 87207)	41	79	98	20	154	**90**	24.0
ICCV 07109	43	81	96	19	154	**90**	24.0
ICC 8474	36	74	92	21	146	**89**	29.6
NBeG 3	41	82	92	16	137	**89**	32.6
ICC 4958	33	79	91	19	148	**86**	31.6
JAKI 9218 (ICCV 93952)	34	79	95	18	145	**86**	20.2
ICCC 37	36	74	90	21	140	**85**	17.6
Kanpur							
Vishal	71	123	95	19	590	**235**	25.7
ICCV 07117	72	124	92	19	457	**195**	20.9
Vaibhav	73	123	95	22	453	**187**	25.4
ICCV 07118	70	122	95	19	377	**185**	27.7
Dilaji	73	125	88	25	407	**180**	16.7
ICCC 37	71	124	93	21	397	**180**	18.5
JG 11	69	123	96	25	397	**180**	25.0
ICC 6874	76	125	91	28	430	**173**	12.3
ICC 4495	76	122	92	23	307	**163**	12.9
JAKI 9218	73	122	95	23	407	**160**	25.0

In the present multi-location experiment, the percentage of filled pods varied between 80% to 100% across 4 locations and different genotypes showed higher yields at each location. Top 10 lines were identified at each location, of which 3 lines (Vishal, JG 11 and ICCV 07118) were found common in all 4 locations (Table 3), single cultivar ICCC 37 was common in 3 locations (except Patancheru) and 7 genotypes were common in any 2 locations. The actual performance of heat tolerant genotypes will be assessed by comparing the yields with late sown conditions. The complete results of normal and late sown experiment conducted at different locations will be available in June 2012.

Table 3: List of common top 10 genotypes found at 4 locations

Jabalpur	**Patancheru**	**Nandyal**	**Kanpur**
Vishal (ICCL 87207)	**Vishal (ICCL 87207)**	**Vishal (ICCL 87207)**	**Vishal (ICCL 87207)**
JG 11 (ICCV 93954)	**JG 11 (ICCV 93954)**	**JG 11 (ICCV 93954)**	**JG 11 (ICCV 93954)**
ICCV 07118	**ICCV 07118**	**ICCV 07118**	**ICCV 07118**
ICCC 37	**-**	**ICCC 37**	**ICCC 37**
-	Vaibhav	-	Vaibhav
JGK 2 (ICCV 95332)	JGK 2 (ICCV 95332)	-	-
NBeG 3	-	NBeG 3	-
-	-	JAKI 9218	JAKI 9218
-	ICCV 07117	-	ICCV 07117
ICCV 07102	ICCV 07102	-	-
ICC 4958	-	ICC 4958	-
KAK 2 (ICC 92311)	-	-	-
-	JG 14 (ICCV 92944)	-	-
-	JG 130 (ICCV 94954)	-	-
-	-	-	ICC 6874
-	-	-	ICC 4495
-	-	-	Dilaji
Vihar (ICCV 95311)	-	-	-
-	ICCV 07105	-	-
-	-	ICCV 07109	-
-	-	ICCV 07110	-
-	-	ICC 8474	-

