Clonal plants revealed higher physiological efficiencies in photosystem protection and antioxidant activities than seedling plants of *Pongamia pinnata* to cope with hot summer climate

Badre Alam*, Sukumar Taria, Sushil Kumar, A.K. Handa and A. Arunachalam

ABSTRACT: *Emphasis on trees, especially multipurpose tree species are being given lately for their potential to cope with climatic aberrations across different land use systems including agroforestry. Considering the potential adverse changing climate scenarios and for future preparedness for the promising trees, it is important to understand how the trees will be able to cope with climatic extremities effectively for adapting the environmental constraints. In this direction, the experiment was conducted with the multipurpose biofuel tree species Pongamia pinnata (L.) Pierre at the field of central research farm of Central Agroforestry Research Institute, Jhansi to decipher its physiological efficiencies to get the mechanistic insights during dry hot summer extremities. Major photosystem activities were highly down regulated and the inhibited photosystem functions have been evidenced in the decrease in CO_2 assimilation rate (Pn), effective PS2 quantum yield (Φ_{PS2}), dark adapted maximum potential quantum yield of photosystem-2 (Fv/Fm) and other associated photosystem functioning. Pn, Fv/Fm and Φ_{PS2} in clonal plants during summer were about 70%, 25% and 34% higher than the seedling plants respectively. To cope with oxidative stress, peroxidase activity was about 58% higher in clonal plants in hot summer than the seedling plants. The clonal plants revealed better photosystem activities during the hot summer than the seedling plants indicating the better tolerance potential in it.From our experiment, it has been distinctly observed that the clonal plants maintained better physiological functioning in the hot dry climate by protecting the photosystems from cellular oxidative stress. To cope with hot and dry atmospheric climate comparatively higher physiological efficiencies providing better photosystem protection in clonal plants have been corroborated with the higher antioxidant activities leading to relatively less oxidative damage. The findings will be useful in selection of multipurpose tree species to cope with the climatic constraints.*

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1. INTRODUCTION

Vulnerability of agricultural systems including the land management options has been increased due to the ongoing impact of climate change which often prompts the loss of economy, livelihood and many other constraints in the diverse climates of the world (Leng and Hall 2019). The major impacts of changing climate have been experienced in increasing atmospheric temperature, water non-availability, drought, excess and untimely rain, high greenhouse gases emission *etc.* which are posing threats to normal cropping systems thereby causing many uncertainties in the farm income and livelihood (Troy et al. 2015). High atmospheric dryness and high temperature due to changing climate induce several physiological alterations which ultimately affect the plant growth and productivity.

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Pongamia pinnata (L.) Pierre is an important multipurpose tree species which has gained importance for its varied utility as a source of animal fodder, fuel, manure, timber, traditional medicine for a long time and the most importantly for its seed oil as biodiesel. However, there are research and knowledge gap about the responses of this tree to climatic extremes especially in field conditions for biodiesel production (Doshi and Srivastava 2013). The multipurpose tree species *Pongamia pinnata* (L.) Pierre locally known as "Karanj" can play remarkable role to cope with the changing climate being a valuable source of biofuel. However, emphasis on the trees in this context is gaining momentum lately as most of the attention has been so far, in general, on the crops. Increasing atmospheric dryness, high temperature, extreme in soil water depletion and drought are among the many to be of serious concerned (Ferguson *et al.* 2021; Chavan *et al.* 2021). Use of tree genetic resources for better land use management and environmental perspectives is on larger interest from all the stakeholders in the backdrop of changing

climate and to meet out the urge of sustainable development where efforts for quality planting materials are being envisaged (Sahoo *et al.* 2021). Tree based land use system has all the time supported the sustainability and development in regional and global level (Singh *et al.* 2013). Perennials especially the trees which can't escape the temporal changing environmental extremes are very much vulnerable and it is essential to unravel the intrinsic mechanism of their adaptability for broader perspectives. Due to changing climate scenarios, for future preparedness for the promising trees, it is important to understand how the trees are managing the constraints. Such environmental constraints like extreme hot summer temperature and atmospheric dryness in field conditions can induce critical physiological and cellular inhibitions which need to be tackled by the perennials. This becomes very much relevant for the multipurpose tree like *Pongamia pinnata* (L.) for enhancing its adaptability as the intrinsic mechanistic insights of such plant materials in field conditions for extreme climate is lacking. Thus, the study aimed to understand how the multipurpose biofuel tree species *P. pinnata* (L.) Pierre manage the climatic constraints namely hot summer atmospheric harshness and to get the insights to unravel mechanism of protecting photosystem from cellular oxidative stresses by the tree species.

