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Evolution of C4 plants and controlling factors in the Central Himalayas during Late Miocene-Pliocene

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The expansion of C4 plants during the late Cenozoic provides critical insights into the evolution of terrestrial ecosystems in the Himalayas. However, existing documents have predominantly focused on the lower elevation foreland areas, leaving a significant gap in our understanding of the higher altitude hinterland. Aiming the above problem, we conducted a comprehensive analyses of glycerol dialkyl glycerol tetraethers (GDGTs), *n*-alkanes, and their carbon and hydrogen isotopes in Late Miocene-Pliocene sediments at the Dati and Gyirong basins, located in the central Himalayas. We found two distinct phases in the carbon isotope ratios of *n*-alkanes. Phase I (8.0-6.8 Ma) is characterized by a significant positive shift, while Phase II (after 6.8 Ma) is marked by a significant negative shift. The significant positive shift in $\delta^{13}C_{C31}$ indicates a transition from a C3-dominated ecosystem to a mixed C3-C4 ecosystem being consistent with the warm climatic conditions inferred from GDGT-based temperature reconstructions during the Late Miocene-Pliocene. Furthermore, comparison of the temperature recorded between the Dati Basin and the Indian Ocean reveals an increasing sea-land temperature gradient around 8 Ma, which is indicative of the intensification of the South Asian Monsoon (SAM). This interpretation is further supported by compound-specific hydrogen isotope data, exhibited a negative shift at ca.8-6 Ma, reflecting an increase in summer seasonal precipitation. Integrating these findings with previous studies, we propose that the intensification of the SAM was the primary driver of the Late Miocene C4 plant expansion in the central Himalayas. In the second stage, the ecosystem transition from a mixed C3-C4 ecosystem to a C3-dominated one. By comparing the salinity index, we deduced that the decrease of C4 plants seems likely be related to the change of drainage source in the central Himalayas. This study enhances our understanding of the relationship of climatic changes, ecosystem evolution and topographic features in high-altitude regions during the late Cenozoic.