3.4 Objective 3: Understand mechanisms and genetics of heat tolerance

3.4.1 Understand mechanisms of heat tolerance

3.4.1.1 Physiological studies at IIPR Kanpur

Reproductive-physiology

Eight chickpea genotypes having different sensitivity to high temperature were assessed under normal and late sown field condition. These genotypes have been identified based on their field performance in two locations IIPR, Kanpur and ICRISAT, Patancheru. Based upon grain yield and allied parameters these genotypes were categorized as heat tolerant or sensitive ones. The heat tolerant genotypes such as ICCV 92944, ICC 15614, ICC 1205, ICC 8950 and ICC 1356 were tentatively selected for their physiological tolerance to high temperature based on stability of reproductive components, membrane injury, chlorophyll fluorescence imaging for photosynthetic capacity and pigment composition. In heat tolerant genotypes particularly ICCV 92944 and ICC 1205, pollen grains at 41^{0}C germinated fast and tubes grew rapidly, both in pollen germination medium and through stylar tissue (Fig 1).Still at higher temperature (43^{0}C) detrimental for pollens viability, only few pollen grains germinated and pollen tubes grew slowly and often completely arrested in the style in heat sensitive lines particularly ICC 10685, ICC 4567 and ICC 5912. Retarded pollen tube growth with a coiled and spring-shaped structure was the prominent adverse effect visible at high temperature exceeding 41^{0}C in almost all the genotypes but more distinct in heat sensitive lines. In heat tolerant line ICCV 92944, the male gamete was visible at the end of the pollen tube. It seems that gamete formation is adversely affected at high temperature. The results indicated that, chickpea can well tolerate upto 41^{0}C so far pollen germination and ovule viability is concerned. However, genetic differences exists in percent pollen germination, rate of pollen tube growth, insertion of pollen tube s within the stylar region at higher temperature