2. MATERIALS AND METHODS

The studies were conducted on clonal and seedling plants of *Pongamia pinnata* (L.) Pierre in the existing field conditions of central research farm at ICAR-Central Agroforestry Research Institute, Jhansi (25° 27′ N latitude and 78° 35′ E longitude, 271 m above MSL) in the semi-arid region of Central India. The age of the trees were about 13 years and the comprehensive experiments were conducted in the peak summer season of the year 2020 where the maximum air temperature during the peak summer in the month of May hovered around 47°C. Various physio-biochemical traits were investigated for comparative understanding of the physiological responses as the plants were experiencing hot atmospheric dryness.

Physiological and biochemical parameters were estimated following the standard and referred techniques. Most important and vital functions of photosystem activities namely CO_2 assimilation rate (Pn), maximum potential quantum yield of photosystem-2 (Fv/Fm), light dependent photosystem-2 (PS2) quantum yield (Φ_{PS2}) and other associated photosystem functioning were estimated using a portable photosynthesis system (LI-6400XT, Licor, U.S.A.) attached with a leaf chamber fluorometer following the standard techniques (Schreiber *et al.* 1998; Alam *et al.* 2018). Sun exposed, fully expanded and mature green leaves were used for estimation of physiological parameters. For estimation of photosynthetic and photosystem activities, intact leaves attached to trees were used. After the observations recorded for photosynthetic and photosystem activities, the leaves were detached for biochemical estimations. Diurnal variation in leaf water potentials were estimated as per the local standard time (IST). Leaf water potentials were measured taking leaf disc and immediately placed within the leaf chamber (C-52, WESCOR, U.S.A.) connected to the water potential measurement system (PSΨPRO, WESCOR, U.S.A) following standard technique.

Enzyme was extracted from the leaf tissue in phosphate buffer (0.1M, pH 7.0) by grinding with pre-chilled mortar and pestle. The supernatant obtained after the centrifugation at 18000g at 5°C for 15 minutes was used for the enzyme source. The antioxidant defense responses were estimated through antioxidant enzyme peroxidase (POD) activities in leaves using the protocols of Putter (1974). Oxidative damage was assessed by determining the content of malondialdehyde (MDA) in leaves using the technique of Heath and Parker (1968). There were nine replications and the means with standard errors are presented. Statistical significance of the means for each of the parameters were tested using t-test for comparison following standard techniques using MS-Excel software.

3. RESULTS AND DISCUSSION

The primary responses to any environmental changes are manifested in the vital functions related to photosynthetic carbon gain (Tezara *et al*. 2005). The high temperature and atmospheric dryness prevailed during the hot summer had affected the physiological processes in the trees. The photosynthetic photon flux density (PPFD) saturated CO_2 assimilation rate (Pn), maximum potential quantum yield of photosystem-2 (Fv/Fm) and light dependent PS2 quantum yield (Φ_{PS2}) declined. These rates of Pn, Fv/Fm and Φ_{PS2} in clonal plants were about 70%, 25% and 34% higher than the seedling plants respectively (Figs.1, 2, 3). Down regulation in crucial functional process in leaf leads to inhibition in photosynthetic performance which are triggered by climatic constraints (Guo *et al.* 2016). In the present case, hot summer and atmospheric dryness posed the challenges to the tree physiological processes and brought the decrease in crucial functions. Amidst the hot atmospheric climatic

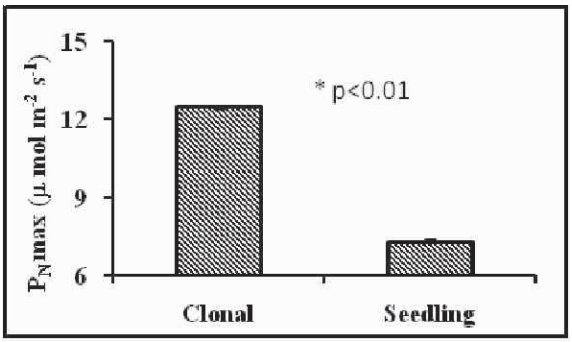

Fig.1 Response in P_N (CO_2 assimilation) of clonal and seedling plants of *Pongamia pinnata* during dry hot summer. * = significant at p<0.01

