



Screening Pigeon Pea Genotypes for Drought Tolerance: A Biochemical Approach

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ABSTRACT

Background: Pigeon pea, being a rainfed crop, suffers water scarcity to a greater extent. The reduction in yield is due to a reduction in photosynthetic rate and the source-sink relationship. The reduction in photosynthesis occurs due to enzyme degradation and also antioxidant production reduction.

Methods: Thus, screening of pigeon pea genotypes (18no.) based on the accumulation of proteins, enzymes and antioxidants will be easy to identify drought tolerant species and susceptible species.

Result: Among 18 genotypes selected for screening, COPH 2, ICPL12755 and ICPL12974 genotypes are high in proline, epicuticular wax, scavenging enzymes like peroxidase and catalase especially during drought condition than control. The same genotypes were proved with remarkable increase in yields. There are few varieties that show lower amounts of the enzymes along with lesser yield such as CO5, ICPL4777 and ICPL6997. This shows that antioxidant activity and proteins are directly involved in improving yield along with tolerance towards drought condition.

Key words: Drought, Epicuticular wax, Pigeonpea, Screening, Yield.

Abbreviations: Co: Coimbatore, Coph-coimbatore pigeonpea hybrid, Icph: Icrisat pigeonpea lines, Jkm: Jawahar khargoan, Vbn: Vamban, Vrg: Vamban red gram.

INTRODUCTION

Pigeon pea, scientifically known as [*Cajanus cajan* (L.) Millsp.], is primarily grown in semi-arid tropical regions, where it is irrigated by rainwater. According to FAOSTAT, (2024), India is responsible for more than 70 per cent of the total cultivated area, with an estimated acreage of 5.01 million hectares and a production of 3.89 million tons. According to Indian Institute of Pulse Research, indias pigeon pea productivity was significantly greater at 859 kg/ha but still it is less potential. The most significant factor that has an impact on production is the unpredictable and non-specific occurrence of drought, which can take place at any point in time during the growing season and has the potential to disrupt both growth and development. The disruption during drought is due to changes in physiological and metabolic processes that have an impact on the growth and development of the crop, which in turn leads to a change in the photosynthetic rate and the source-sink connections. The crop is more susceptible to the effects of drought stress, particularly when it is exposed to drying conditions during the late blooming and early pod development stages, which leads to significant output losses.

Drought stress significantly impacts pigeon pea productivity, during the reproductive stage, by reducing enzyme activity and reproductive processes (Costa and Shanmugathan, 1999; Kosar *et al.*, 2020). It impairs metabolic functions, diminishes antioxidant enzyme activity and inhibits protein synthesis and photophosphorylation, ultimately stunting plant growth (Naderi *et al.*, 2020). These effects contribute to yield loss, economic instability and food insecurity (Mansoor *et al.*, 2021). In response, plants activate defense

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mechanisms, including the production of enzymatic and non-enzymatic antioxidants to scavenge reactive oxygen species (Saman *et al.*, 2022). Screening pigeon pea genotypes for drought tolerance involves evaluating the overexpression or downregulation of stress-responsive enzymes and proteins, which vary due to genotype environment interactions.

MATERIALS AND METHODS

The field experiment was conducted at the Millet Breeding Station, Tamil Nadu Agricultural University (TNAU), Coimbatore, India using 18 pigeon pea genotypes obtained from the Department of Pulses, TNAU and the National Pulses Research Centre, Vamban. The genotypes include COPH2, VRG11, VRG17, VRG54, VRG61, VRG62, JKM144,

JKM185, CO5, VBN2, ICPL4777, ICPL6997, ICPL11119, ICPL11175, ICPL12755, ICPL12974, ICPL11375 and ICPL11038. The research was conducted during 2023-24 in Department of Crop Physiology, Tamil Nadu Agricultural University, Coimbatore.

The field experiment was conducted using a randomized block design with three replications. The moisture stress was imposed by suspending irrigation during the flowering and pod development stages.