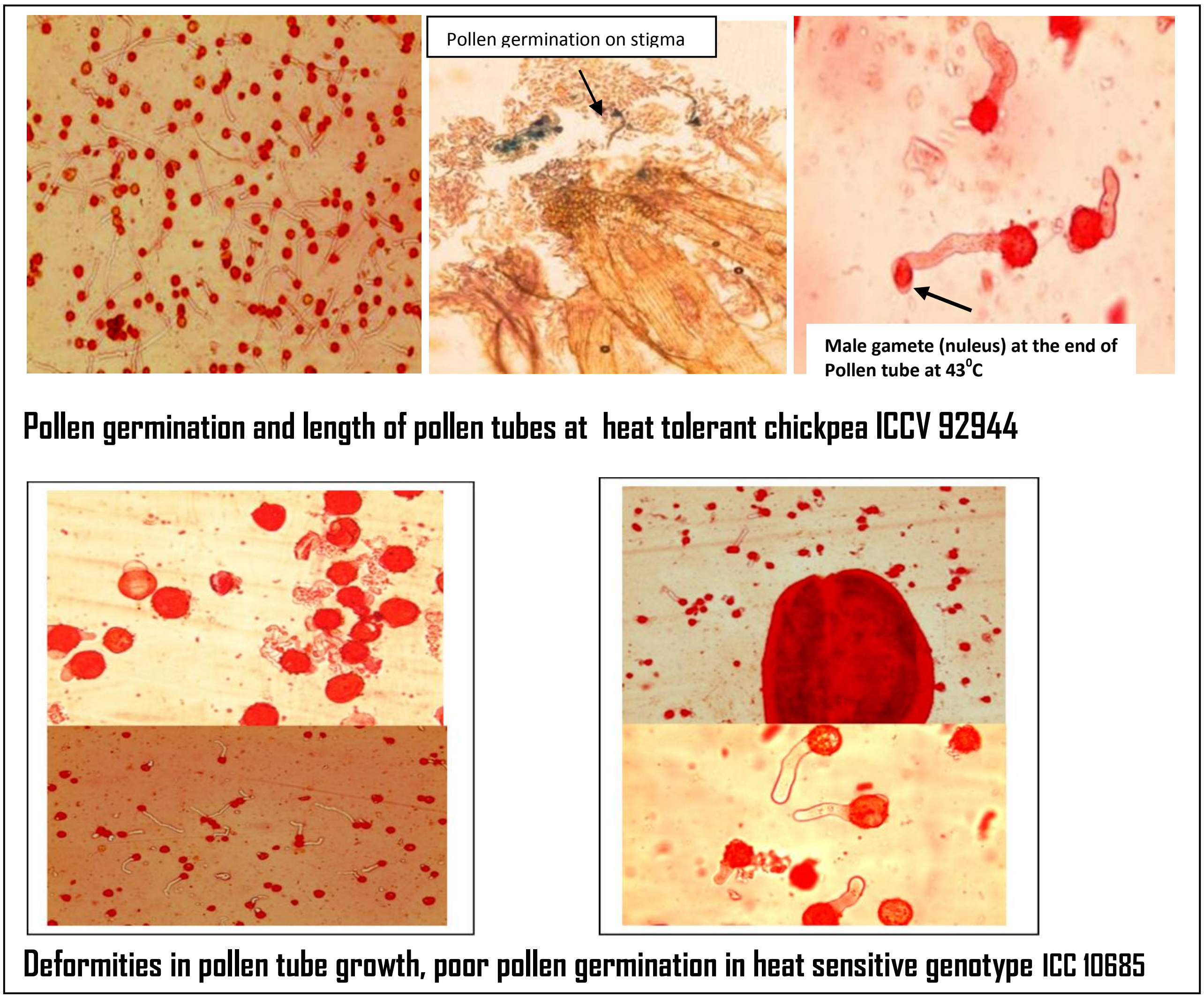

Fig 1: Effect of high temperature on pollen tube growth in heat tolerant and sensitive lines

Chlorophyll fluorescence imaging

Damage of photosynthetic system was assessed in intact leaves of contrasting genotypes by putting half portion of leaf dipped into hot water (43^{0}C) for 1 hour and then fluorescence imaging was taken in order to quantify the extent of damage of photosynthetic machinery. Normal photosynthetic tissue not treated to high temperature (25^{0}C)was appeared as blue fluorescence image(top ; Fig 2) while damaged leaf displayed either no fluorescence image or yellowish-green to brown fluorescence images indicating either complete or partial inhibition of photosynthesis (bottom , Fig 2). The fluorescence images of heat sensitive line ICC 10685 showed complete inhibition of photosynthetesis at temperature 43^{0}C (bottom leaf) while heat tolerant genotype ICCV 92944 showed reduced photosynthesis but leaf remained photosynthetically active even at 43^{0}C.

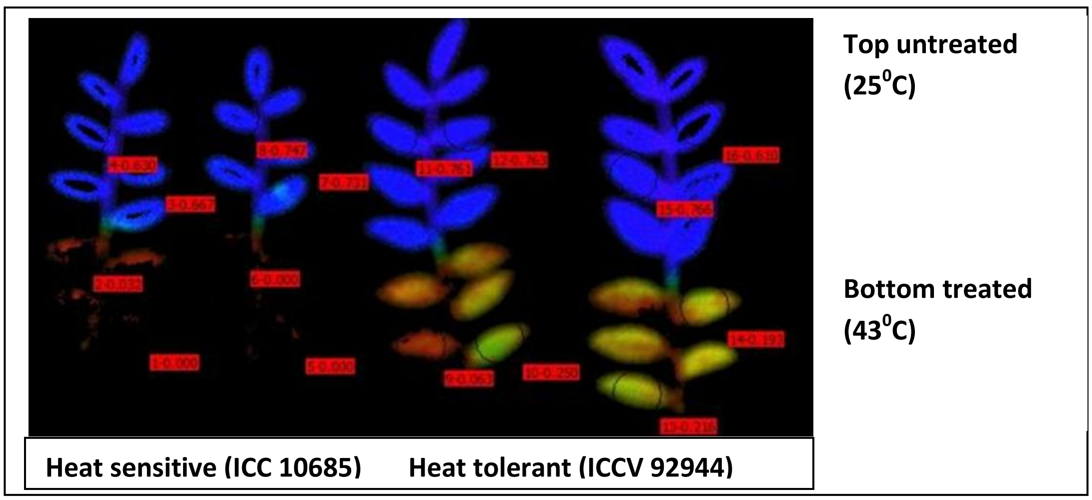

Fig 2: Fluorescence images of heat sensitive (L) and heat tolerant line (R)

Light response curve showed that photosynthetic quantum yield was fairly stable with increasing the level of irradiance from 0 to 700 µmol $m^{-2}s^{-1}$ in normal untreated leaf exposed at 25^{0}C. When high irradiance with high temperature both superimposed, the photosynthesis activity drastically declined. In this respect heat tolerant genotype ICCV 92944 was found more resilient (Fig 3).

