

## Response of contrasting groundnut genotypes to water deficit during Pre- and Post-flowering stages

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### Abstract

Groundnut (*Arachis hypogaea* L.) is an important crop globally, providing food, oil, and fodder, yet its productivity is severely impacted by drought stress. This study investigates the effects of drought at two critical growth stages—pre-flowering and post-flowering—on the performance of different groundnut genotypes. A set of groundnut genotypes was exposed to deficit moisture stress in controlled pot experiment at both the stages, and the resulting variations in growth and yield parameters were analysed. Results indicate significant genotype-by-environment interactions, with certain genotypes displaying better tolerance to drought stress. Most of the traits investigated showed a significant decrease under pre-flowering and post-flowering drought stress conditions. The study highlights that drought stress during the pre-flowering stage leads to a marked reduction in growth, while post-flowering stress primarily affects overall yield. Based on Stress Tolerance Index (STI) and Stress Susceptibility Index (SSI) values, the genotypes Kadiri Lepakshi and Phule Unnati were identified as tolerant and genotype ICG-297 identified as susceptible. These genotypes can be utilized in breeding programme to develop drought-tolerant groundnut varieties, offering potential solutions for improving productivity in regions affected by drought stress.

**Keywords:** Groundnut, drought stress, pre- and post-flowering drought, drought-resilient genotypes, morpho-physiological, stress tolerant, STI

### Introduction

Groundnut (*Arachis hypogaea* L.), a member of the Fabaceae family, is an important oilseed crop grown worldwide, and highly valued for its oil, protein, and carbohydrate content. Drought is one of the most severe environmental stresses affecting crop yield, especially in semi-arid and arid regions where water availability is unpredictable. Groundnut is sensitive to drought stress particularly during critical stages such as flowering, pegging, and pod-filling. Previous studies (Rao *et al.* 1985<sup>[11]</sup>; Meisner and Karnok, 1992)<sup>[8]</sup> have reported pod yield reductions up to 49% due to drought stress during these critical stages.

To bridge the prevailing yield gap, genotypes with good drought tolerance need to be identified which can significantly mitigate drought effects and can provide a long-term and cost-effective solution to rainfed farmers (Boraiah *et al.*, 2023)<sup>[3]</sup>. While the effects of drought stress on groundnut have been widely studied, the specific impacts of pre- and post-flowering drought on key traits and yield remain underexplored. Despite its importance, comprehensive research on how different groundnut genotypes respond to drought at these distinct growth stages is still limited. Such insights are crucial for developing drought-tolerant climate resilient varieties. The Stress Tolerance Index (STI) and Stress Susceptibility Index (SSI) values can be used to identify genotypes with different levels of stress resistance, which could inform breeding programs aimed at improving stress tolerance in crops.

The objectives of this research are to study the impact of pre-flowering and post-flowering drought on morpho-

physiological traits and yield, as well as to study the genetic variability of these traits in groundnut under moisture deficit conditions. The contrasting genotypes used in this study were selected based on our results of previous research trials conducted in field conditions during the *Summer* 2022-23 and *Kharif* 2023-24 seasons.

By identifying drought-resilient genotypes and understanding the mechanisms behind their tolerance, this research seeks to contribute valuable knowledge for groundnut breeding programs aimed at improving drought resistance.

### Methodology

#### Materials and experimental site

The experiment was conducted at the ICAR-National Institute of Abiotic Stress Management (NIASM), Baramati (MS), India (18°09' N, 74°30' E and 560 MAMSL). The material used in the present study consisted of ten erect or bunchy type contrasting genotypes of groundnut from ICRISAT mini core collection and two released popular varieties in India. The contrasting genotypes were selected based on our previous research trials conducted in field conditions. Among these, three genotypes were susceptible and 9 genotypes were tolerant (Table 1).

#### Imposition of moisture stress

The pot experiment was undertaken in partially controlled environmental conditions with no light control. Two seeds were sown in each plastic pot (30 cm height and 30 cm head diameter) filled with 18 kg clay loam red soil. After

germination, the plants were thinned to one healthy seedling per pot. Three moisture treatments *viz* pre-flowering moisture deficit, post-flowering moisture deficit and no stress were imposed with five replications, imposed pre-flowering moisture deficit (T1) by withholding irrigation from Seedling emergence stage up to 50% flowering stage i.e., 15 DAS to 35 DAS and rewatering afterwards. Imposed Post Flowering moisture deficit (T2) withholding irrigation from Flowering stage up to Pegging and Pod Development stage i.e., 50 DAS to 70 DAS and rewatering and Control (T3) normal irrigation maintained above 80% FC.