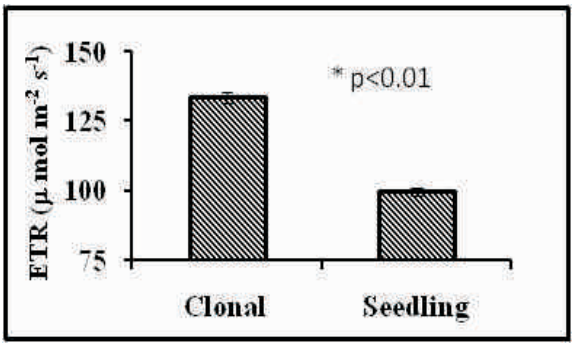

Fig.4 Response in electron transport rate (ETR) across PS2 of clonal and seedling plants of *Pongamia pinnata* during dry hot summer. * = significant at p<0.01

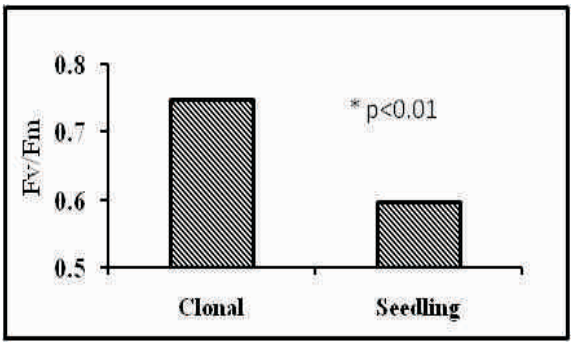

Fig. 2 Dark adapted maximum PS2 quantum yield (Fv/Fm) of clonal and seedling plants of *Pongamia pinnata* during dry hot summer. * = significant at p<0.01

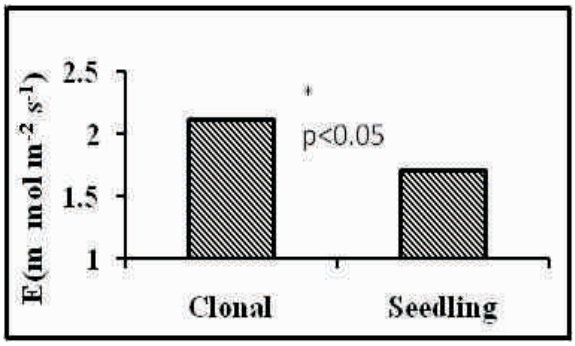

Fig.5 Differential response in transpiration (E) of clonal and seedling plants of *Pongamia pinnata* during hot atmospheric dryness in summer. * = significant at p<0.05

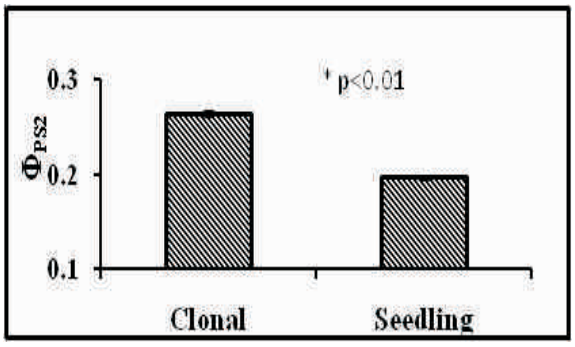

Fig. 3 Effective PS2 quantum (Φ_{PS2}) yield of clonal and seedling plants of *Pongamia pinnata* during dry hot summer. * = significant at p<0.01

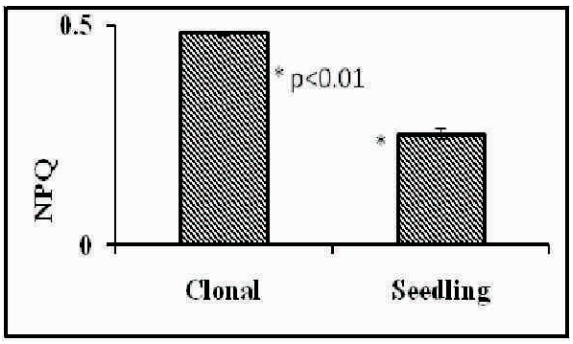

Fig.6 Comparative Non-photochemical quenching (NPQ) of clonal and seedling plants of *Pongamia pinnata* during dry hot summer.* = significant at p<0.01

constraint during summer, the photosynthetic functions in clonal plants have sustained efficiently relatively better than the seedling plants indicating the differential response.