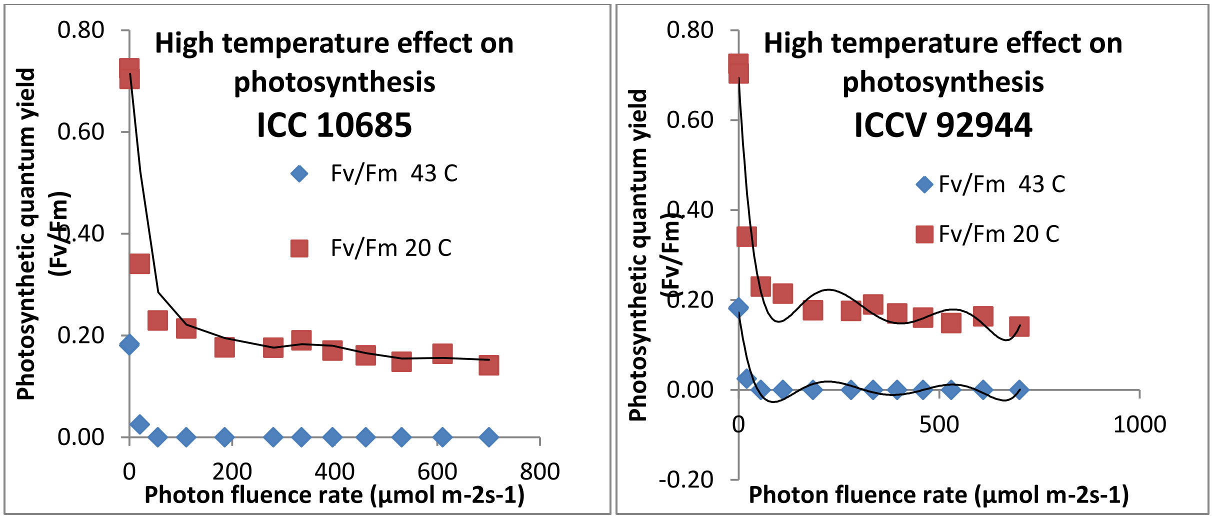

Fig 3: Light response of photosynthetic quantum yield

Membrane injury index

Significant genetic variation in the membrane injury index was observed in the differential lines used in the experiment. The heat tolerant line ICCV 92944 showed the lowest membrane injury when subjected to high temperature (Table 1). While sensitive line ICC 10685 had the maximum injury. However, many heat tolerant genotypes such as ICC 8950 yielding high under warmer environment had higher membrane injury index than poor yielding sensitive line ICC 5912. This suggested that many mechanisms for heat tolerance might be operating in chickpea.

Table 1 : Percent membrane injury at high temperature (each value represents Mean of 50 leaf samples)

	ICC-10685	ICC-1205	ICC-15614	ICC-1356	ICC-4567	ICC-8950	ICCV-92944	ICC-5912
Normal sown	21.53	15.19	18.59	19.22	15.61	24.00	**11.22**	12.78
Late sown	18.22	18.10	12.52	18.89	17.79	16.91	**13.33**	15.28

Chlorophyll a/b ratio

The general trend showed an increase in the chlorophyll a to b ratio under late sown warmer environment as compared to normal cool-season grown chickpea crop. This could be considered as one of the adaptive strategies of chickpea to get acclimatized to warmer environment. Except two heat sensitive lines ICC 10685 and ICC 5912, all the other heat tolerant lines showed significant increase in the chlorophyll a/b ratio under late sown condition (Table 2)

Table 2: Chlorophyll a to b ratio during normal and late sown condition

Genotype	Chl a/b ratio	
	Normal sown	Late sown
ICC 10685	2.70	2.55
ICC 1205	**2.52**	**2.66**
ICC 15614	**2.62**	**2.69**
ICC 1356	**2.56**	**2.67**
ICC 4567	2.66	2.69
ICC 8950	2.52	2.58
ICCV 92944	**2.52**	**2.69**
ICC 5912	2.54	2.58

3.4.1.2 Physiological Studies at PU, Chandigarh

Four heat tolerant genotypes (ICC 1356, ICC 8950, ICC 15614 and ICCV 92944) and two heat sensitive genotypes (ICC 5912 and ICC 10685) were sown in earthen pots on 1^{st} Nov, 2011 (Normal sowing) and 9^{th} Feb, 2012 (late sown sowing for imposing heat stress). The observations were taken at two temperatures i.e. normal temperature (25^0C/ 15^0C) and high temperature (above 35^0C/ 20^0C) on following parameters:

1. Stress injury in leaves:
    a. Electrolyte leakage
    b. Relative leaf water content
    c. Cellular oxidising ability
    d. Total Chlorophyll
    e. Carotenoids
2. Carbohydrate metabolism: invertase, α- amylase, β- amylase, Starch phosphorylase, starch, total sugars, reducing sugars, sucrose synthase, sucrose phosphate synthase, trehalose
3. Nitrogen metabolism: nitrate reductase, proline, free amino acids, protease, proteins, leghaemoglobin
4. Oxidative metabolism: Malondialdehyde (lipid peroxidation), Hydrogen persoxide
5. Enzymatic antioxidants (Catalase, Superoxide dismutase, Ascorbate peroxidase)

6. Non-enzymatic antioxidants (glutathione, ascorbic acid)
7. Floral biology: Pollen viability, Pollen load, Stigma receptivity, Pollen germination (*in vitro* and *in vivo)*, Ovule viability
8. Stomatal conductance, Chlorophyll fluorescence, Leaf temp,
9. Plant height, Nodule no, Nodule wt
10. Phenology (days to flowering and podding)
11. Growth as total no. of flowers, pods, no. of aborted flowers, pods, root weight, shoot weight,
12. Yield as seed number, seed size, seed weight
13. Daily temperature and relative humidity was also recorded.

    The results have been concluded just recently i.e. at the end of April. The observations are being analysed and would be presented in the project meeting.

3.4.1.3 Studies on reproductive behavior of heat tolerant and heat sensitive lines at ICRISAT, Patancheru

Observations in the field from late season experiments (Feb-May) and various high temperature regimes generated in controlled environments showed clear genetic variation in male reproductive tissue (anther and pollen), its function (pollen germination and tube growth) and pod set. The greater pod setting ability of heat tolerant genotypes (ICC 1205 and ICC 15614) compared to heat sensitive genotypes (ICC 4567; ICC 10685) was observed in both the field and controlled conditions. Both anthers and pollen showed more structural abnormalities, such as changes in anther locule number, anther epidermis wall thickening and pollen sterility, rather than function (e.g. *in vivo* pollen tube growth). The critical temperature for pod set was ≥37 ˚C in heat tolerant genotypes (ICC 1205 and ICC 15614) and ≥33 ˚C for heat sensitive genotypes (ICC 4567; ICC 10685). Overall, pod set showed greater sensitivity in the controlled environments where a 67% reduction was observed at ≥ 34/19 ˚C compared to the control (27/16 ˚C). In the field a pod set reduction of more than 50% occurred at high ambient day temperature (36 ˚C) and, the stigma was still receptive at 40.2/25.5 ˚C. In contrast, under controlled conditions the stigma was still receptive at 35/20 ˚C in four genotypes. Clearly, chickpea pollen grains are more sensitive to high temperature than the stigma in both the field and controlled environments. Among the four genotypes tested, ICC 1205 was the most heat tolerant and ICC 4567 the most heat sensitive.

3.4.2 Understand genetics of heat tolerance

3.4.2.1 Genetic Studies at ICRISAT:

Six crosses, which included four Sensitive × Tolerant (ICC 4567 x ICC1205, ICC 4567 x ICC 15614, ICC 10685 x ICC 1205, ICC 10685 x ICC 15614), one Sensitive × Susceptible (ICC 4567 x ICC 10685) and one Tolerant × Tolerant (ICC 1205 x ICC 15614), were made at ICRISAT for studying genetics of heat tolerance. F2s along with F1s and parents were sown during late-sown conditions during 2011 to screen for heat tolerance. F3 progenies from two crosses were further screen for heat tolerance under late-sown conditions during 2012.

Two crosses (ICC 4567 x ICC 15614, ICC 4567 x ICC 1356) are being advanced for development of recombinant inbred lines (RILs) for molecular mapping of genes involved in heat tolerance. F3 from these crosses were grown during crop season 2011-12 in the field. Presently, F4 populations are being grown in the greenhouse.