Biochemical assessments were conducted at three developmental stages *viz.*, vegetative, flowering and pod formation. The following parameters were recorded using established protocols: The total chlorophyll content was measured in fully expanded leaves at specified intervals using the method of Yoshida *et al.* (1971) and were expressed in mg g^{-1} . Soluble protein was quantified following Lowry *et al.* (1951) and reported as mg g^{-1} . The determination of nitrate reductase activity in young leaves was carried out by utilizing the technique of Nicholas *et al.* (1976) and expressed in $\text{mg NO}_2 \text{ g}^{-1} \text{ h}^{-1}$. The IAA oxidase activity was assessed using the method that was proposed by Parthasarathy *et al.* (1970) with results expressed as $\mu\text{g unoxidized auxin g}^{-1} \text{ h}^{-1}$. Proline accumulation in leaf was estimated in leaf tissue according to Bates *et al.* (1973) and stated as $\mu\text{g g}^{-1}$ fresh weight. The peroxidase activity was measured using the technique outlined by Sadasivam and Manickam, (2015) and the results were expressed as enzyme units $\text{mg}^{-1} \text{ protein}^{-1}$. The amount of catalase was quantified and expressed as the $\mu\text{g H}_2\text{O}_2 \text{ min}^{-1} \text{ g}^{-1}$. The epi cuticular wax concentration was determined using potassium dichromate and expressed in $\mu\text{g cm}^{-2}$ (Ebercon *et al.*, 1977).

Yield attributes such as number of branches, flowers, pods per plant, fertility coefficient and seed yield were also assessed. A statistical analysis was performed on the data that was acquired to examine it in accordance with the methodology of Panse and Sukhatme (1954).

RESULTS AND DISCUSSION

The present study was conducted to identify pigeon pea genotypes suitable for cultivation in drought prone areas

and variable rainfall regions by evaluating their drought tolerance through biochemical and yield-related traits. Genotypes exhibiting higher biochemical content with minimal variation between control and stress conditions were classified as *tolerant*, whereas those with lower content and greater per cent reduction were deemed susceptible.

Biochemical parameters

Chlorophyll content

Different genotypes of pigeon pea plants experiencing moisture stress may have reduced photosynthetic pigment composition (31-43%), especially reduction in the chlorophyll content than compared with control. During the flowering stage, the total chlorophyll concentration was found to be high (Fig 1), but it quickly decreased as the plant progressed through the senescence stage. In the pigeon pea genotype CPH2, the photosynthetic pigment composition was found to be high, whereas in the genotype ICPL6997, it was found to be low. Similar results were observed from the Jha *et al.* (2023) who noticed reduction in chlorophyll content in mesophyll cells during water stress. Drought stress reduced chlorophyll development by lowering chlorophyll a/b ratio and damages photosynthetic machinery and accumulation of reactive oxygen species, which led to further structural and functional alterations (Naderi *et al.*, 2020).

Soluble protein

The content of soluble proteins (Table 1) is regarded to be an index for photosynthetic efficiency since it is a measure of the activity of RuBP carboxylase. Drought stress induced throughout the flowering stage and the pod maturation stage showed the maximum soluble protein content in genotype ICPL12755 and the minimum in ICPL6997 had a negative impact on the soluble protein content, with the per cent reduction being 27.3% and 29.8% respectively. The decrease in soluble protein, lead to a decrease in the activity of RuBP carboxylase and, consequently, the rate of photosynthesis. It was confirmed that drought causes

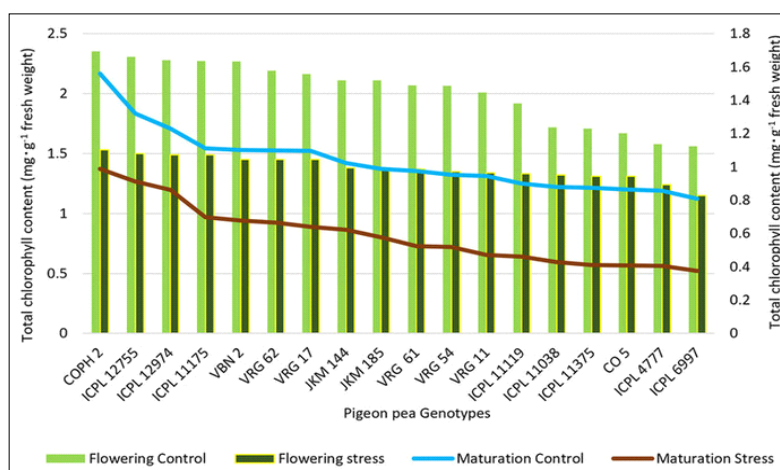


Fig 1: Effect of drought on total chlorophyll content (mg g^{-1} fresh weight) in pigeon pea genotypes.

significant changes because water plays an important role in carboxylation process of photosynthesis. The drop in soluble protein that occurs under drought stress may be the result of either an increase in proteolysis enzymes, reduced production of RUBISCO or ROS allocation on degradation or both (Hasnain *et al.*, 2023).

