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PHYSIOLOGICAL AND BIOCHEMICAL ADJUSTMENT UNDER CONTINUOUS DROUGHT AND HEAT STRESS AFFECT YIELD IN CHICKPEA (*CICER ARIETINUM* L.)

Sadhana Maurya[1,2*], Amit Kumar[3], N.S. Panwar[2,4], Neha Sharma[2] and A.K. Chopra[5]

[1]ICAR- Indian Agricultural Research Institute, New Delhi-110012, India
[2]ICAR- National Bureau of Plant Genetic Resources, New Delhi-110012, India
[3]ICAR- National Bureau of Plant Genetic Resources, Regional Station, Jodhpur, Rajasthan, India
[4]ICAR- National Bureau of Plant Genetic Resources, Regional Station, Ranchi, Jharkhand, India
[5]Gurukul Kangri University, Haridwar, U.K. 249404, India
*Corresponding author E-mail: sadhana@icar.org.in

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ABSTRACT

Chickpea is an important source of protein and required optimum range of abiotic conditions for profitable yield. Under abiotic stress, physiological and biochemical adjustments effects yield significantly. A pot experiment was carried out during 2019-20 and 2020-21 with two genotypes: the tolerant ICC 4958 and the sensitive Flip 90-166 to assess the impact of two stress such as drought (-60Kpa) and high temperature (2.6 and 2.8°C) individually as well as in combination to understand the magnitude of physiological traits and biochemical response that affect yield. Results revealed significant reductions in seed yield (16-22% in ICC 4958 and 24-30% in Flip 90-166), under drought stress. Conversely, proline accumulation was found increased in the range of 81-109% and 45-72% in ICC 4958, Flip90-166 respectively. The soluble sugar accumulation has been increased 24-37% in ICC 4958 and 14-16% in Flip 90-166 under drought treatment at different crop stage. The enhanced proline and soluble sugar content conferring osmotic adjustment and cellular protection. Under combined stress (drough + heat) exacerbated yield losses to 26-28% (ICC 4948) and 35-42% (Flip 90-166) and caused even greater declines in physiological performance, accompanied by a marked increase in proline and sugar accumulation. Based on the performance recorded under the present investigation, ICC 4958 consistently maintained superior physiological status including higher relative water content as well as chlorophyll stability than Flip 90-166) and under combined effect. These findings highlight the importance of integrating physiological and biochemical traits to identify chickpea genotypes with improved drought and heat stress resilience.

***Key words*:** Chickpea, drought, high temperature, MSI, Photosynthesis, Proline, RWC.

Introduction

Chickpea (*Cicer arietinum* L.) bears intrinsic capacity to combat hidden hunger by providing protein, fiber, iron, zinc, folate, and vitamins etc. especially to the low-income global population as well as vegetarian populations (Didinger and Thompson, 2021). The World Health Organization recommends 80 g daily intake of chickpea in India. Chickpea, being a biological nitrogen fixing crop, is a sustainable solution to improve the nutritional food security at global level as cultivated >50 countries (Mahato, 2025). India ranks first globally in both the area under chickpea cultivation and its production, accounting for 70.57% of the world's total chickpea-growing area and 69.21% of global production (Sharma and Sharma, 2020). Among Indian states, Maharashtra (25.97% contribution to national production), contributes the largest share, followed by Rajasthan (20.65%), Madhya Pradesh (18.59%) Uttar Pradesh (5.64%), and Gujarat (10.10%), is major chickpea producing states of India (https://www.icar-iipr.org.in/chickpea-crop/ on

10.10.2025). In Mediterranean region chickpea is cultivated in the form of a dry weather crop (Devkota *et al.*, 2021); however Australian region/ semi arid tropics, it is grown as a rainfed crop (Kumar *et al.*, 2021). Terminal drought alone causes up to 50 % yield reduction globally (Gaur *et al.*, 2012). As reported by the Ministry of Earth Sciences (MoES, 2020), due to human induced climate change, India's average temperature has risen by 0.7 °C since the early 20th century, and it is projected to increase further by about 4.7 °C to 5.5 °C by the end of the 21st century if the current GHG emission rates are sustained. Worsening the effects of India's drought vulnerability is not only the rising heat but also insufficient irrigation. The extreme heat at flowering and pod formation stage create drought condition and reduced chickpea productivity. Terminal drought along with heat stress causes upto 40-45% yield loss in chickpea (Rani *et al.*, 2020). Globally, drought accounts for a 40 - 45% reduction in yield, while temperatures exceeding 35° C during reproductive development can reduce yield by approximately 39% (Devasirvatham and Tan 2018).