3.4.2.2 Genetic Studies at IIPR-Kanpur:

Following eight crosses were made to study the inheritance of heat tolerant traits

S No	Cross
1.	ICCV 15614 x JG 2003-14-16
2.	IPC 08-103 x ICCV 15614
3.	ICCV 15614 x JG 2003-14-16
4.	IPC 08-100 x ICCV 15614
5.	IPC 08-100 x ICCV 16915
6.	IPC 08-100 x ICCV 1205
7.	ICCV 1205 x JG 2003-14-16
8.	IPC 08-103 x ICCV 16915

3.5 Objective 4: Introgress heat tolerance in selected cultivars/elite breeding lines

3.5.1 Development of breeding material at JNKVV- Jabalpur:

Following new crosses were made during 2011-12

S. No.	Crosses	F_1 seeds	S. No.	Crosses	F_1 seeds
1.	JG 63 x ICCV 06301	6	11	JG 1307 x ICC 4958	21
2.	JG 1307 x ICCV 06301	21	12.	JG 12 x ICC 8474	22
3.	JG 12 x ICCV 06301	18	13.	JG 63 x ICC 8474	11
4.	JG 9605 x ICCV 06301	5	14	JG 1307 x ICC 8474	3
5.	JG 12 x ICCV 07105	14	15	JG 63 x ICC 7441	3
6.	JG 1307 x ICCV 07105	16	16	JG 12 x ICC 7441	6

S. No.	Crosses	F_1 seeds	S. No.	Crosses	F_1 seeds
7.	JG 63 x ICCV 07105	22	17	JG 1307 x ICC 7441	25
8.	JG 12 x ICC 4958	32	18	JG 9605 x ICCV 7441	12
9.	JG 63 x ICC 4958	33	19	JG 63 x ICC 14402	2
10	JG 9605 x ICC 4958	13	20	JG 1307 x ICC 14402	1

Generation advancement during 2011-12:

S. No	Crosses $F_1 \rightarrow F_2$
1	JG 63 x ICC 1205
2	JG 130 x ICC 1205
3	JG 63 x ICC 15614
4	JG 130 x ICC 15614

S. No	Crosses $F_2 \rightarrow F_3$
1	JG 63 x ICCV 07110
2	JG 11 x ICCV 07110
3	JG12 x ICCV 07110
4	JG 16 x ICCV 07110
5	JG 16 x JG 14
6	JG 11 x JG 14
7	JG 63 x JG 14
8	JG 130 x JG 14
9	JG 12 x JG 14
10	JAKI 9218 x JG14

MAGIC populations supplied by ICRISAT

S. No	$F_4 \rightarrow F_5$ populations
1	ICCX-080060
2	ICCX-080061
3	ICCX-080062
4	ICCX-080063
5	ICCX-080064
6	ICCX-080065
7	ICCX-090019
8	ICCX-090020
9	ICCX-090021
10	ICCX-090024

3.5.1 Development of breeding material at ICRISAT-Patancheru:

F1 plants of the following crosses were advanced to F2 during 2011-12

S No	Cross name
1	JAKI 9218 x ICC 1205
2	JAKI 9218 x ICC 15614
3	ICC 4958 x ICC 1205
4	ICC 4958 x ICC 15614
5	ICC 1205 x ICC 15614
6	ICC 92944 x ICC 1205
7	ICC 92944 x ICC 15614
8	JG 11 x ICC 1205
9	JG 130 x ICC 1205
10	GG 2 x ICC 1205
11	JG 11 x ICC 15614
12	JG 130 x ICC 15614
13	GG 2 x ICC 15614

Different segregating and breeding materials screened for heat tolerance at ICRISAT under field conditions during 1st Feb 2012 to 10th May 2012 (data analysis is in progress):

1. Four F2 populations (JG 11 x ICC 07110, JG 11 x ICCV 92944, ICCC 37 x ICCV 07110 and ICCC 37 x ICCV 92944) segregating for heat tolerance traits were evaluated.
2. 140 F3 progenies of cross ICC 4567 x ICC 1356 were screened, and selections were made based on segregation of heat tolerance traits.
3. 778 advanced breeding lines evaluated
4. A study was conducted on reproductive biology of four sensitive (ICC 8950, ICC 5912, ICC 4567 & ICC 10685) and four tolerant (ICCV 92944, ICC 1205, ICC 15614 & ICC 1356) genotypes
5. 36 F3 progenies of general breeding program were evaluated
6. 1200 F4 MAGIC lines developed from eight cultivars (ICCV 93954, ICCV 94954, ICC 93952, ICCV 10, ICC 4958, ICCV 97105 and ICCV 00108) were evaluated