The pot experiment was laid out in a completely randomized block pattern. Regular weighing of pots was done before

and after giving irrigation to maintain field capacity by gravimetric method. The field capacity of the soil used in the experiment was attained by maintaining around 9.09% of soil moisture. Accordingly, imposed the moisture deficit at both the stages by tracking the pots weight.

Observations were recorded on key traits such as plant height at harvest (cm), number of primary branches plant-1 at harvest, days to 50 per cent flowering, total number of flowers per plant, days to physiological maturity, and dry pod yield per plant (g). Stress Tolerance Index (STI) and Stress Susceptibility Index (SSI) were calculated using Pour-Aboughadareh *et al.* (2019) [9]. Statistical analysis was done by Factorial Completely Randomized Design (FCRD).

**Table 1:** Details of genotypes used in the experiment

Sr. No.	Genotype	Source	Country of Origin	Primary Seed Colour	Response to Deficit Moisture*
1	ICG-3421	ICRISAT, Hyderabad	India	Tan	Susceptible
2	ICG-297	ICRISAT, Hyderabad	Mauritius	Tan	Susceptible
3	ICG-11249	ICRISAT, Hyderabad	Tanzania	Tan	Susceptible
4	ICG-4543	ICRISAT, Hyderabad	Unknown	Tan	Tolerant
5	ICG-3673	ICRISAT, Hyderabad	Republic of Korea	Dark Red	Tolerant
6	ICG-3584	ICRISAT, Hyderabad	India	Light Tan	Tolerant
7	ICG-1519	ICRISAT, Hyderabad	India	Tan	Tolerant
8	ICG-36	ICRISAT, Hyderabad	India	Tan	Tolerant
9	ICG-6703	ICRISAT, Hyderabad	Paraguay	Dark Purple	Tolerant
10	ICG-4684	ICRISAT, Hyderabad	USA	Tan	Tolerant
11	Kadiri Lepakshi	ANGRAU, Kadiri (2021)	India	Rose	Tolerant
12	Phule Unnati	MPKV, Rahuri (2019)	India	Red	Tolerant

\*Based on field experiments conducted during the Summer 2022-23 and Kharif 2023-24 seasons.

## Results and Discussion

### Impact of pre- and post-flowering moisture stress on morpho-physiological traits

The study examined the effects of pre- and post-flowering moisture stress on various morpho-physiological traits in groundnut genotypes. Stress at both stages reduced plant height, with pre-flowering stress having a more significant impact. Moisture deficit stress also negatively affected the number of primary branches, with Kadiri Lepakshi and Phule Unnati showing better resilience. Leaf thickness decreased under both stress conditions, with genotypes such as ICG-4543 and ICG-3673 maintaining better drought tolerance. Relative water content (RWC) also dropped under stress, but some genotypes like ICG-4543 and Kadiri Lepakshi were better at retaining water, indicating higher drought tolerance. Overall, the study demonstrated that drought stress, particularly at the pre-flowering stage, significantly impacts plant growth and development, but certain genotypes showed better resilience and adaptability to water stress.

### Plant Height (cm) at Harvest

Genotypes under control conditions (T3) showed the tallest plant heights, while pre-flowering (T1) and post-flowering (T2) stress reduced plant height. Plant height varied across genotypes, ranging from 18.72 cm to 33.94 cm, with ICG-297, ICG-3421, and ICG-11249 being the tallest under control, while Kadiri Lepakshi was the shortest.

Pre-flowering stress significantly reduced heights, while post-flowering stress also led to a reduction but to a lesser extent. Under pre-flowering stress, ICG-297 (29.83 cm) and ICG-3421 (22.17 cm) had higher heights, while Phule Unnati (14.83 cm) and Kadiri Lepakshi (15.67 cm) had the lowest. Under post-flowering stress, ICG-297 (33.33 cm)

and ICG-3421 (31.17 cm) were the tallest, with Phule Unnati (23.33 cm) and Kadiri Lepakshi (19.67 cm) being the shortest. ANOVA showed that both stress treatments and genotypes had a significant impact on plant height, with some genotypes being more tolerant to stress (Table 2).