Drought directly affects key physiological processes, including photosynthesis, chlorophyll stability, crop duration, and relative water content (Fazeli-Nasab *et al.*, 2025, Sachdeva, 2022). Drought and heat stress affected plant growth and flowering of chickpea. Physiologically plant growth is damaging of chlorophyll structures due to drought and high temperatures and subsequent those affect photosynthetic performance and alter metabolites (Fig 4B). The impairment of related metabolic pathways leads to flower and pod abortion (Rani *et al.*, 2020). At the biochemical level, chickpea responds through osmotic adjustment mechanisms, such as increased accumulation of proline and soluble sugars, which maintain cell turgor and sustain protein activity (Rani *et al.*, 2020, Negussu *et al.*, 2023). However, prolonged exposure to stress leads to reproductive failure, accelerated senescence, reduced seed set, and lower seed weight, ultimately compromising yield potential (Awasthi *et al.*, 2024, Rani *et al.*, 2020). Terminal drought and high temperatures during flowering and grain - filling stages collectively account for nearly 50% of total yield losses (Benali *et al.*, 2023, Rani *et al.*, 2020). The most investigation conducted in chickpea is the focused either on drought or heat stress. The combinational effects have been investigated in the other genotypes, which are presently not fully utilizable at field level.

Additionally, climate variability is increasingly causing the coincidence of terminal drought and heat stress, in leading chickpea growing area of the globe. Keeping this in view, the present investigation has been focused towards evaluation of the magnitude of the impact of drought and heat stress in combination considering the future potentially of varieties. Therefore, it is essential to investigate the combined effects of drought and heat stress on chickpea physiology and biochemical responses, and how these alterations ultimately influence productivity.

Materials and Methods

Experimental details

The pot experiment was conducted in years 2019-20 and 2020-21 during *Rabi* season (November-March) using controlled environment facilities at Indian Agricultural Research Institute (IARI), New Delhi (at 28° 352 N latitude,77°122 E longitude and at 228.16 m above mean sea level with a fairly leveled topography). The experiment was conducted with two contrasting genotypes of chickpea i.e, desi cultivar 'ICC 4958' and kabuli cultivar "Flip 90-166".

Soil and Crop management

Non-calcareous, slightly alkaline and sandy loam in texture soil is taken to fill the pots of 19 kg capacity. The bulk density, pH and EC of soil were 1.56 Mg m^{-3}; 7.3; EC 0.49 dS m^{-1} respectively. The recommended dose of fertilizer i.e, Nitrogen (urea), phosphorus (single superphosphate) and potassium (muriate of potash) 20, 20 and 40 kg ha^{-1} were provided to the soil at time of pot preparation. Six seeds were shown with help of dibbler in each pot at 10cm depth. 20days after germination, each pot is thinned and three plants were kept at each pot. The weeding in pots was done manually time to time.10 pots per treatment was taken for study.

Drought treatment

Drought treatment was given to chickpea plants by withholding the water. Measurement of soil water potential was performed through soil tensiometer (Macro Scientific Works Pvt. Ltd., Delhi, India) installed in soil. The probe was inserted upto a depth of 10 cm. Water potential was maintained between - 40k Pa to - 60k Pa, while in control pots water level was always maintained below -20kPa. Tensiometer readings were recorded daily between 10.00 to 11.00 A.M.

Heat treatment

Heat stress treatment was imposed using air blowers and initiated after first emergence of flower and continued till maturity by using automatic heater (N128 - BT, Nova, heat convector New Delhi, India) as described by Chaturvedi *et al.*, (2017). The air temperature inside OTCs was measured in different location (50 cm apart) covering the entire OTC and uniform increase in maximum temperature at day time +2.6°C and +2.8°C

(Fig. 1), whereas increase in minimum temperature +1.2°C +1.6°C in 2019-20 and 2020-21 respectively were recorded (Fig. 1). During the entire experimental period, temperature (°C) and humidity (RH) inside all OTCs were recorded continuously with the help of sensors (LOGKACO2, KeepAlert, Australia).

Relative water Content

RWC was estimated in both genotypes with different treatments as per the method of Barrs and Weatherley (1962). The third leaf (1g) was picked and placed in double distilled water in a petri dish for 4 h to make the leaf tissue turgid. The turgid weight of the leaf material was recorded after carefully keeping the tissues between the two filter papers. Subsequently this leaf material was dried in oven at 65 °C till constant weight.