3.6 Objective 5: Evaluate selected heat tolerant lines at farmers' fields

The heat tolerant cultivar JG 14 (ICCV 92944) released from JNKVV, Jabalpur is being evaluated at farmers' fields in late sown conditions in different states.

Madhya Pradesh: Eleven villages were selected to conduct demonstrations on JG 14 variety under late sown conditions (1st fortnight of December) in Jabalpur district. Seed samples were given to a total of 50 farmers with a range of 2-14 farmers per village. Each demonstration was conducted on 0.4 ha and total area of demonstrations conducted was 20 ha. The results are awaited.

Uttar Pradesh: Six demonstrations were conducted on JG 14 under late sown conditions in Fatehpur district in Utter Pradesh. The total area sown under demonstrations was 3 ha. Seed from demonstrations will be collected and supplied to other farmers to expand the demonstrations to new areas.

Jharkhand: ICRISAT supplied 1.0 ton seed of JG 14 to Birsa Agricultural University (BAU), Kanke for seed production and supplying to farmers for evaluation after rainy season rice. A total of 660 kg seed was distributed to farmers by BAU-Kanke and Zonal Research Station (ZRS), Chianki. This includes 160 kg seed distributed to 33 farmers (~ 2 ha) by BAU and 500 kg seed supplied to 115 farmers (~ 6.25 ha) by ZRS, Chianki.

Orissa: ICRISAT supplied 30 kg seed of JG 14 to Orissa Tribunal Empowerment and Livelihood Program (OTELP), Bhubaneswar, Odisha for distribution of seed to farmers in Odisha state.

Chhattisgarh: ICRISAT supplied 200 kg seed of JG 14 to Chhattisgarh Tribal Development Project for enhancing adoption of this variety in rice-fallows of Chhattisgarh.

3.7 Publications

Research Papers, Conference papers from the project work

Journal Articles

Mishra, Stuti and Babbar, Anita (2011) Selection strategy for improving yield in desi chickpea genotypes evaluated under normal and heat stress environments in Kamore plateau zone of Madhya Pradesh. *JNKVV Res J*. 45(1): 58-62.

Conference presentations

Babbar, Anita and Thakur, Rashmi (2011). Assessment of chickpea promising lines for its phenology, yield traits and reaction to Fusarium wilt under normal and high temperature condition. Presented at National Seminar on Indian Agriculture: Preparedness for Climate change, organized by Indian Society of Agriculture Science, New Delhi, 24-25, March 2012.

Babbar, Anita and Thakur, Rashmi (2011) Screening of chickpea genotypes for biotic and abiotic stresses. Presented at National Seminar on Contemporary Approaches to Crop Improvement, Sponsored by Indian society of Genetics and Plant Breeding, IARI New Delhi and UAS Bangalore, 22-23 April 2011. pp 224.

Babbar, Anita; Thakur, Rashmi**;** Yadav S.S., Prakash. V. and Pandey Suneeta (2011). Resistant sources against *Fusarium* wilt in chickpea grown under normal and heat stress environment. National symposium on Biodiversity and Food Security: Challenges & Devising Strategies, IIPR Kanpur, December 10-11, 2011. pp 64.

Babbar, Anita and Thakur, Rashmi (2012) Effect of high temperature on morpho-phenological yield related traits in chickpea. National Seminar on Indian Agriculture: Preparedness for Climate change", organized by Indian Society of Agriculture Science, New Delhi, March 24-25, 2012. pp 41.

Mishra, Stuti and Babbar, Anita (2012) Analysis of growing degree days as a climate impact indicator in chickpea under normal and high temperature conditions. National Seminar on Indian Agriculture: Preparedness for Climate change", organized by Indian Society of Agriculture Science, New Delhi, March 24-25, 2012.pp 146.