Our results are in consistence with Ross (2007) who reported that high moisture was directly proportional to plant height in groundnut. However, there was greater reduction in the plant height when stress was imposed at the early flowering than at pod formation stage. Soil moisture depletion decreased plant height in groundnut. Bhattacharya *et al.* (1995) [1] also reported that under soil moisture stress condition, the plant height was reduced in groundnut.

### No. of Primary Branches at Harvest

Drought stress generally negatively impacted the number of primary branches, particularly under pre-flowering stress. Kadiri Lepakshi and Phule Unnati maintained the highest number of branches (3.89 and 4.22, respectively) under control conditions, with only a modest reduction under stress, suggesting better resilience to stress. ICG-3421 and ICG-297 showed a significant reduction in branches, indicating higher sensitivity to water stress.

ANOVA results showed that both water stress treatments and genotypes significantly affected branch number. However, the interaction between treatments and genotypes was not significant, indicating a consistent response across genotypes to the stress conditions tested (Table 2). Reddy *et al.* (2003) [13] also reported that number of branches were reduced in the drought treatment.

### Leaf Thickness (mm)

Leaf thickness, an important trait reflecting a plant's adaptation to water stress, and it typically decreases under

drought conditions to conserve water. Under pre-flowering and post-flowering stress, the mean leaf thickness reduced from 30.04 mm to 27.23 mm and from 28.55 mm to 23.58 mm, respectively. Genotype responses varied: ICG-3421, ICG-297, and ICG-11249 showed significant reductions in leaf thickness under both stress conditions, while ICG-4543 and ICG-3673 had more moderate reductions, indicating higher drought tolerance. Phule Unnati and Kadiri Lepakshi showed the best maintenance of leaf thickness under stress, suggesting strong drought tolerance.

ANOVA results confirmed that both water stress treatments and genotypes significantly impacted leaf thickness, with genotype-dependent responses to stress. The interaction between treatments and genotypes was also significant, indicating that the effect of stress on leaf thickness varied across genotypes (Table 2).

Our findings align with Reddy *et al.* (2000)<sup>[12]</sup> and Ennajeh *et al.* (2010)<sup>[5]</sup>, who reported that water stress influences leaf thickness by altering leaf structure and chlorophyll content. Genotypes that can maintain optimal leaf thickness under drought conditions are likely to perform better by balancing water conservation and photosynthesis.

#### Relative Water Content (%)

The Leaf RWC data for each genotype shows significant variation between the control and stress treatments, and also between the two stress periods (pre-flowering and post-flowering stress). Under control conditions, the mean RWC is 69.44%. Pre-flowering stress reduces the mean RWC to 61.51%, a decrease of 11.41%. Post-flowering stress results in a mean RWC of 61.70%, a decrease of 13.29%.

ICG-4543 and ICG-3673 show the smallest reductions in RWC under both stress conditions. For instance, ICG-4543 has a decrease of only 4.40% under pre-flowering stress and 6.73% under post-flowering stress, suggesting these genotypes have relatively better drought tolerance and can maintain water content in their leaves more effectively under stress conditions.

Phule Unnati and Kadiri Lepakshi are also relatively better at retaining water, with smaller decreases in RWC. Phule Unnati shows a 4.29% decrease under pre-flowering stress and 6.42% under post-flowering stress, while Kadiri Lepakshi has 3.96% and 6.28% decreases, respectively (Table 3).

Overall, the data reveals that genotypes like ICG-4543, ICG-3673, Phule Unnati, and Kadiri Lepakshi are more drought-tolerant compared to other genotypes like ICG-3421 and ICG-297, which exhibit a more considerable loss in leaf RWC under stress.

#### Impact of pre- and post-flowering moisture stress on yield and its attributing traits

The study investigated the impact of pre- and post-flowering moisture stress on yield and its attributing traits in groundnut genotypes. Water stress reduced the number of flowers per plant, with pre-flowering stress having a more severe effect. Genotype-specific responses were observed, as some genotypes maintained a higher number of flowers despite stress. Stress also influenced the days required to reach 50% flowering, with pre-flowering stress leading to earlier flowering, while post-flowering stress had a minor delay. Pre-flowering stress accelerated physiological maturity, reducing the average time to maturity, while post-flowering stress had a lesser effect. Water stress also

reduced pod weight, with genotype-specific variations in response; some genotypes, like Kadiri Lepakshi and Phule Unnati, maintained higher yields despite stress, while others, such as ICG-297, were more vulnerable. The findings align with previous studies that highlight the significant impact of water stress on flower production, flowering time, maturity, and pod weight.