The RWC was calculated (in %) by as:

$$\text{RWC (\%)} = \frac{\text{(Fresh weight - dry weight)}}{\text{(Turgid weight - dry weight)}} \times 100$$

Membrane Stability Index

Membrane stability index was estimated as per Deshmukh *et al.*, (1991). 100 mg fresh leaf sample of each treatment was placed in a test tube containing 10 ml of double distilled water. Electrical conductivity (C_1) of the solution was measured at 40° C in water bath (Yorkco scientific Industries) for 30 min with the help of conductivity bridge of ELICO Pvt. Ltd. (CM 82T). Conductivity (C_2) was measured again after shifted to boiling water bath (100° C) for 10 min and immediately cooled in ice to room temperature and. The membrane stability index was calculated (in %) as given below:

$$\text{Membrane stability index} = 1 - \frac{C_1}{C_2} \times 100$$

where,

C = conductivity in Mho

Photosynthesis

Observations on photosynthesis were obtained using LI-COR portable photosynthesis system (Li-Cor 6400; Li-Cor, Inc., Lincoln, NE, USA). The rate of photosynthesis (µmol CO_2 $m^{-2}s^{-1}$) was measured using photosynthesis system that was operated in the closed mode. The photosynthetic rate was determined between 10.00 AM to 12.00 PM when photosynthetically active radiation (PAR) ranged between 1000 and 1500 µmol $m^{-2}s^{-1}$. The leaf was enclosed in the chamber and the net exchange of CO_2 between the leaf and the atmosphere was measured with five replicates per each treatment.

Chlorophyll content

Chlorophyll content was determined according to Hiscox and lsraelstam (1979). Leaf samples were cut into small pieces and 50 mg sample of each treatment was placed in test tube containing 10 ml of dimethyl sulphoxide (DMSO) for 3 hrs. The vials were covered with aluminum foil to avoid light and placed in a constant temperature incubator at 65° C. The absorbance of the aliquot was measured at 663 nm, 645 nm and 470 nm using UV visible spectrophotometer (Specord Bio.200 AnalytikJena, Germany). Chlorophyll a and b and total chlorophyll contents were calculated according to Arnon's (1949) expressed as mg g^{-1} fr.wt.

$$\text{Chlorophyll a} = 12.7\ (A_{663}) - 2.69\ (A_{645}).\ V/W \times 1000 \quad (3)$$

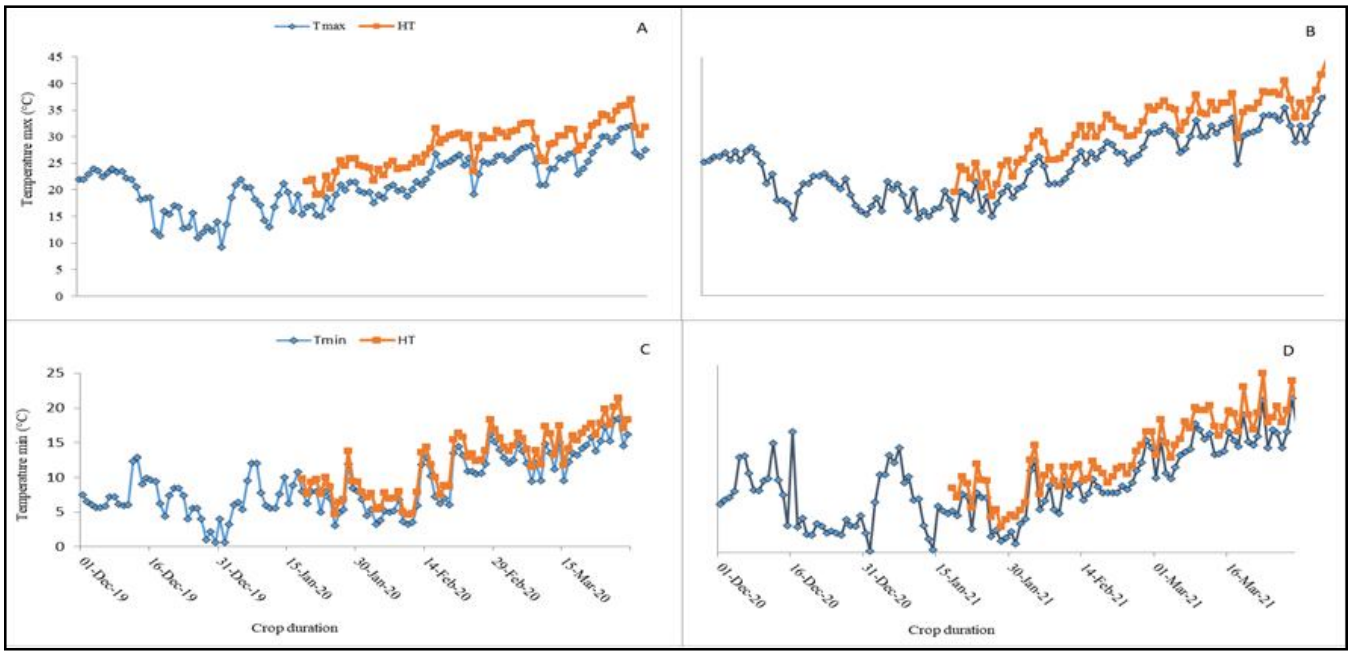

Fig. 1: Maximum and minimum teperature with high temperature of year 2019-20 and 2020-21.