Nitrate reductase enzyme

Being a leguminous crop, pigeon pea fix atmospheric nitrogen through symbiotic relationship with nitrogen in root nodules with the help of nitrate reductase enzyme. This enzyme converts the nitrate into nitrate which is a crucial

reaction in biological nitrogen fixation. Nitrate reductase enzyme is the most sensitive enzyme which gets reduced during drought condition. According to our study, it was observed that nitrate reductase loss was more during stress condition which reflected in yield aspect. ICPL6997 had reduced enzyme activity compared to genotype CPH2 (Fig 2). Enzyme activity dropped to 29.0% and 53.2% during blooming and pod development due to drought stress. Drought lowered nitrogen fixation, lowering nitrate concentration and nitrate reductase activity. Souza *et al.*, (2023), stated that during nitrogen metabolism, nitrate reductase enzyme inactivation reduce nitrate content in the

Table 1: Effect of drought on soluble protein (mg g^{-1}) at different growth stages of pigeon pea genotypes.

Genotypes	Soluble protein (mg.g^{-1})				
	Vegetative stage	Flowering stage		Pod maturation stage	
		Control	Stress	Control	Stress
COPH2	38.3	40.3	25.3	29.7	19.3
ICPL12755	34.4	38.2	27.5	24.6	19.7
ICPL12974	32.5	37.7	27.9	24.0	17.3
ICPL11175	31.3	32.3	25.8	24.3	17.0
VBN2	30.3	32.7	22.7	24.4	17.3
VRG62	30.6	31.7	24.3	23.4	16.3
VRG17	29.3	30.7	22.5	22.4	16.6
JKM144	30.7	29.1	23.1	22.0	15.5
JKM185	29.1	26.4	20.4	21.7	15.4
VRG 61	29.4	24.3	20.3	22.9	15.2
VRG54	27.0	25.3	20.2	19.5	15.3
VRG11	30.7	25.3	19.7	19.1	13.7
ICPL11119	25.1	24.4	15.3	19.5	13.1
ICPL11038	25.6	21.2	15.1	18.7	12.8
ICPL11375	26.7	20.6	14.8	18.2	11.5
CO5	24.7	19.2	13.3	16.9	11.1
ICPL4777	23.2	19.3	12.7	15.1	10.5
ICPL6997	21.1	19.7	12.1	12.7	8.8
Mean	29.0	27.8	20.0	21.1	14.8
SEd	0.7	1.1	0.9	0.7	0.6
CD (P= 0.05)	1.5	2.4	1.8	1.4	1.1

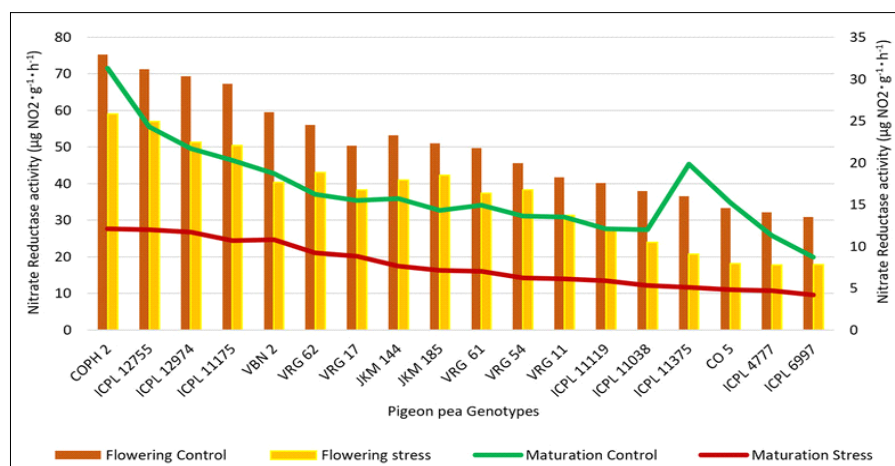


Fig 2: Effect of drought on nitrate reductase activity ($\mu\text{g NO}_2 \text{ g}^{-1} \text{ h}^{-1}$) at different growth stages of pigeon pea genotypes.

plants. This reduction in nitrate reductase enzyme, limits the amino acid production needed for protein synthesis. However, no studies were observed so far about nitrate reductase enzyme in drought in pigeon pea.

