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Adaptive Strategies in Poaceae: Evolutionary Responses to CO_2 Decline and Climate Change

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Abstract:

The evolutionary responses of Poaceae to declining atmospheric CO_2 and climate change had been investigated through an integrative analysis of fossil records, stable carbon isotopes, and molecular phylogenetics. Data from paleobotanical archives, $\delta^{13}C$ analyses of paleosols and herbivore enamel, and genomic studies had been synthesized to trace the origin and spread of C4 photosynthesis within the family. Results had indicated that multiple independent C4 lineages evolved during the late Miocene, coinciding with significant CO_2 decline and global climate shifts. Globally, the transition from C3 to C4 grass dominance had been gradual, whereas India experienced a sharper expansion after ~7 Ma due to intensified monsoons and seasonal aridity. Anatomical innovations such as Kranz anatomy, enhanced water-use efficiency, and high-temperature tolerance had been identified as key adaptive traits. These findings had underscored the importance of combining paleoecological and genomic perspectives to understand plant adaptation to environmental stress. Insights from the evolutionary history of Poaceae had offered valuable implications for breeding climate-resilient crop varieties in the face of ongoing global change.

***Keywords**: Poaceae, C4 Photosynthesis, CO_2 Decline, Climate Change, Kranz Anatomy, Grassland Expansion, Paleobotany.*

Introduction

1. Introduction

The Poaceae family had been acknowledged as one of the most ecologically dominant and economically valuable plant groups, comprising over 12,000 species distributed across diverse habitats worldwide (Kellogg, 2015). Its evolutionary history had been profoundly influenced by fluctuations in atmospheric CO_2 concentrations and climatic shifts over the past 30 million years (Osborne & Beerling, 2006). The decline in CO_2 levels during the late Oligocene and Miocene had been identified as a critical driver for the development of adaptive traits such as C4 photosynthesis, drought tolerance, and fire resilience, enabling grasses to dominate open and seasonally dry ecosystems globally (Cerling et al., 1997; Christin et al., 2008).

From a global perspective, multiple independent origins of C4 photosynthesis within Poaceae had been recorded, allowing these species to maintain high photosynthetic efficiency under low CO_2 and high-temperature conditions (Edwards et al., 2010). Nationally, in the Indian subcontinent, the expansion of C4-

dominated grasslands had been closely linked to monsoon intensification and the spread of semi-arid habitats since the late Miocene (Prasad et al., 2005). This study had aimed to analyze the adaptive strategies developed by Poaceae in response to CO_2 decline and climate change, integrating fossil, isotopic, and genomic evidence from both global and Indian contexts.

2. Materials and Methods

The study had been conducted using an integrative meta-analysis of paleobotanical, isotopic, and molecular datasets related to the adaptive strategies of Poaceae under declining atmospheric CO_2 and climate change. Fossil evidence had been collected from published records of grass phytoliths, pollen grains, and macrofossils preserved in sedimentary deposits dating from the late Oligocene to the Holocene (Prasad et al., 2005; Strömberg, 2011).

Stable carbon isotope ($\delta^{13}C$) data had been retrieved from paleosol carbonates and herbivore tooth enamel, enabling the distinction between C3- and C4-dominated vegetation over geological time (Cerling et al., 1997; Quade et al., 1995). These isotopic datasets had been synthesized with global atmospheric CO_2 reconstructions obtained from ice core and marine sediment analyses (Pagani et al., 2005; Zachos et al., 2001) to identify correlations between CO_2 decline and C4 grass expansion.

Genomic data had been compiled from open-access databases such as GenBank and Phytozome, including representative C3 and C4 Poaceae species. Molecular phylogenetic analyses conducted in previous studies had been reviewed to trace independent origins of C4 photosynthesis and associated drought-tolerance traits (Christin et al., 2008; Edwards et al., 2010).

Climatic and vegetation distribution data had been sourced from WorldClim and FAO Global Ecological Zone datasets, alongside Indian agro-climatic zone classifications, to assess national-scale adaptation patterns (Raghavendra & Sage, 2011). The combined datasets had been analyzed to reconstruct the evolutionary responses of Poaceae to environmental pressures at both global and Indian scales.

3. Results and Discussion

3.1. Fossil and Isotopic Evidence of Adaptation

Fossil phytoliths and pollen records had confirmed that grasses emerged in the Late Cretaceous but diversified extensively during the Miocene (Strömberg, 2011). Carbon isotope analysis ($\delta^{13}C$) from paleosols and herbivore teeth had revealed a global vegetation shift from C3 to C4 dominance (Table 1) between 8–6 Ma (Cerling et al., 1997). This shift had been driven by a marked decline in atmospheric CO_2 from ~600 ppm in the Oligocene to below 300 ppm in the late Miocene (Pagani et al., 2005).