Chlorophyll 'b' = 22.9 (A_{645}) – 4.68 (A_{663}). V/W× 1000 (4)

Total Chlorophyll = 22.2 (A_{645}) + 8.02 (A_{663}). V/W ×1000 (5)

where,

A_{663} and A_{645} are the absorbance values at 663 and 645 nm respectively

W = weight of the sample (mg)

V = volume of the solvent used (ml).

Proline Content

Proline determination was done according to Bates *et al.*, (1973) based on proline's reaction with ninhydrin. 0.2 g of frozen plant sample is homogenized in 2ml of 3% sulphosalicylic acid and centrifuged at 10,000 for 10min. For proline colorimetric determinations, a 1:1:1 of plant extract, ninhydrin acid and glacial acetic acid was incubated at 100ºC for 1 hour. The chromophore was extracted with 4 ml toluene and its absorbance at 520 nm was determined by spectrophotometer (Specord Bio.200 AnalytikJena, Germany). The amount of proline (µmol g^{-1} FW) was determined by plotting standard graph of proline.

Sugar and Starch content

100mg plant leaf material was homogenized in 5 ml hot 95% ethanol and centrifuged at 10,000 rpm for 10min as described by McCready *et al.*, (1950). Supernatant was kept for sugar estimation and overnight dried pellets was dissolved in 52% perchloric acid and centrifuged at 10,000 rpm for 10min for starch estimation. 100 µl of supernatant was diluted upto 1ml with distilled water and 4ml of freshly prepared ice cold Anthrone reagent (0.2% Anthrone reagent dissolved in sulphuric acid) was added. Heated for 10 minutes at 100º C (in water bath) and cool rapidly to 0º C on ice and absorbance was recorded 630nm. Sugar and starch content (mg g^{-1} FW) was calculated by plotting the standard of glucose.

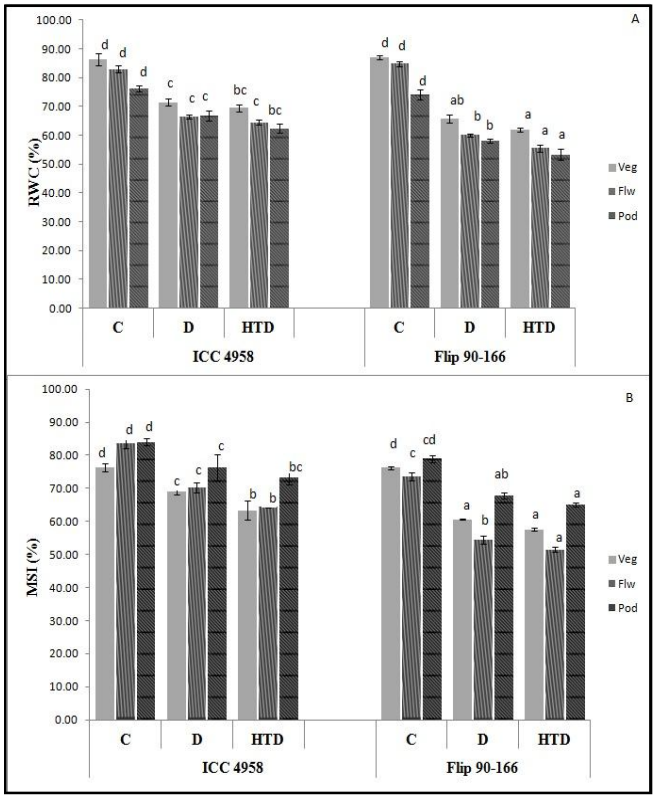

Fig. 2: Pooled mean relative water content (A) and Membrane Stability index (B) of chickpea at vegetative, flowering and pod formation stage under drought and high temperature stress. Data represent average of two experiments (2019-20 and 2020-21) with three replications. Values are mean ± SE.

Reproductive phenology

The data on phenology (days to flowering, days to pod initiation and days to maturity) were recorded by taking daily observations manually between 10am - 11am.

Yield attributes

At maturity, 5 plants were randomly selected from pots for seed yield and yield attributes (total biomass, grain weight $plant^{-1}$, filled and unfilled pod $plant^{-1}$, total pod weight $plant^{-1}$, and 100 grain weight) were recorded as described in our earlier paper Maurya and Chopra (2024).

Statistical Analysis

The data of the present experiments were analyzed using SPSS v.16 for Windows (SPSS Inc., Chicago, USA). The data was statistically verified with analysis of variation (ANOVA) and the significance of difference was measured using Duncan's post-hoc test at 5%.