IAA oxidase enzyme

IAA oxidase enzyme reduces IAA responsible for plant growth and development. In our experiment, the value determines the amount of IAA available in the plant without oxidation. The temporal pattern of IAA oxidase activity (Fig 3) demonstrated a decrease in the rate of activity as the crop growth progressed. The genotype VRG61 exhibited the highest level of activity, while ICPL4777 showed the lowest level of activity. The drought stress showed a decrease of 24.0% during the flowering stage and 27.5% during the pod maturation stage. CPH2 showed maximum IAA content in our study maintaining a balance between growth suppression and stress adaptation. The decrease in IAA oxidase activity led to the preservation of elevated auxin levels and an enhanced fertility coefficient. The activity of IAA oxidase in pigeon pea

doubled under the circumstances of moisture stress (Souza *et al.*, 2023) leading to accelerated leaf senescence.

Proline

The proline buildup in the cells of pigeon pea is associated with the decrease in tissue water stress and the largest accumulation occurred during the pod initiation stage is caused by the reduction in water potential. Proline is believed to protect plant tissues against stress by acting as nitrogen storage, an Osmo regulator and a protectant for enzymes and cellular structure. The genotype CPH2 exhibited the highest proline content, while ICPL6997 had the lowest (Fig 4). The proline content increased by 32.6% and 48.5%, respectively. Plants experiencing drought stress accumulate organic osmolytes (proline), which are recognized for their role in enhancing the plant's ability to withstand water scarcity. The accumulation of proline may have facilitated an osmotic process in the root, allowing the maintenance of water potential gradient in the roots (Loho *et al.*, 2025). This resulted in less water stress injury in the plant. A substantial elevation in proline concentration

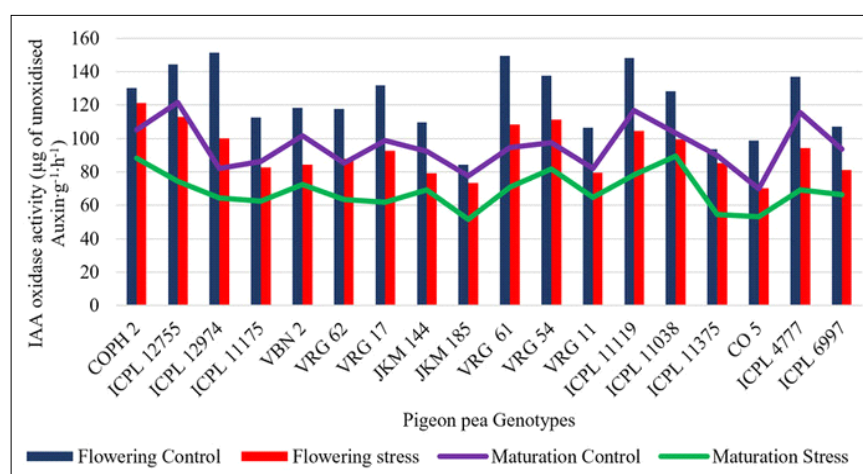


Fig 3: Effect of drought on IAA oxidase activity ($\mu\text{g of unoxidised auxin g}^{-1} \text{ h}^{-1}$) at different growth stages of pigeon pea genotypes.

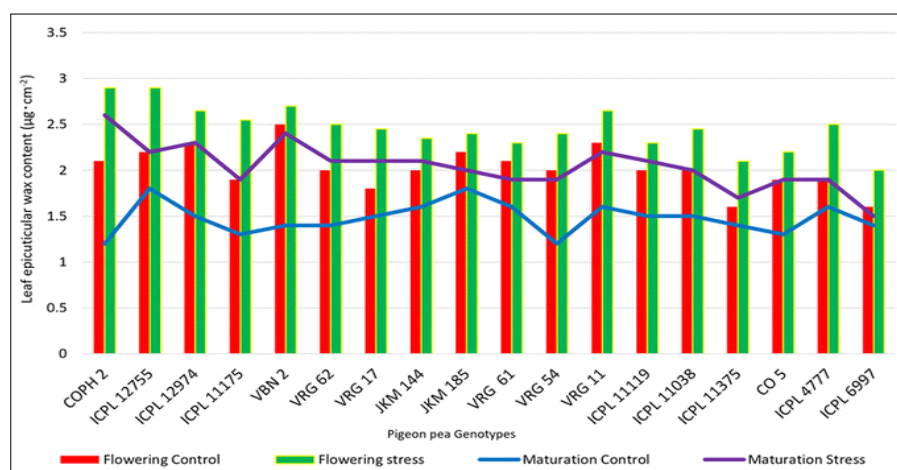


Fig 4: Effect of drought on leaf epicuticular wax content ($\mu\text{g cm}^{-2}$) at lowering stages of pigeon pea genotypes.

was seen when the stress intensified in pigeon pea (Bisht and Garg, 2023).