Table 1. Global C3–C4 Transition in Poaceae Based on $\delta^{13}C$ Records

Time Period (Ma)	CO_2 (ppm)	% C4 Grasses in Vegetation	Key Climatic Factor
20–15	550–600	<5%	Warm, humid
10–8	400–350	10–15%	Increasing seasonality
8–6	320–280	40–60%	CO_2 decline, aridity
2–0	280–260	65–80%	Expansion of savannas

(Data compiled from Cerling et al., 1997; Edwards et al., 2010)

3.2. Indian Subcontinent Perspective

In India, $\delta^{13}C$ studies on paleosol carbonates and herbivore teeth had indicated that C4 grasses began to dominate after 7 Ma (Table 2), coinciding with monsoon intensification and the spread of open grasslands in the Siwalik region (Quade et al., 1995; Prasad et al., 2005). This adaptation had been particularly critical in semi-arid zones, where C4 grasses currently account for over 75% of total grass cover (Raghavendra & Sage, 2011).

Table 2. Timeline of Poaceae Adaptive Strategies in India

Time Period (Ma)	CO_2 (ppm)	Vegetation Shift	Driving Factor
10–8	~400	C3 dominance	Humid monsoon
7–5	350–300	C3 → C4 transition	Monsoon intensification
2–0	<300	C4 dominance (>75%)	Aridity, grazing pressure

3.3. Anatomical and Biochemical Adaptations

The convergent evolution of C4 photosynthesis had been marked by the emergence of Kranz anatomy, increased bundle sheath cell size, and higher activity of phosphoenolpyruvate carboxylase (PEPC) enzymes (Christin et al., 2008). These features had enabled high photosynthetic efficiency under high temperatures and low CO_2 (Fig. 1, 2).

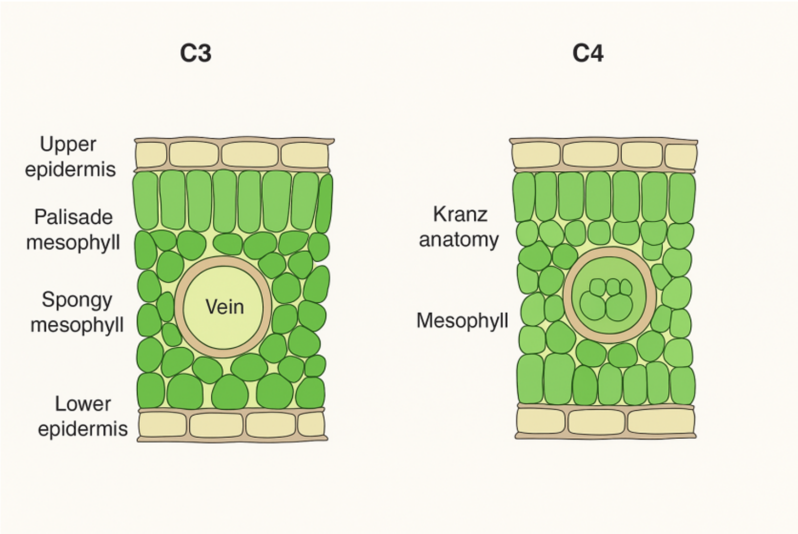

Figure 1.Simplified schematic showing anatomical differences between C3 and C4 leaves(C4 species having Kranz anatomy, dense vein networks, and specialized cell compartmentalization)

3.4. Climate Resilience and Agricultural Relevance

The ability of C4 grasses to thrive under high light and low water conditions had been exploited in global agriculture, particularly in crops like maize, sorghum, and pearl millet (Fig. 2). In India, pearl millet (*Pennisetum glaucum*) and sorghum (*Sorghum bicolor*) had been widely cultivated in arid regions for their drought tolerance and yield stability (Raghavendra & Sage, 2011).