Result and Discussion:

Physiological parameters

Phenology, Chl, RWC, MSI and photosynthesis: Crop duration of both chickpea genotype reduced in both years. The pooled data of year 2019-20 and 2020-21 was represented in Fig. 2 & 3. Early flower initiation (3-4 days) and development observed in both genotypes under drought stress. To avoid drought stress plant reduces seed filling period and matured early. The total crop duration was reduced was 6-12 days under drought stress while 11-16 days under combined drought and heat stress in both genotypes. Seed filling rate and duration both decreased under stress, especially when drought and heat were combined (Awasthi *et al.*, 2024).

Water stress triggers early senescence by rapid chlorophyll Chl a breakdown. This imbalance disrupts the photosynthesis process, leading to reduced carbon assimilation, lower biomass, and yield loss (Yang *et al.*, 2021). In current study, at vegetative stage, slower degradation of chl a and moderate pigment reduction was

observed (Fig 3A). Drought-induced pigment reduction was severe at the flowering stage than at the vegetative stage. The reduction was significant ($p<0.001$) under drought, it was 18% and 22% in ICC 4958 and Flip 90-166 respectively at flowering stage. Whereas the reduction under interactive effect of drought and high temperature were 25% and 33% in ICC 4958 and Flip 90-166 respectively at flowering stage. This is due to increased metabolic demand, oxidative stress, and early senescence during reproductive development (Hu *et al.,* 2023). Improvement in Chl a was observed higher at pod formation stage than the flowering stage. Drought-induced pigment reduction is severe at the flowering stage than at the vegetative stage, especially for chl a. The greater pigment loss was observed in Chl a. Highest reduction in chl a was at flowering stage 13% and 18% in ICC 4958 and Flip 90-166 respectively. Under drought and high temperature, the reduction was 18% and 23% in ICC 4958 and Flip 90-166 respectively, Plants are more sensitive during reproductive development hence, greater pigment loss, especially in Flip 90-166 sensitive genotype. At vegetative and pod formation stage, the reduction was non-significant in both genotypes. Awasthi *et al.,* (2024); Karim *et al.,* (2022) also observed the non-significant reduction in pigments at vegetative stage and pod formation stage in chickpea.

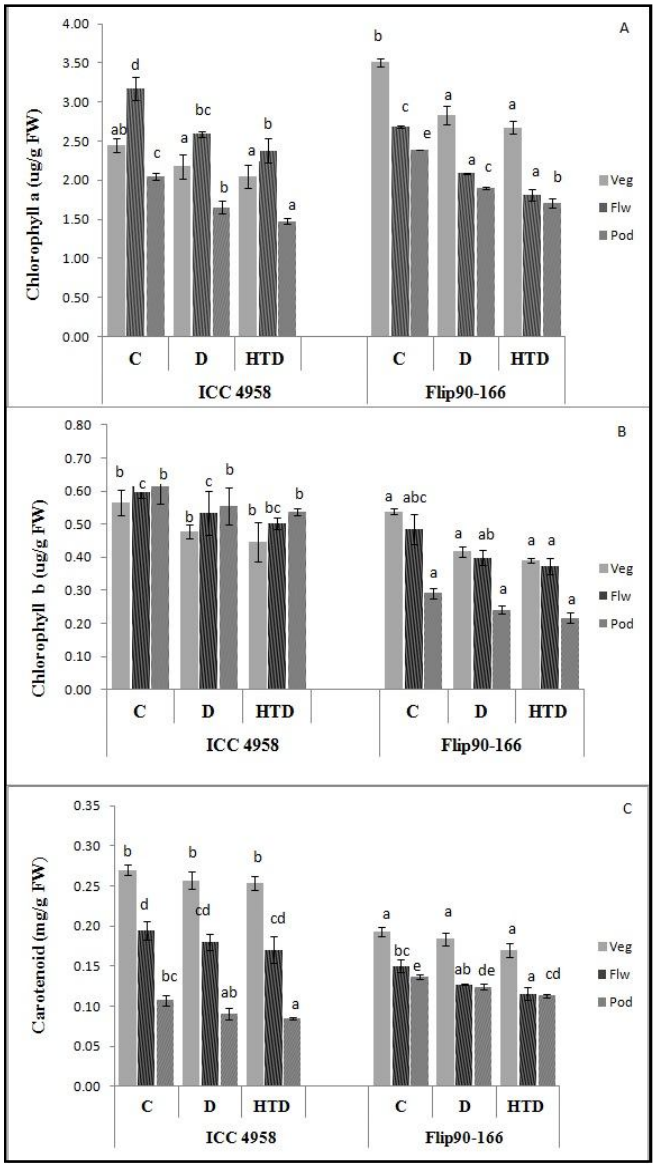

Fig. 3: Pooled mean chlorophyll a (A), chlorophyll (B) and carotenoid content (C) of chickpea at vegetative, flowering and pod formation stage under drought and high temperature stress. Data represent average of two experiments (2019-20 and 2020-21) with three replications. Values are mean ± SE.