Antioxidant enzymes- peroxidase

During stress condition, plants undergo osmotic and ionic stress, with higher production of ROS which are harmful to the plants under high concentration. It will suppress the activities of cells and their respective organs. Plants possess inherent defense mechanisms by increasing enzyme activities peroxidase and catalase, which helps in protecting them from adverse conditions and are responsible for eliminating and getting rid of harmful substances. Modulation on concentration of antioxidant enzyme activity may be essential for plants to withstand environmental drought. Peroxidase, an enzyme, is highly reactive to changes in the environment and is regarded as an indicator of a plant's ability to withstand abiotic stresses. Peroxidase plays a critical role in the process of morphogenesis and the oxidation of auxin (Bakala *et al.*, 2024). In our study, the enzymatic activity exhibited an upward trend until reaching maturity. CPH2 exhibited a high level of peroxidase concentration, while ICPL6997 had a low level during drought (Table 2). This clearly explains that CPH2 could able to tolerate drought condition by mitigating osmotic stress by increasing their scavenging enzyme-peroxidase enzyme.

Catalase

The enzyme catalase plays a crucial role in the neutralization of reactive oxygen species, particularly hydrogen peroxide

which will harm the structures of chloroplasts and mitochondria in the pigeon pea leaves (Murali *et al.*, 2025). In this study, the catalase activity exhibited an initial increase till the flowering stage, followed by a subsequent reduction as the crop progressed toward maturity. CPH2 exhibited elevated catalase activity, while the CO5 sample displayed reduced catalase activity. At the flowering stage, moisture stress caused an 82.9% rise in catalase activity, while at the pod maturity stage, it caused an 88.8% increase (Table 3). This was in correlation with increase in catalase enzyme followed by their permeability of the plasma membrane in soybeans during drought stress (Porcel and Ruiz-Lozano, 2004).

Epicuticular wax on leaves is a crucial characteristic associated with the ability to withstand drought. The wax content exhibited an increase until the flowering stage, followed by a progressive fall until maturity. CPH2 exhibited a higher wax content, while ICPL6997 had a lower wax level. At the flowering stage, drought stress led to a 22.3 per cent increase in wax content, whereas at the pod maturity stage, the rise was 40.2 per cent (Fig 5). The amount of wax on the surface of leaves increased as the soil moisture deficit increased. The presence of a significant amount of epicuticular wax might enhance the ability of a plant to withstand drought conditions. This is due to the fact that high levels of epicuticular wax reduce water loss by epicuticular transpiration, but promote more gaseous exchange through stomata even when the soil moisture is limited (Samdur *et al.*, 2003).

Table 2: Effect of drought on peroxidase activity ($\mu\text{moles H}_2\text{O}_2 \text{ g}^{-1} \text{ min}^{-1}$) at different growth stages of pigeon pea genotypes.

Genotypes	Peroxidase activity ($\mu\text{moles H}_2\text{O}_2 \text{ g}^{-1} \text{ min}^{-1}$)				
	Vegetative stage	Flowering stage		Pod maturation stage	
		Control	Stress	Control	Stress
CPH2	0.021	0.026	0.036	0.029	0.041
ICPL12755	0.019	0.024	0.034	0.029	0.041
ICPL12974	0.019	0.022	0.032	0.027	0.040
ICPL11175	0.018	0.021	0.031	0.027	0.040
VBN2	0.017	0.019	0.028	0.026	0.036
VRG62	0.017	0.018	0.026	0.026	0.035
VRG17	0.016	0.018	0.025	0.024	0.032
JKM144	0.015	0.015	0.023	0.024	0.031
JKM185	0.015	0.015	0.024	0.021	0.030
VRG 61	0.015	0.016	0.021	0.019	0.030
VRG54	0.014	0.015	0.023	0.016	0.027
VRG11	0.010	0.014	0.026	0.016	0.025
ICPL11119	0.014	0.017	0.028	0.017	0.029
ICPL11038	0.014	0.015	0.022	0.019	0.028
ICPL11375	0.011	0.015	0.028	0.016	0.027
CO5	0.004	0.009	0.019	0.015	0.022
ICPL4777	0.008	0.009	0.027	0.015	0.028
ICPL6997	0.006	0.009	0.017	0.011	0.021
Mean	0.014	0.016	0.026	0.021	0.031
SEd	0.0008	0.0008	0.0009	0.0010	0.0011
CD (P= 0.05)	0.0016	0.0017	0.0018	0.0020	0.0023

Yield and yield components

Pigeon pea yield is primarily determined by key components such as the number of branches, pods, flowers, fertility coefficient, seed weight and the harvest index serves as crucial indicators for selecting high-performing genotypes, under drought conditions where yield potential becomes more sensitive to physiological efficiency and plant architecture.