#### No. of Flowers/Plant

Water stress significantly reduced the number of flowers per plant in groundnut genotypes. Under control conditions, the average number of flowers was 29.61, which decreased to 20.19 under pre-flowering stress and 23.28 under post-flowering stress (Table 3). Pre-flowering stress had a more severe impact on flower production, likely due to its critical role in reproductive organ establishment.

The treatment factor confirmed that water stress at any stage negatively affects flower production. Genotype also played a significant role, with different genotypes showing varying responses to stress. Some genotypes maintained a higher number of flowers despite stress, indicating genotype-specific drought tolerance mechanisms.

Our results are in line with the results of Chung *et al.* (1997)<sup>[4]</sup> who reported that water deficit produced a smaller number of total flowers per plant. Williams *et al.* (1975)<sup>[16]</sup> also found that the number of flowers produced per plant varied among genotypes.

#### Days required to 50% flowering

Water stress affects the number of days to 50% flowering in groundnut genotypes. For most genotypes, water stress either at the pre-flowering or post-flowering stage resulted in a reduction in days to 50% flowering, meaning that these plants flower earlier under stress.

Under control conditions, plants flowered at an average of 28.67 days. Pre-flowering stress led to earlier flowering (26.42 days), while post-flowering stress caused a slight delay (27.25 days). ICG-297, ICG-4543, and ICG-3673 showed earlier flowering under stress, while Phule Unnati had a later flowering time, with only a slight reduction under stress (from 36 days to 34-35 days) (Table 4).

ANOVA results showed that water stress, genotype, and their interaction all significantly affected flowering time. Some genotypes flowered earlier under stress, while others had delayed flowering, indicating genotype-specific responses to water stress. Ramos *et al.* (2022)<sup>[10]</sup> reported that early flowering is highly desirable, particularly in water-restricted environments.

#### Days required for physiological maturity

Under control conditions, genotypes took an average of 113.33 days to reach physiological maturity. Pre-flowering stress accelerated maturity, reducing the average time to 103.08 days, while post-flowering stress had a lesser impact, with maturity at 110.75 days (Table 4). Pre-flowering stress likely triggers earlier flowering and faster maturation, shortening the time to maturity, as seen in genotypes like ICG-3421 and ICG-11249. In contrast, post-flowering stress had a smaller effect, as plants had already committed to reproductive growth.

There was variation among genotypes, with some, like ICG-297 and Phule Unnati, showing less impact on maturity time, while others, like ICG-3421 and ICG-11249, exhibited more pronounced changes under pre-flowering stress. Singh

and Singh (2001) [15] have also reported that Genotype x environment interactions were highly significant for days to maturity.

**Pod weight/plant (g)**

Water stress reduces pod weight in most genotypes. Under control conditions, the average pod weight was 22.77 g, but it decreased to 18.32 g under pre-flowering stress and 17.05 g under post-flowering stress. Genotype-specific responses varied: ICG-3421 decreased from 19.80 g (control) to 13.07 g (post-flowering stress), while ICG-297 dropped significantly from 11.00 g to 7.37 g. Kadiri Lepakshi, the highest yielding genotype, showed moderate reductions from 40.10 g (control) to 32.08 g (post-flowering stress) (Table 5). Phule Unnati also performed well with moderate reductions.

ANOVA results showed that both water stress and genotype significantly affected pod weight, with some genotypes, like Kadiri Lepakshi and Phule Unnati, maintaining higher yields under stress, while others, like ICG-297, were more vulnerable to water limitations.

Falke *et al.* (2019) observed that drought stress significantly decreased the pod weight per plant. Hamidou *et al.* (2011) [7] reported that water stress imposed at flowering time decreased pod weight per plant by 68%. The findings of our study are in agreement with earlier works.

**Validation of stress tolerant and susceptible genotypes through stress indices.**

The yield under stress and normal condition is very crucial to judge the variety as a tolerant. The stress indices comprising more than 20 indices are being used by plant breeders for the purpose of identification of tolerant varieties. However, Stress Tolerance Index (STI) and Stress Susceptibility Index (SSI) are major indices as they correlate and represent other indices. Hence, the present study used these indices to validate the stress morpho-physiological response of the contrasting genotypes based on yield under different condition.