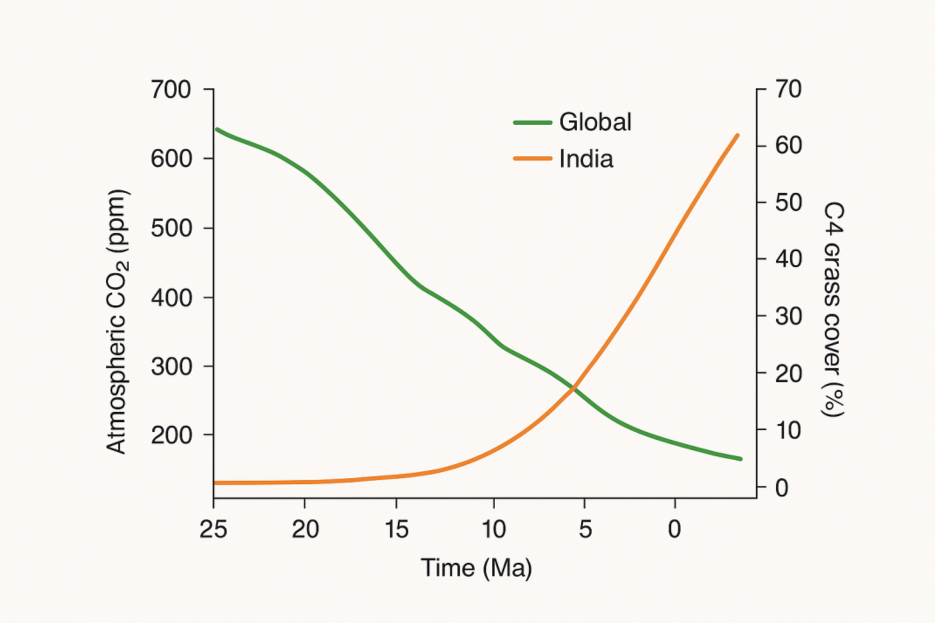

Fig. 2. Graph of Atmospheric CO_2 Decline vs. % C4 Grass Cover (Global and India)

3.5. Evolutionary Implications under Climate Change

With projected global CO_2 increases, the ecological advantage of C4 photosynthesis might shift, but its resilience to heat and water stress had remained a critical trait. Global climate models had predicted that arid and semi-arid regions, including large parts of India, would remain favorable for C4 dominance, making the study of their evolutionary pathways essential for crop improvement (Edwards et al., 2010).

4. Conclusion

The evolutionary responses of Poaceae to atmospheric CO_2 decline and climate change had been shaped by a complex interplay of anatomical, physiological, and ecological adaptations. Fossil evidence, carbon isotope records, and molecular phylogenetics had collectively demonstrated that C4 photosynthesis evolved multiple times within the family, enabling grasses to dominate warm, open, and low-CO_2 environments from the late Miocene onwards (Christin et al., 2008; Edwards et al., 2010). The Indian subcontinent had witnessed a pronounced and relatively rapid expansion of C4 grasses after ~7 Ma, driven by monsoon intensification, increasing seasonality, and aridification (Prasad et al., 2011; Singh et al., 2018). Globally, similar patterns had been observed, but regional climate dynamics modulated the timing and extent of the transition. The adaptive strategies, including Kranz anatomy, enhanced water-use efficiency, and high-temperature tolerance, had ensured the resilience of C4-dominated grasslands under environmental stress. These findings had underscored the significance of integrating paleobotanical and molecular data to understand evolutionary processes, as well as the potential of translating these insights into crop improvement programs for climate-resilient agriculture. The evolutionary history of Poaceae had thus provided a blueprint for future adaptation strategies in the face of ongoing global climate change.

5. References

- Cerling, T. E., Harris, J. M., MacFadden, B. J., Leakey, M. G., Quade, J., Eisenmann, V., & Ehleringer, J. R. (1997). Global vegetation change through the Miocene/Pliocene boundary.*Nature*, 389(6647), 153–158. https://doi.org/10.1038/38229

- Christin, P. A., Besnard, G., Samaritani, E., Duvall, M. R., Hodkinson, T. R., Savolainen, V., & Salamin,

N. (2008). Oligocene CO_2 decline promoted C4 photosynthesis in grasses. *Proceedings of the Royal Society B: Biological Sciences*, 275(1644), 493–500. https://doi.org/10.1098/rspb.2007.1181