The number of branches showed a significant aspect that affects crop production in indeterminate crops. VRG11 had

many branches, while VBN2 had a small number. Drought stress applied throughout the flowering and pod maturity stages resulted in a reduction of branch numbers by 20.8%, respectively resulting in a low rate of production. This reduced branch growth may ultimately have a negative impact on the overall seed yield of the crops. However, the additional secondary and tertiary branches do not significantly contribute to the yield. The variations in drought resistance across different genotypes were

Table 3: Effect of drought on catalase activity ($\mu\text{moles H}_2\text{O}_2 \text{ g}^{-1} \text{ min}^{-1}$) at different growth stages of pigeon pea genotypes.

Genotypes	Catalase activity ($\mu\text{moles H}_2\text{O}_2 \text{ g}^{-1} \text{ min}^{-1}$)				
	Vegetative stage	Flowering stage		Pod maturation stage	
		Control	Stress	Control	Stress
COPH2	5.9	5.2	10.1	11.3	14.2
ICPL12755	5.7	5.2	10.0	11.0	13.9
ICPL12974	5.0	5.1	9.4	10.9	13.9
ICPL11175	5.0	5.0	8.5	10.6	13.7
VBN2	4.6	4.8	8.4	10.6	13.5
VRG62	4.5	4.8	8.1	10.5	13.3
VRG17	4.6	4.6	8.0	10.1	12.8
JKM144	4.0	4.3	7.7	10.0	12.4
JKM185	4.0	4.2	7.5	9.9	12.1
VRG 61	3.9	3.9	7.1	9.6	12.0
VRG54	3.0	3.3	6.8	8.3	10.6
VRG11	2.9	3.0	6.3	8.5	10.5
ICPL11119	3.1	3.5	6.1	8.9	11.1
ICPL11038	3.2	3.7	6.0	9.4	11.4
ICPL11375	3.2	3.0	5.9	8.6	9.8
CO5	3.5	2.7	5.2	8.5	9.8
ICPL4777	3.3	3.1	5.1	8.7	9.5
ICPL6997	2.9	2.5	4.7	8.6	9.9
Mean	4.01	3.99	7.27	2.67	4.91
SEd	0.163	0.156	0.278	0.170	0.277
CD (P= 0.05)	0.344	0.330	0.588	0.360	0.584

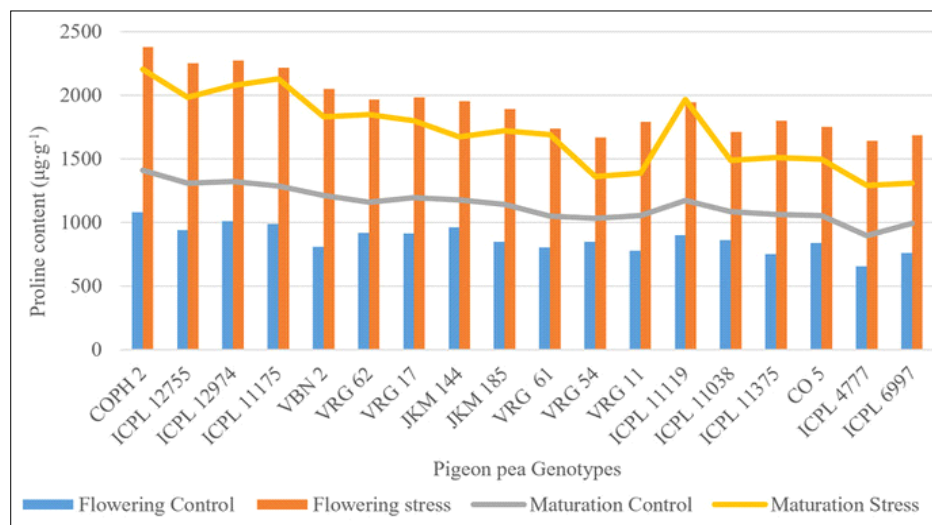


Fig 5: Effect of drought on proline content ($\mu\text{g g}^{-1}$) at different growth stages of pigeon pea genotypes.

evident in their capacity to sustain the number of branches and LAI (Durga *et al.*, 2003).

Number of flowers is an essential traits in determining pod yield. VRG11 had a higher number of flowers compared to ICP 12755 due to relatively higher growth potential. The flower yield was decreased by 16.6 per cent due to water stress. The initial fertilized ovary in an inflorescence suppresses the development of subsequent blooms that appear later in the same inflorescence (Jha *et al.*, 2023).