Carotenoids (light harvesting pigment) function as photoprotecter to stabilize chlorophyll under stress (Sun *et al.,* 2022). In current study carotenoid content (Fig. 3 C) at vegetative stage is relatively stable under drought and interactive effect of drought and high temperature. The decrease was observed significantly ($p<0.05$) at flowering and pod formation stage in both genotypes. Carotenoids decrease more sharply due to photo-oxidative damage to chlorophyll content, leaf senescence and reduced pigment biosynthesis (Sun *et al.,* 2019). However, an increase in carotenoids and chlorophyll content was observed in checkpea (Çiçek *et al.,* 2015). This variability in results might be due to variability in the genotype performance.

Drought leads to reduced soil moisture**,** as a result, the water content in leaves and other tissues drops (Amoah and Seo 2021). A reduction in RWC was observed significant ($p<0.001$) at all stages in both genotypes (Fig. 2 A). Drought causes greater reduction in both RWC and MSI during flowering stage compared to the vegetative stage. It might be due to the higher sensitivity and energy demand of flowering stage than vegetative, which in-turn imparts higher physiological stress and reduction in yield through losing cell turgor, leads wilting, reduction in Pn and growth impairment (Awasthi *et al.,* 2024). At flowering stage, water loss is more severe and it was 66% and 60% in ICC 4958 and Flip 90-166 respectively. Under the effect of drought and high temperature the RWC was low as compared to drought. It was 64% and 55% in ICC 4958 and Flip 90-166 respectively. At pod formation stage, the RWC was better as compared to flowering stage. Drought also leads to oxidative stress damage cell membranes, causing leakage of ions and solutes (Fazeli-Nasab *et al.,* 2025). As a result, membrane integrity is compromised and membrane stability index was decreases significantly ($p<0.001$) at all stages and in both genotypes (Fig. 2 B). The drought tolerant genotype performed better than the

sensitive one across stress treatments. The membrane damage also rose with duration of drought is also reported by Fazeli-Nasab *et al.*, (2025) in chickpea and Amoah and Seo (2021) in wheat.

Photosynthesis was decreased significantly ($p<0.001$) at all stages in both of the genotypes. However, under the drought and high temperature, at flowering stage the improvement the photosynthesis was observed in both genotypes compared to drought. This might be due increase in photosynthesis under mild increase in temperature. The reduction was 22% and 33% in ICC 4958 and Flip 90-166 respectively. The Pn in vegetative and pod formation stage is not found significant comparable to drought. Photosynthetic rate, was key physiological correlates of drought tolerance in chickpea (Fazeli-Nasab *et al.*, 2025)

Biochemical adjustment

Sugar: Non-structural carbohydrates (NSCs) in plants serve multiple roles such as growth, carbon storage, osmotic adjustment, and supporting synthesis of antioxidants for defense under stress (Dong and Beckles 2019, Nawaz *et al.*, 2025). It has traditionally been thought that under stress, resources are diverted toward defense at the expense of growth (Zang *et al.*, 2022). Enzymes involved in starch and sucrose metabolism also dropped under combined stress, affecting nutritional quality (Awasthi *et al.*, 2024). Soluble sugars (like glucose, fructose and sucrose) play dual roles in plants: first act as energy sources and building blocks second as osmoprotectant. Increase in sugar content during drought is a biomarker of drought tolerance (Dien *et al.*, 2019). The content of sugars varies between among stages and is affected by drought condition. The highest increase was observed at pod formation stage in ICC 4958 (37% in D and 48% in DHT). Whereas in flip the highest increase was observed at flowering stage it was 22% and 28% in drought and drought with high temperature respectively (Fig. 5 A). The accumulation of sugar helps in osmotic adjustment and survival of cell. This means ICC 4958 maintains and mobilizes sugars effectively.

Proline: Drought stress has been found a significant ($p<0.001$) enhancer of proline content (Fig. 4 A). Its role in osmotic adjustment helps in maintaining cell turgor and water potential during drought stress (Kishor *et al.*, 2005, Hossain *et al.*, 2019). The highest increase was observed at vegetative stage followed by flowering and pod formation stage in both genotypes. At vegetative stage the increase was 109% and 69% under drought in ICC 4958 and Flip 90-166 respectively. Similarly, 164% and 99% increase was observed under drought with high