Despite adverse hot climatic situations, the leaf physiological traits in clonal plats maintained comparatively better status than the seedling plants and it was noted to be associated with the phenomena of photosystem protection. Higher electron transport rate (ETR) across photosystem-2 (Fig.4), leaf cooling through transpiration (Fig.5) and higher non-photochemical quenching (NPQ) for heat dissipation (Fig.6) have supported the sustained photosystem and associated vital activities. Sustained ETR and good photochemical responses mainly indicated their contributions in the photosynthetic carbon gain (Alam *et al.* 2018; Mckew *et al.* 2013). Despite dry atmospheric harshness, dynamics of leaf water potentials was better maintained in clonal plants than the seedling plants during the hot summer (Fig.7)

Alongside with the leaf-environment gas exchange phenomena, the other most important event in the cellular event required for maintaining the photosystem integrity is the cellular antioxidant defense system (Stefanov and Terashima 2008). In this direction to get differential insights into these, one of the most important enzymatic antioxidants peroxidase (POD) activity was assayed. It has been observed that POD in clonal plants were about 58% higher than seedling plants (Fig.8).

Higher POD activity protected the photosystems from oxidative damage and such protection was at much higher level in clonal plants than the seedlings. POD played greater role to prevent stress-induced oxidative injury (Ennajeh *et al.* 2009).

Plasma membrane and enveloped organelles are the major target of oxidative stress and the degraded product like malondialdehyde (MDA) is the indication of the level of the cellular injury (Alam and Jacob 2002; Kosar *et al.* 2015). During hot summer, the content of malondialdehyde (MDA) in clonal plants was found about 48% lower than the seedling plants (Fig.9). Relatively higher level of POD and lower level of MDA in clonal plants clearly indicated that mechanism of the photosystem protection during hot summer are very much evidently manifested. Overall, from the findings it has been clearly indicated that the clonal trees have relatively better tolerance potential to cope with the climatic challenges as being experienced in the dry semi-arid region.

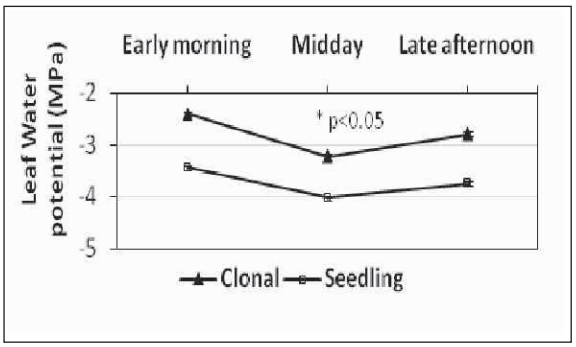

Fig. 7 Dynamics of leaf water potential of *Pongamia pinnata* trees in field during dry hot summer. * = significant at p<0.05

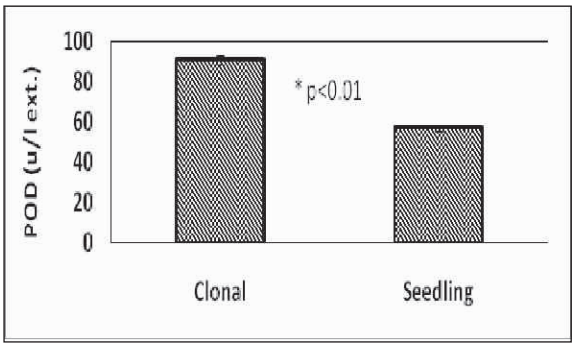

Fig. 8 Comparative antioxidant activities (Peroxidase) in clonal and seedling plants in dry hot summer. * = significant at p<0.01

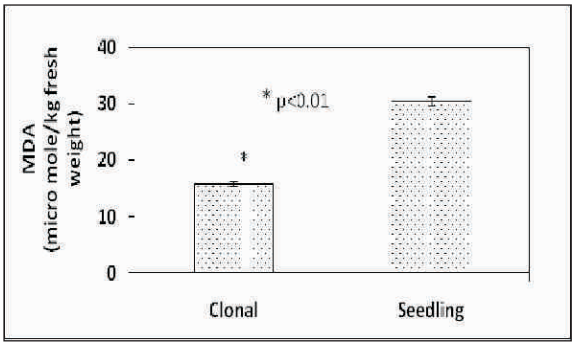

Fig.9 Lipid peroxidation as the content of malondialdehyde (MDA) in clonal and seedling plants in dry hot summer. * = significant at p<0.01

4. CONCLUSIONS

Clonal plants of *Pongamia pinnata* exhibited higher protection mechanism of leaf photosynthetic system through efficient managing of photosystem activities and antioxidant defense system during hot summer. Our results revealed that the clonal trees have relatively better tolerance potential to cope with the adverse very hot summer climate as being experienced in the dry semi-arid region of central India which have greater significance for better coping with environmental constraints through perennials like trees in the perspectives of climate-smart trees in the context of changing climate scenarios.