Variation in pod yield was primarily driven by an increase in the number of pods per plant, which was closely associated with enhanced development of pod-bearing branches. The genotype ICPL12755 exhibited a higher pod count compared to CO5. Drought during flowering have restricted the conversion of flowers into pods, thereby affecting overall productivity.

Drought affects fertility co-efficient, which reflects pod setting percentage. ICPL12755 has a higher co-efficient than CO5 with 25.8% reduction under drought showed. CPH2 had the largest seed production and ICPL6997 the lowest. Seed weight was high in ICPL11119 and low in ICPL11038. The hundred seed weight dropped to 13.6% due to drought stress during blooming and pod maturation. The restricted mobilization of metabolites to reproductive sinks may diminish seed weight. Several plant developmental stages leads to seed yield where CPH2 had the largest seed production and ICPL6997 the lowest. The main cause of yield loss due to drought was due to blossom or pod abortion and drought-induced meiosis impairment. Eventhough floral characters was very good in VBN11 than compared with other genotypes especially CPH2, yield was found reduced due to the drought imposed during pod development stage. CPH2 showed higher yield, due to efficient translocation of starch from leaves to reproductive parts especially under drought condition (Sharma and Garg, 2024; Zhang *et al.*, 2017). Harvest index (HI) measures plant biomass partitioning efficiency towards reproductive parts. CPH2 had a higher HI than JKM 44 dropped 23.3% during drought. A high harvest index substantially correlates with high grain production in pigeon peas.

CONCLUSION

Biochemical and physiological parameters play a critical role in determining pigeon pea yield under drought. Biochemical parameters such as chlorophyll content, soluble protein, scavenging enzymes (catalase, peroxidase), IAA oxidase activity and epicuticular wax were evaluated alongside yield components. Genotypes CPH2, ICPL12755, ICPL12974, ICPL11175, VBN2 and VRG62 consistently demonstrated superior drought tolerance and higher yields. The study highlights that enhanced activity of scavenging enzymes is not only important for drought resilience but also contributes significantly to yield improvement in pigeon pea.

Conflict of interest

There is no conflict of interest.

REFERENCES

- Bakala, H.S., Devi, J., Singh, G. and Singh, I. (2024). Drought and heat stress: Insights into tolerance mechanisms and breeding strategies for pigeonpea improvement. *Planta*. **259**: 123.
- Bates, L.S., Waldren, R.D. and Teare, I.D. (1973). Rapid determination of free proline in water stress studies. *Plant Soil*. **39**: 205-207.
- Bisht, A. and Garg, N. (2023). Harnessing the role of arbuscular mycorrhizae in arresting nodular senescence by modulating osmolyte synthesis and ascorbate-glutathione pool in cadmium stressed pigeon pea. *Plant Growth Regulation*. **102**: 409-427.
- Costa, W.D. and Shanmugathan, K.N. (1999). Effects of irrigation at different growth stages and source-sink manipulation on yield and yield components of mung bean, *Vigna radiata* (L.) Wilczek in dry and intermediate zones of Sri Lanka. *Journal of Agronomy and Crop Science*. **183**: 111-117.
- Durga, K.K., Rao, M.M., Reddy, M.V. and Rao, Y.K. (2003). Effect of early drought stress on morpho-physiological characters and yield of mungbean and urbean cultivars. *Indian Journal of Pulses Research*. **16**(2): 133-135.
- Ebercon, A., Blum, A. and Jordan, W.R. (1977). A rapid colorimetric method for epicuticular wax content of sorghum leaves. *Crop Science*. **17**: 179-180.
- Hasnain, Z., Zafar, S., Usman, S., Zhang, L. and Elansary, H.O. (2023). Elucidating role of melatonin foliar spray in ameliorating adverse effects of drought stress on growth and physio-biochemical attributes of *Brassica rapa* plants. *Scientia Horticulturae*. **321**: 112336.
- Jha, Y., Yadav, K. and Mohamed, H.I. (2023). Plant growth-promoting bacteria and exogenous phytohormones alleviate the adverse effects of drought stress in pigeon pea plants. *Plant and Soil*. **505**(1): 163-183.
- Kosar, F., Akram, N.A., Ashraf, M., Ahmad, A. and Alyemeni, P. (2020). Impact of exogenously applied trehalose on leaf biochemistry, achene yield and oil composition of sunflower under drought stress. *Physiologia Plantarum*. **172**(2): 317-333.
- Loho, L., Jena, N., Mohanty, S.K. and Nedunchezhyian, M. (2025). Stress tolerance in sugar beet under various drought stress cycles. *Indian Journal of Agricultural Research*. **59**(6): 906-913. doi: 10.18805/IJARE.A-6362.
- Lowry, O.H., Rose Brought, N.T., Farr, L.A. and Randall, R.J. (1951). Protein measurement with folin phenol reagent. *Journal of Biological Chemistry*. **193**(1): 265-275.
- Mansoor, S., Kour, N., Manhas, S., Zahid, S., Wani, O.A., Sharma, V., Wijaya, L., Alyemeni, M.N., Alsahli, A.A., El-Serehy, H.A., Paray, B.A. and Ahmad, P. (2021). Biochar as a tool for effective management of drought and heavy metal toxicity. *Chemosphere*. **271**: 129458.
- Murali, R., George, A., Jolly, G.E. and Jincy, M. (2025). Impact and response of drought stress in pigeonpea (*Cajanus cajan* L.): A review. *Agricultural Reviews*. **46**(4): 555-565. doi: 10.18805/ag.R-2713.