**Stress Tolerance Index (STI)**

It is a measure of how well a genotype can tolerate stress. A higher STI indicates better stress tolerance. Overall, the STI values are generally higher in the pre-flowering stage compared to the post-flowering stage for most genotypes, suggesting better stress tolerance during pre-flowering stage. Genotypes such as Kadiri Lepakshi and Phule Unnati exhibit the highest STI values in pre-flowering (2.636 and 2.285) and post-flowering stress (2.481 and 2.151) respectively, indicating they are the most stress-tolerant. ICG-4543 and ICG-6703, demonstrate moderate to high stress tolerance with stable STI values across both stages. On the other hand, genotype ICG-297 show low STI values (0.175 pre-flowering, 0.156 post-flowering) indicating poor stress tolerance (Table 5).

**Stress Susceptibility Index (SSI)**

It is a measure of how susceptible a genotype is to stress. A higher SSI value indicates greater susceptibility to stress. The SSI values tend to be slightly higher in the post-flowering stage, indicating that genotypes become more susceptible to post-flowering stress. Genotypes Kadiri Lepakshi and Phule Unnati exhibit the lower SSI values in pre-flowering (0.768 and 0.769) and post flowering (both 0.796) stress, suggesting minimal stress susceptibility. For ICG-4543 and ICG-6703 SSI remains constant at 1.023 and 0.996, indicating that these genotypes have a relatively stable response to stress and performs well under both stress conditions. On the other hand, genotype ICG-297 show high SSI values (1.279 pre-flowering, 1.314 post-flowering), indicating poor stress tolerance and high susceptibility (Table 5).

Based on STI and SSI it was concluded that Kadiri Lepakshi and Phule Unnati are tolerant to moisture deficit. These findings are confirming the reports of Boraiah *et al.* (2023) [2] as they reported that Kadiri Lepakshi as drought tolerant variety.

**Table 2:** Mean Plant Height (cm), No. of Primary Branches at Harvest and Leaf Thickness (mm) as influenced by groundnut genotypes under control (T3) and pre-flowering (T1) and post flowering (T2) drought condition

S. N.	Genotype	Plant Height (cm) at Harvest				No. of Primary Branches				Leaf Thickness (mm)					
		T <sub>3</sub>	T <sub>1</sub>	T <sub>2</sub>	Mean	T <sub>3</sub>	T <sub>1</sub>	T <sub>2</sub>	Mean	T <sub>3</sub>	T <sub>1</sub>	Mean	T <sub>3</sub>	T <sub>2</sub>	Mean
1	ICG-3421	36.00	22.17	31.17	29.78	2.00	1.33	1.33	1.56	30.25	25.33	27.79	29.33	20.83	25.08
2	ICG-297	38.67	29.83	33.33	33.94	2.00	1.33	2.00	1.78	30.83	24.17	27.50	27.75	20.77	24.26
3	ICG-11249	38.00	22.33	31.67	30.67	2.00	1.67	2.00	1.89	32.67	25.83	29.25	29.92	20.84	25.38
4	ICG-4543	28.33	19.83	25.83	24.67	3.00	2.00	2.00	2.33	30.92	29.25	30.08	28.67	25.30	26.99
5	ICG-3673	26.00	17.67	27.17	23.61	3.00	2.00	3.00	2.67	31.08	29.86	30.47	28.50	25.62	27.06
6	ICG-3584	35.17	20.33	22.33	25.94	2.67	2.00	2.67	2.44	28.67	26.83	27.75	26.83	20.78	23.81
7	ICG-1519	30.67	20.83	24.17	25.22	2.00	2.00	2.00	2.00	28.58	25.50	27.04	27.33	23.49	25.41
8	ICG-36	34.33	21.17	23.83	26.44	2.33	2.00	2.00	2.11	28.33	26.92	27.63	27.92	22.36	25.14
9	ICG-6703	25.67	18.33	25.83	23.28	2.33	1.33	2.00	1.89	29.33	27.58	28.46	29.08	25.03	27.06
10	ICG-4684	22.83	21.50	26.83	23.72	3.00	1.67	2.33	2.33	29.42	27.00	28.21	29.00	24.03	26.51
11	Kadiri Lepakshi	20.83	15.67	19.67	18.72	4.33	3.33	4.00	3.89	30.58	29.83	30.21	26.83	24.68	25.76
12	Phule Unnati	22.50	14.83	23.33	20.22	4.67	3.67	4.33	4.22	29.75	28.67	29.21	31.42	29.28	30.35
Tr. Mean		29.92	20.38	26.26		2.78	2.03	2.47		30.04	27.23		28.55	23.58	