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REFERENCES

Alam, B., Singh, R., Uthappa, A.R., Chaturvedi, M., Singh, A.K., Newaj, R., Handa, A.K. and Chaturvedi, O.P. (2018). Different genotypes of *Dalbergia sissoo* trees modified microclimate dynamics differently on understory crop cowpea (*Vignaungui culata)* as assessed through ecophysiological and spectral traits in agroforestry system. *Agricultural and Forest Meteorology* 249: 138-148.

Alam, B., Singh, R., Chaturvedi, M., Newaj, R. and Chaturvedi, O.P. 2018. Determination of critical low light limit and adaptive physiological and biochemical traits regulating growth and yield of mustard (*Brassica juncea* Coss.). *Physiology and Molecular Biology of Plants.* 24(5):985-992.

Alam, B. and Jacob, J. (2002). Overproduction of photosynthetic electrons is associated with chilling injury in green leaves. *Photosynthetica* 40(1), 91-95.

Chavan, S.B., Newaj, R., Rizvi, R.H., Ajit, Prasad, R., Alam, B.,Handa, A.K., Dhyani, S.K., Jain, A. and Tripathi, D.2021. Reduction of global warming potential vis -a -vis greenhouse gases through traditional agroforestry systems in Rajasthan, India. *Environment, Development and Sustainability*, 23: 4573–4593

Doshi P and Srivastava G (2013). Sustainable approach to produce bioethanol from Karanja (*Pongamia pinnata*) oilseed residue. *Turkish Journal of Agriculture and Forestry* 37 781-788.

Ennajeh M, Vadel AM, Khemira H (2009) Osmoregulation and osmo protection in the leaf cells of two olive cultivars subjected to severe water deficit. Acta Physiologiae Plantarum 31:711–721.

Ferguson JN, Tidy AC, Murchie EH, Wilson ZA. 2021. The potential of resilient carbon dynamics for stabilising crop reproductive development and productivity during heat stress. Plant, Cell & Environment 44:2066–2089.

Guo YY, Yu HY, Kong DS, Yan F, Zhang YF (2016) Effects of drought stress on growth and chlorophyll fluorescence of *Lyciumruthenicum* Murr. Seedlings. Photosynthetica 54:524–531.

Heath, RL, Parker, L. (1968) Photoperoxidation in isolated chloroplast. I. kinetics and stoichiomestry of fatty acid peroxidation. *Arch. Biochem. biophys.* 125:189-198

Kosar F, Asram NA, Ashraf M (2015) Exogenously-applied 5-aminolevulinic acid modulates some key physiological characteristics and antioxidative defense system in spring wheat (*Triticum aestivum* L.) seedlings under water stress. Afr. J. B. 96:71-77.

Leng G, Hall J (2019) Crop yield sensitivity of global major agricultural countries to droughts and the projected changes in the future. Sci Total Environ 654:811–821

Mckew BA, Davey P, Finch SJ, Hopkins J, Lefebvre SC, Metodiev MV, Oxborough K, Raines CA, Lawson T, and Geider RJ (2013) The trade-off between the light-harvesting and photoprotective functions of fucoxanthin-chlorophyll proteins dominates light acclimation in *Emilianiahuxleyi* (clone CCMP 1516). New Phytol. 200:74–85.

SahooG ,Swamy SL, Singh AK and Mishra A (2021)Propagation of *Pongamia pinnata* (L.) Pierre: Effect of auxins, age, season and C/N ratio on rooting of stem cuttings. Trees, Forests and People 5 (2021) 100091.

Schreiber, U, Bilger, W, Hormann H and Neuberger C (1998) Chlorophyll fluorescence as a diagnostic tool: basics and some aspects of practical relevance, in: Raghavendra, A.S. (Ed), Photosynthesis: A comprehensive Treatise. Cambridge University Press, Cambridge, U.K, pp. 320-333.

Singh, B., Bishnoi, M., Baloch, M. R. and Singh, G. (2013). Tree biomass, resource use and crop productivity in agri-horti-silvicultural systems in the dry region of Rajasthan, India. *Archives of Agronomy and Soil Science,* 60 (8), 1031–1049.

Stefanov D and Terashima I (2008) Non-photochemical loss in PSII in high- and low-light-grown leaves of *Viciafaba* quantified by several fluorescence parameters including L_{NP}, F0/F'm, a novel parameter. Physiol. Plant. 133:327–338.

Tezara W, Marin O, Rengifo E, Martinez D, Herrera A (2005) Photosynthesis and photoinhibition in two xerophytic shrubs during drought. Photosynthetica 43(1):37–45.

Troy TJ, Kipgen C, Pal I (2015) The impacts of climate extremes and irrigation on US crop yields. Environ Res Lett 10:054013. https://doi.org/10.1088/1748-9326/10/5/054013