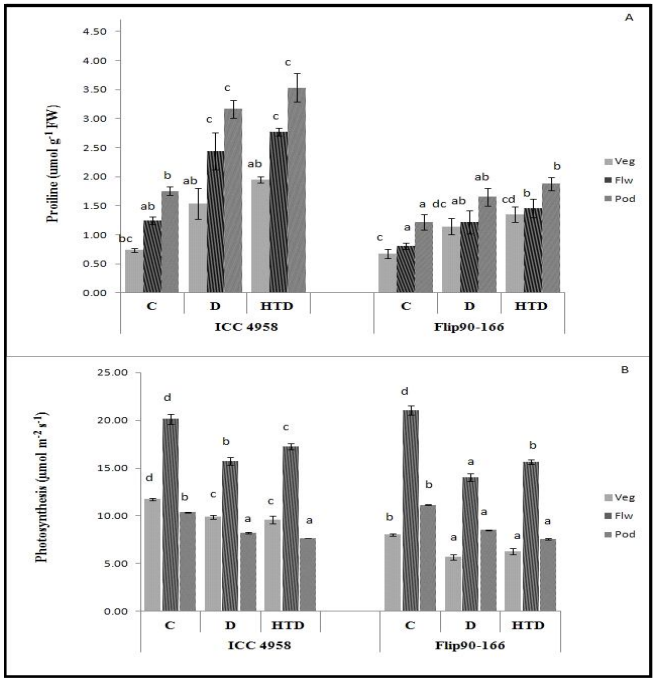

Fig. 4: Pooled mean proline (A) and Photosynthesis of chickpea at vegetative, flowering and pod formation stage under drought and high temperature stress. Data represent average of two experiments (2019-20 and 2020-21) with three replications. Values are mean ± SE.

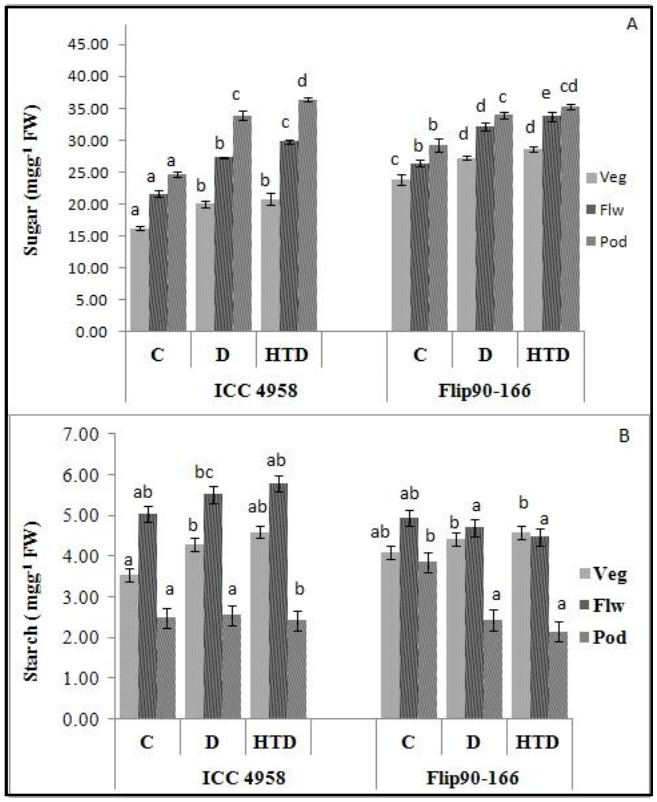

Fig. 5: Pooled mean sugar (A) and starch (B) of chickpea at vegetative, flowering and pod formation stage under drought and high temperature stress. Data represent average of two experiments (2019-20 and 2020-21) with four replications. Values are mean ± SE.

Table 1: Effect of drought and high temperature on yield and yield parameters of chickpea genotypes.

Year	Genotype	Treatmen	Total biomass	Pod fertility	No.of Pod	Pod wt	GW	TW
2019-20	ICC 4958	C	13.1±0.43 bc	73.69±9.26 d	35.60±0.81 e	6.15±0.40 b	4.56±0.52 bc	28.98±0.11 d
		D	11.30±0.25 ab	64.62±2.20 c	30.80±0.58 cd	5.14±0.15 ab	3.82±0.33 abc	26.15±0.19b
		HTD	10.54±0.40 a	62.05±3.66 bc	28.60±0.87 bc	4.52±0.24 a	3.38±0.13 abc	23.91±0.24 a
	Flip 90-16	C	21.40±0.53 cd	70.45±11.68 d	32.80±1.50 d	7.46±0.80 c	4.85±0.77 c	33.39±0.28 e
		D	15.40±1.29 d	58.09±6.16 ab	27.20±0.51 b	6.11±0.28 b	3.74±0.13 abc	28.84±0.17 d
		HTD	14.40±0.44 e	54.47±2.48 a	25.00±0.73 a	5.23±0.31 ab	3.19±0.14 a	26.96±0.12 c
2020-21	ICC 4958	C	12.36±0.57 b	77.36±2.21 c	29.60±1.81 c	4.83±0.17c	4.25±0.16 d	28.24±0.45 d
		D	10.38±0.29 a	67.86±2.25 b	26.40±2.16 bc	3.82±0.13 b	3.23±0.07 c	25.58±0.26 b
		HTD	9.72±0.35 a	62.71±0.64 b	23.60±1.25 ab	3.34±0.10 a	2.76±0.04 b	24.23±0.37 a
	Flip 90-16	C	19.77±0.63 d	62.25±2.15 b	27.60±2.25 bc	5.24±0.27 c	4.04±0.21 d	30.39±0.27 e
		D	14.46±0.54 c	48.47±1.80 a	22.00±1.48 ab	3.86±0.12 b	2.84±0.12 b	26.85±0.13 c
		HTD	13.78±0.95 bc	45.56±1.87 a	20.20±1.46 a	3.21±0.13 a	2.33±0.12 a	25.51±0.33 b

temperature in ICC 4958 and Flip90-166 respectively.