ANOVA	Plant Height (cm) at Harvest			No. of Primary Branches			Leaf Thickness (mm)					
	S. E. (m)±	C. D.	F-test	S. E. (m)±	C. D.	F-test	S. E. (m)±	C. D.	F-test	S. E. (m)±	C. D.	F-test
Treatments	0.417	1.179	S	0.119	0.336	S	0.095	0.270	S	0.150	0.428	S
Genotypes	0.835	2.359	S	0.238	0.672	S	0.232	0.661	S	0.367	1.048	S
Interaction	1.446	4.085	S	0.412	NS	NS	0.328	0.935	S	0.520	1.482	S

**Table 3:** Mean Leaf Relative Water Content (%) as influenced by groundnut genotypes under control (T<sub>3</sub>) and pre-flowering (T<sub>1</sub>) and post flowering (T<sub>2</sub>) moisture deficit condition

Sr. No.	Genotype	Relative Water Content (RWC) (%)								No. of Flowers/Plant			
		Pre-Flowering Stress				Post-Flowering Stress				T <sub>3</sub>	T <sub>1</sub>	T <sub>2</sub>	Mean
		Control	Stress	Mean	% Decrease	Control	Stress	Mean	% Decrease				
1	ICG-3421	57.05	43.43	50.24	23.87	65.20	51.15	58.18	27.47	27.33	21.33	24.67	24.44
2	ICG-297	69.45	50.68	60.07	27.03	64.07	49.83	56.95	28.57	24.00	16.00	22.67	20.89
3	ICG-11249	70.25	50.81	60.53	27.68	69.87	54.28	62.08	28.72	41.33	24.33	30.00	31.89
4	ICG-4543	73.36	70.13	71.75	4.40	72.37	67.80	70.09	6.73	39.67	23.00	23.67	28.78
5	ICG-3673	74.84	70.29	72.56	6.08	74.92	70.75	72.83	5.89	50.33	22.67	33.00	35.33
6	ICG-3584	63.92	55.72	59.82	12.83	65.06	57.15	61.11	13.83	30.33	26.00	24.67	27.00
7	ICG-1519	64.83	56.84	60.83	12.32	64.74	57.10	60.92	13.39	34.00	27.67	29.00	30.22
8	ICG-36	71.27	68.36	69.82	4.08	71.79	64.11	67.95	11.98	31.33	21.67	23.33	25.44
9	ICG-6703	65.09	58.00	61.54	10.89	66.54	59.24	62.89	12.32	23.00	18.00	19.33	20.11
10	ICG-4684	70.31	67.32	68.82	4.25	70.00	63.94	66.97	9.48	24.67	20.67	24.67	23.33
11	Kadiri Lepakshi	74.96	71.98	73.47	3.96	75.26	70.81	73.03	6.28	15.33	13.33	13.67	14.11
12	Phule Unnati	77.93	74.59	76.26	4.29	79.00	74.23	76.62	6.42	14.00	7.67	10.67	10.78
	Mean (Treat.)	69.44	61.51		11.41	69.90	61.70		13.29	29.61	20.19	23.27	

ANOVA	SE (m)	CD	F-test	SE (m)	CD	F-test	S.E (m)	C.D	F-test
Treatments	0.72	2.04	S	0.08	0.24	S	0.335	1.003	S
Genotypes	1.76	5.00	S	0.20	0.58	S	0.710	2.006	S
Interaction	2.49	7.07	S	0.29	0.82	S	1.230	3.474	S

**Table 4:** Mean days required to 50% flowering and mean days required to physiological maturity as influenced by groundnut genotypes under control (T<sub>3</sub>) and pre-flowering (T<sub>1</sub>) and post flowering (T<sub>2</sub>) drought condition