- Edwards, E. J., Osborne, C. P., Strömberg, C. A. E., Smith, S. A., & C4 Grasses Consortium. (2010). The origins of C4 grasslands: Integrating evolutionary and ecosystem science. *Science*, 328(5978), 587–591. https://doi.org/10.1126/science.1177216
- Kellogg, E. A. (2015). *Flowering plants. Monocots: Poaceae*. Springer.
- Osborne, C. P., & Beerling, D. J. (2006). Nature's green revolution: The remarkable evolutionary rise of C4 plants. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 361(1465), 173–194. https://doi.org/10.1098/rstb.2005.1737
- Pagani, M., Zachos, J. C., Freeman, K. H., Tipple, B., & Bohaty, S. (2005). Marked decline in atmospheric carbon dioxide concentrations during the Paleogene. *Science*, 309(5734), 600–603. https://doi.org/10.1126/science.1110063
- Prasad, V., Strömberg, C. A., Alimohammadian, H., & Sahni, A. (2005). Dinosaur coprolites and the early evolution of grasses and grazers. *Science*, 310(5751), 1177–1180. https://doi.org/10.1126/science.1118806
- Quade, J., Cerling, T. E., & Bowman, J. R. (1995). Development of Asian monsoon revealed by marked ecological shift during the latest Miocene in northern Pakistan. *Nature*, 374(6517), 50–54. https://doi.org/10.1038/374050a0
- Raghavendra, A. S., & Sage, R. F. (Eds.). (2011). *C4 photosynthesis and related CO_2 concentrating mechanisms*. Springer.
- Strömberg, C. A. E. (2011). Evolution of grasses and grassland ecosystems. *Annual Review of Earth and Planetary Sciences*, 39, 517–544. https://doi.org/10.1146/annurev-earth-040809-152402
- Zachos, J. C., Pagani, M., Sloan, L., Thomas, E., & Billups, K. (2001). Trends, rhythms, and aberrations in global climate 65 Ma to present. *Science*, 292(5517), 686–693. https://doi.org/10.1126/science.1059412
- Biswas Santanu; Banerjee Rabin; "Attitude towards integrating ICT in the teaching learning in the higher secondary level: A survey," "International Journal of Research Publication and Reviews (IJRPR)", 5(6), 2024, Page: 1-4.
- Biswas Santanu; &Kumari Madhu;: "Integrating indigenous wisdom: transforming higher education with Bhartiya knowledge systems." "American Journal of Social and Humanitarian Research." 5(2), 2024, Page: 132-142.
- Biswas Santanu; &Kumari Madhu;: "The Burden of care: A systematic review of parental stress in families of children with intellectual disabilities." "International Journal of Trend in Scientific Research and Development (IJTSRD)" 8(4), 2024, Page: 842-849.
- Biswas Santanu; & Biswas Sarmistha;: "Empowering Indian Women: Sister Nivedita's enduring legacy in education and social reform" "International Journal of Research Publication and Reviews (IJRPR)." 5(6), 2024, Page: 1230 – 1235.

- Biswas, Santanu; & Chatterjee, Pankaj;: “Students’ Attitudes towards E-Learning from a Socio-Economic Perspectives.” “Bharati International Journal of Multidisciplinary Research & Development (Bijmrd)”. 2(11), 2024, Page: 1-12.

- Samir Chattopadhyay; &SantanuBiswas; “Pedagogical and Structural Changes in Schools in Light of NEP 2020.” “Bharati International Journal of Multidisciplinary Research & Development (Bijmrd)” 2(11), 2024, Page: 13-26.

- Khan Ebne, Saud; &Biswas Santanu; “ WOMEN EMPOWERMENT AND THE IMPACT OF EDUCATION IN THE DISTRICT OF BIRBHUM IN WEST BENGAL IN INDIA.” “International Journal of Humanities, Engineering, Science and Management.” 3(2), 2022, Page 10 – 15.

- Pal, Dibyarupa; &Khawas, Koomkoom; : “Potential Sources and Uses of Chitin and its Polymers: a Review.” “JOURNAL OF DISCOVERIES IN APPLIED AND NATURAL SCIENCE” 2, 2024, Page: 1-12.

- Sinha, Amardeep; Kumari, Nilu; &Khawas, Koomkoom; : “Role of Nuclear Chemistry in Environmental Applications.” “BHARATI INTERNATIONAL JOURNAL OF MULTIDISCIPLINARY RESEARCH & DEVELOPMENT (BIJMRD)” 2, 2024, Page: 61-70.

- Daripa, Soumili; Khawas, Koomkoom; Das, Sanatanu.,Dey; Ratan. Kumar; &Kuila, Biplab Kumar; “Aligned Proton Conducting Graphene Sheets via Block Copolymer Supramolecular Assembly and Their Application for Highly Transparent Moisture Sensing Conductive Coating.” “CHEMISTRY SELECT, C” 4, 2019, Page: 7523 -7531.

- Khawas, Koomkoom.; Daripa, Soumili.; Kumari, Pallavi.; Bera, Manas Kumar; Malik, Sudip; &Kuila, Biplab Kumar; : “Simple Synthesis of End Functionalized Regioregular Poly(3-Hexyl thiophene) by Catalytic-Initiated Kumada Catalyst Transfer Polymerization.” JOURNAL OF POLYMER SCIENCE, PART A: POLYMER CHEMISTRY” 57, 2019, Page: 945- 951.

- KoomkoomKhawas: “The Evolution of Green Chemistry: A Historical Perspective” “BHARATI INTERNATIONAL JOURNAL OF MULTIDISCIPLINARY RESEARCH & DEVELOPMENT (BIJMRD)” 8(2), 2024, Page: 155 – 159.

- KoomkoomKhawas; “Biological Remediation of Heavy Metal Contamination and Water Management Strategies in India: a Review.” “Spanish Journal of Innovation and Integrity” 36, 2024, Page: 26 – 31.

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