- Naderi, S., Fakheri, B.A., Maali-Amiri, R. and Mahdinezhad, N. (2020). Tolerance responses in wheat landrace Bolani are related to enhanced metabolic adjustments under drought stress. *Plant Physiology and Biochemistry*. **150**: 244-253.
- Nicholas, J.C., Harper, J.S. and Hageman, H.S. (1976). Nitrate reductase activity in soybean [*Glycine max* (L.) Merr.]: I. Effect of light and temperature. *Plant Physiology*. **58(6)**: 731-735.
- Panse, V.G. and Sukhatme, P.V. (1954). Statistical Methods for Agricultural Workers. II Edition. ICAR, New Delhi, India, pp. 100-119.
- Parthasarathy, K., Balu, D.R.C. and Rao, P.S. (1970). Studies on sandal spur. VII. Polyphenol oxidase activity and metabolism of sandal (*Santalum album*) in healthy and diseased. *Proceedings in Indian Academy of Science*. **72**: 277-284.
- Porcel, R. and Ruiz-Lozano, J.M. (2004). Arbuscular mycorrhizal influence on leaf water potential, solute accumulation and oxidative stress in soybean plants subjected to drought stress. *Journal of Experimental Botany*. **55(403)**: 1743-1750.
- Sadasivam, S. and Manickam, A. (2015). Biochemical Methods. III Edition. New Age International Publishers, New Delhi, India, pp. 100-101.
- Saman, R.U., Shahbaz, M., Maqsood, M.F., Lili, N., Zulfikar, U., Haider, F.U., Naz, N. and Shahzad, B. (2022). Foliar application of ethylenediamine tetra acetic acid (EDTA) improves the growth and yield of brown mustard (*Brassica juncea*) by modulating photosynthetic pigments, antioxidant defense and osmolyte production under lead (Pb) stress. *Plants*. **12(1)**: 115. doi: 10.3390/plants12010115.
- Samdur, M.Y., Manivel, P., Jain, V.K., Chikani, B.M., Gor, H.K., Desai, S. and Misra, J.B. (2003). Genotypic differences and water deficit induced enhancement in epicuticular wax load in peanut. *Crop Science*. **43(4)**: 1294-1299.
- Sharma, V. and Garg, N. (2024). Nitric oxide and AMF-mediated regulation of soil enzymes activities, cysteine-H₂S system and thiol metabolites in mitigating chromium [Cr (VI)] toxicity in pigeonpea genotypes. *Biometals*. **37**: 185-209.
- Souza, L.C., Monteiro, G.G.T.N., Marinho, R.K.M., Souza, E.F.L., Oliveira, S.C.F., Ferreira, A.C.S. and Okumura, R.S. (2023). Nitrogen metabolism in maize plants submitted to drought, brassinosteroids and azospirillum. *Brazilian Journal of Biology*. **83**: e276264.
- Yoshida, S., Forno, D.A. and Cock, J.H. (1971). Laboratory Manual for Physiological Studies of Rice. International Rice Research Institute. 2nd Ed. Los Bannos. pp: 61-64.
- Zhang, B., Qiao, G. and Wen, X. (2017). Molecular cloning of an S-adenosylmethionine synthase gene from pigeon pea (*Cajanus cajan*) and its expression analysis under arbuscular mycorrhizae fungi colonization and drought stress. *Legume Research*. **40(2)**: 345-350. doi: 10.18805/lr.v0i0.7298.