Sr. No	Genotype	Days to 50% Flowering				Days to Physiological Maturity			
		T <sub>3</sub>	T <sub>1</sub>	T <sub>2</sub>	Mean	T <sub>3</sub>	T <sub>1</sub>	T <sub>2</sub>	Mean
1	ICG-3421	26.00	26.00	26.00	26.00	110	100	107	105.67
2	ICG-297	28.00	26.00	27.00	27.00	120	110	116	115.33
3	ICG-11249	26.00	25.00	25.00	25.33	110	100	117	109.00
4	ICG-4543	28.00	26.00	26.00	26.67	110	100	105	105.00
5	ICG-3673	28.00	25.00	25.00	26.00	120	110	115	115.00
6	ICG-3584	26.00	25.00	25.00	25.33	110	100	106	105.33
7	ICG-1519	26.00	25.00	25.00	25.33	110	100	106	105.33
8	ICG-36	27.00	25.00	26.00	26.00	110	100	110	106.67
9	ICG-6703	25.00	23.00	25.00	24.33	110	100	110	106.67
10	ICG-4684	34.00	26.00	28.00	29.33	120	107	112	113.00
11	Kadiri Lepakshi	34.00	31.00	34.00	33.00	110	100	110	106.67
12	Phule Unnati	36.00	34.00	35.00	35	120	110	115	115.00
	Tr. Mean	28.667	26.417	27.25		113.33	103.08	110.75	

ANOVA	S. E. (m)±	C. D.	F-test	S. E. (m)±	C. D.	F-test
Treatments	0.180	0.508	S	0.710	2.006	S
Genotypes	0.36	1.017	S	1.420	4.012	S
Interaction	0.623	1.761	S	2.460	NS	NS

**Table 5:** Mean Pod weight/plant (g), Stress Tolerance Index (STI) and Stress Susceptibility Index (SSI) as influenced by groundnut genotypes under control and pre-flowering and post flowering drought condition

Sr. No.	Genotype	Pod weight/plant (gm)				Pre-flowering Stress		Post-flowering Stress	
		Control	Pre-Flowering Stress	Post Flowering Stress	Mean	STI	SSI	STI	SSI
1	ICG-3421	19.80	14.85	13.07	15.91	0.567	1.279	0.499	1.353
2	ICG-297	11.00	8.25	7.37	8.87	0.175	1.279	0.156	1.314
3	ICG-11249	21.40	16.05	14.55	17.33	0.662	1.279	0.601	1.274
4	ICG-4543	21.30	17.04	15.97	18.10	0.700	1.023	0.656	0.996
5	ICG-3673	21.10	16.88	15.82	17.93	0.687	1.023	0.644	0.996
6	ICG-3584	17.10	13.68	12.82	14.53	0.451	1.023	0.423	0.997
7	ICG-1519	20.20	16.16	15.15	17.17	0.630	1.023	0.590	0.995
8	ICG-36	15.50	12.40	11.62	13.17	0.371	1.023	0.347	0.997
9	ICG-6703	26.10	20.88	19.57	22.18	1.051	1.023	0.985	0.996

10	ICG-4684	22.30	17.84	16.72	18.95	0.767	1.023	0.719	0.996
11	Kadiri Lepakshi	40.10	34.08	32.08	35.42	2.636	0.768	2.481	0.796
12	Phule Unnati	37.34	31.73	29.87	32.98	2.285	0.769	2.151	0.796
	Tr. Mean	22.77	18.32	17.05					
	ANOVA	SE (m)±	CD	F-test					
	Treatments	0.144	0.408	S					
	Genotypes	0.289	0.816	S					
	Interaction	0.500	1.413	S					

## Conclusion

This study provides valuable insights into the effects of drought stress at different growth stages—pre-flowering and post-flowering—on groundnut (*Arachis hypogaea* L.) genotypes. Most of the traits investigated showed a significant decrease under pre-flowering and post-flowering drought stress conditions, also a significant genotypic variation was observed. Key agronomic traits such as plant height, number of branches, leaf thickness, flower production, and pod weight per plant were all adversely affected under drought conditions, but the extent of the impact varied across different genotypes.

The genotypes Phule Unnati and Kadiri Lepakshi demonstrated a higher degree of drought resilience, maintaining relatively better growth and yield parameters under both pre- and post-flowering drought stress, while genotypes such as ICG-297 exhibited higher sensitivity to water deficit.

Genotypes Kadiri Lepakshi and Phule Unnati are the most stress-tolerant in both pre-flowering and post-flowering stages, as indicated by their high STI and low SSI values. ICG-6703 and ICG-4543 also showed strong performance in terms of stress tolerance, though slightly lower than Kadiri Lepakshi and Phule Unnati. ICG-297 show low stress tolerance (low STI and high SSI) and would likely perform poorly under stress conditions. These results underline the potential of using these resilient genotypes in breeding programs aimed at improving drought tolerance in groundnut.