Starch content: Starch is a major carbohydrate storage form in leaves. Under normal conditions, it's synthesized during the day and broken down at night to fuel metabolism (Scialdone and Howard 2015). Under drought stress, starch metabolism is disrupted due to reduced photosynthesis, altered translocation, and increased breakdown for stress responses (Awasthi *et al.*, 2017, Khan *et al.*, 2019). In present study, leaf starch content highly increases at vegetative stage in both genotypes. Contrary to vegetative stage starch content is decreased in Flip 90-166 at flowering as well pod formation stage. In Flip 90-166 at flowering and pod formation stage, starch breaks down to sustain metabolism and osmo-protection. In ICC 4958 the value of starch increased significantly ($p< 0.05$) in drought as well as under drought and high temperature stress (Fig. 5 B). There was no significant effect on starch was observed in pod formation stage in ICC 4958. The pattern of accumulation is stage-dependent and influenced by the balance between photosynthesis, translocation, and metabolic demand (Nikkanen *et al.*, 2016). At pod formation stage starch is mobilize to support grain/ pod filling. This mobilization is exaggerated depleting leaf starch reserves.

Yield: Drought stress is one of the most significant abiotic limiting factor of plant growth and yield. In the present study, drought treatment had a pronounced effect on yield and yield parameters. Total biomass, pod weight, grain yield and 100 grain weight reduced in both genotypes under drought stress in both years (Table 1). The effect was steeper in Flip 90-166. The reduction in total biomass was 14-16% and ~28% in both years in ICC 4958 in Flip 90-166 respectively. Drought stress strongly reduces cell division and elongation that reduces leaf expansion, therefore biomass is reduced (Avramova *et al.*, 2016). In present study the reduction in yield was 16-24% in ICC 4958 and 22-30% in ICC 4958 and Flip 90-166 respectively. A reduction in pod fertility also observed in present study it was 11-12% and 17-22% in ICC 4958 and Flip 90-166 respectively. Reduction in plant growth disrupt flower and fruit development and fall in yield (Fazeli-Nasab *et al.*, 2025, Awasthi *et al.*, 2024). Further Water deficit reduces pollen viability, pollen germination, and pollen tube growth, while also affecting ovule fertilization and embryo development. Pod abortion rate also increased during drought stress resulting yield loss.

Under the interactive effect of drought and high temperature, compared to drought effect, the growth and grain weight, pod weight and test weight and crop duration dropped. A reduction in grain weight was 26% to 28% in ICC 4958 and 35% to 42% in Flip 90-166 in 2019-20 and 2020-21 respectively. Under combined stress, causing large reductions in seed weight and pod number plant shows significant additive nature on growth and physiological response (Awasthi *et al.*, 2024, Benali *et al.*, 2023). Both stress conditions caused over a 50 % reduction in plant height, biomass, and seed yield reported by Benali *et al.*, 2023 in chickpea.

Genotype ICC 4958 (drought tolerant) demonstrated superior resilience tolerant compared to sensitive genotype Flip 90-166, particularly maintaining higher relative water content (66-72% in ICC 4958 and 58-67% in Flip 90-166) and membrane stability. ICC 4958 consistently outperformed the sensitive genotype under both stress and non stress conditions, making it a promising candidate for breeding programs aimed at enhancing drought resilience in chickpea genotypes. Drought and high temperature stress adversely affected cell membrane integrity, photosynthesis, and water regulation, with combined stresses producing the most pronounced negative effects. The results further revealed that under the studied stress conditions, chickpea genotypes can complementarily allocate carbon to growth and defense, rather than compromising one for the other. This nuances understanding of the relationship between growth and defense has practical implications for improving crop resilience and yield under studied environmental stress.

Author contribution statement

Sadhana Maurya and A.K. Chopra: Conceived and designed the experiments; Sadhana Maurya Performed the experiments Analyzed and interpreted the data; writing original draft and editing

Amit Kumar, N.S. Panwar & Neha Sharma: Analysis tools, writing original draft and editing

: Analyzed and interpreted the data, Supervision and Administration; Reviewing and editing

Conflict of Interest: The authors declare no conflict of interest.

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