Ultimately, identifying and selecting drought-tolerant genotypes based on critical morphological and physiological traits is essential for enhancing groundnut productivity under water-limited conditions. This research contributes to the broader goal of identifying drought-tolerant groundnut genotypes, which is crucial for ensuring food security and sustainable agriculture in regions vulnerable to water scarcity. Further studies, focusing on the molecular mechanisms underlying drought tolerance of these genotypes, will complement these findings and aid in the development of genetically superior drought-resistant groundnut varieties.

## References

- Bhattacharya A, Singh DN, Raj D. Association of yield and yield components under soil moisture stress and non-stress conditions in chickpea. *Legume Research*,1995;18(4):193–199.
- Boraiah KM, Basavaraj PS, Harisha CB, Jadhav P, Kakade VD, Morade A, Khapte PS, Pal KK, Reddy KS. Multiple stress tolerant crop varieties in India: scope, status and a way forward. ICAR-National Institute of Abiotic Stress Management, Baramati, Pune, Maharashtra, India, 2024, 145.
- Boraiah KM, Basavaraj PS, Kakade VD, Harisha CB, Khapte PS, Halagundegowda GR, Krishnamurthy D, et al. Abiotic stress-tolerant crop varieties in India: status and a way forward. *Recent Trends in Plant Breeding and Genetic Improvement*. Intech Open, 2023. doi:10.5772/intechopen.1001916.
- Chung SY, Vercellotti JR, Sanders TH. Increase of glycolytic enzymes in peanuts during peanut maturation and curing: evidence of anaerobic metabolism. *J Agric Food Chem*,1997;45:4516–4521.
- Ennajeh M, Vadel AM, Cochard H, Khemira H. Comparative impacts of water stress on the leaf anatomy of a drought-resistant and a drought-sensitive olive cultivar. *J Hortic Sci Biotechnol*,2010;85(4):289–294.
- Bacharou FA, Hamidou F, Halilou O, Harou A. Assessment of groundnut elite lines under drought conditions and selection of tolerance associated traits. *Adv Agric*,2019;2019(1):3034278.
- Hamidou F, Ratnakumar P, Halilou O, Mponda O, Kapewa T, Monyo E, et al. Selection of intermittent drought tolerant lines across years and locations in the reference collection of groundnut (*Arachis hypogaea* L.). *Field Crops Res*,2011;124(2):109–117. doi:10.1016/j.fcr.2011.10.009.
- Meisner CA, Karnok KJ. Peanut root response to drought stress. *Agron J*,1992;84:159–165. doi:10.2134/agronj1992.00021962008400020007x.
- Pour-Aboughadareh A, Yousefian M, Moradkhani H, Moghaddam Vahed M, Poczai P, Siddique KH. iPASTIC: An online toolkit to estimate plant abiotic stress indices. *Appl Plant Sci*,2019;7(7):e11278. doi:10.1002/aps3.11278.
- Ramos JPC, Cavalcanti JJV, Freire RMM, Silva CRC da, Silva M de FC da, Santos RC dos. Selection indexes and economic weights applied to runner-peanut breeding. *Braz J Agric Environ Eng*,2022;26:327–334. doi:10.1590/1807-1929.
- Rao RCN, Singh S, Sivakumar MVK, Srivastara KL, Williams JH. Effect of water deficit at different growth phases of peanut: I yield response. *Agron J*,1985;77:782–786.
- Reddy PV, Asalatha M, Babitha. Relationship of mineral ash and chlorophyll content with transpiration efficiency in groundnut under different moisture regimes. *Indian J Plant Physiol*,2000;5(1):59–63.
- Reddy TVB, Prakasa Rao JS, Vijayalakshmi K. Physiological and biochemical evaluation of groundnut cultivars differing in drought tolerance. *Indian J Plant Physiol*,2003;8(4):359–363.
- Ross BB. Peanut irrigation. *Peanut Production Guide*, 2007, 64–67.
- Singh SB, Singh JP. Genotype environment interaction effects in groundnut (*Arachis hypogaea*) tested in the mid-western plain zone of Uttar Pradesh. *Indian J Agric Sci*,2001;71:126–127.
- Williams JH, Wilson JH, Batle GC. The growth of groundnuts (*Arachis hypogaea* L.) cv. Makalu Red at three altitudes in Rhodesia. *Rhodesian J Agric Res*,1975;13:33–43.