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Application of fossil cuticles in determining palaeoatmospheric CO_2 concentration

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During the last decade stomatal index analysis from fossil leaf cuticles has emerged as a powerful tool in estimating palaeo CO_2 (pCO_2) levels. In India, this particular method has yet not been applied on fossil leaves. In order to reconstruct pCO_2 concentration of the time of deposition of the fossil, this technique is applied on a fossil leaf of *Terminalia catappa* Linn., family Combretaceae which has recently been described from the Upper Siwalik sediments of West Kameng District, Arunachal Pradesh and is considered as of Upper Plio-Pleistocene in age.

IT is necessary to study the past CO_2 concentration in order to understand the future climatic changes. The amount of CO_2 is rapidly increasing in the atmosphere due to industrial revolution and human activities. The rise in temperature is related to the increase in CO_2 level in atmosphere. Thus, this increase in CO_2 is alarming as it is expected to increase the earth's mean temperature by 2–5°C at the end of this century[1]. The increase in temperature is responsible for the melting of glaciers that are ultimately responsible for the rise in sea level. El Nino, the weather phenomenon which caused havoc, displaced many people from their homes and caused about 30,000 deaths in the last decade is also linked with the increase in CO_2 level. Higher CO_2 level causes plants to develop a more extensive root system which allows the plant to exploit more water and nutrients from the soil and therefore, the good effect of the increase in CO_2 concentration is the increase in the productivity of plants due to stimulation in photosynthesis.

Quantifying palaeo CO_2 (pCO_2) is essential in order to understand climatic changes and their effect on global temperature. The instrumental record of CO_2 concentration is available only for the last six decades. Hence, a number of methods have been evolved to reconstruct pCO_2 in the geologic past, each having its own merits, demerits and limitations. The most reliable method for estimation of pCO_2 concentration during Quaternary is the analysis of air trapped in polar ice. However, this method is only applicable for the past 400 ka because of the absence of ice before this time. Though it is difficult to measure pCO_2 concentration directly with the same accuracy before this period, it is possible to measure it from the proxy signals obtained from carbon isotope analysis of palaeosols, peat or marine organic matter; boron isotope analysis of planktonic foraminifera and by modelling the long-term global carbon budget[1]. Recently, stomatal index (SI) analysis from fossil leaf cuticles has emerged as a powerful tool in deducing pCO_2 levels[1–6]. In India, this particular aspect has not yet been touched and we are applying this method on the Indian Pleistocene fossil leaf to reconstruct pCO_2 concentration.

Recently, Joshi *et al.*[7] described a fossil of *Terminalia palaeocatappa* Awasthi and Mehrotra[8] leaf along with its cuticle from the Upper Siwalik sediments of West Kameng District, Arunachal Pradesh. The age of the fossil ranges from the Upper Pliocene to Pleistocene. The fossil was considered similar to the extant species *Terminalia catappa* Linn., family Combretaceae because of the close resemblance in the morphological features of the leaf and cuticle.

Woodward[9] pointed out, on the basis of the herbarium leaf material collected over the past 200 years, that the stomatal frequency of leaves of woody plants is inversely proportional to atmospheric CO_2 concentration. Stomatal frequency is generally expressed either in terms of stomatal density (no. per mm^2) or SI[10] [stomatal density/(stomatal density + epidermal cell density)] × 100. It has been proved through the experiments done by various workers that SI is relatively stable under varying climatic conditions and water supply because changes in the rate of leaf expansion do not affect the ratio between stomata and epidermal cells[1]. Herbarium leaf material of *T. catappa*

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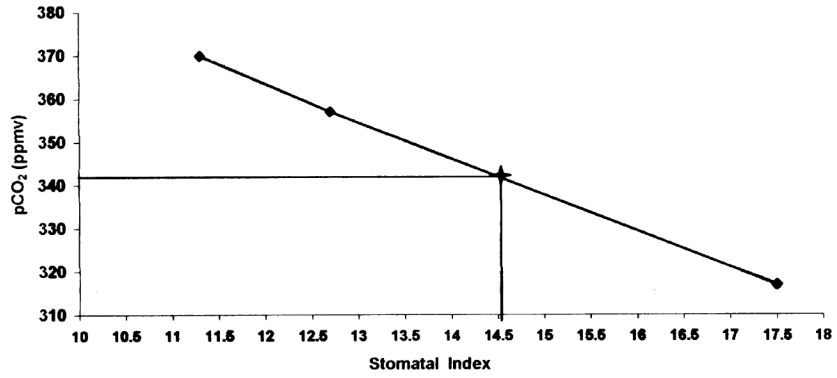

Figure 1. Response of average stomatal index of *Terminalia catappa* to CO_2 concentration and estimation of pCO_2 of the fossil leaf.

Table 1. Stomatal index (SI) and pCO_2 data for extant and fossil leaves of *T. catappa*

Extant leaf	SI#	pCO_2 (ppmv)
2002	11.3	370
1992	12.7	357
1960	17.5	317
Fossil leaf	14.5	342 (estimated)

#SI = [Stomatal density/(stomatal density + epidermal cell density)] × 100.

collected during 1960, 1992 and 2002 was procured to assess its SI response to CO_2 increase in the atmosphere. Quantitative pCO_2 reconstructions can be made by establishing an SI–CO_2 relationship under known pCO_2 for a species; then by using this 'calibration set' it is possible to estimate pCO_2 from the SI of the same species from the fossil record.

A number of readings of SIs of the herbarium leaf material of *T. catappa* were taken into account in order to calculate the average SI. Data are presented in Table 1. A perusal of the table points out that the SI decreases with the increase in CO_2 concentration. A comparison of SI of the fossil (a number of readings were taken from the type material to calculate average SI) with the historical responsiveness of that of the modern leaf clearly indicates that pCO_2 concentration during Upper Plio-Pleistocene time should not be greater than the present value of 370 ppmv. The average SI data presented in Table 1 were plotted on a graph (Figure 1) in order to infer a quantitative estimation of atmospheric CO_2 of the depositional period. When SI of the modern leaf of various ages has been plotted against the known CO_2 concentrations, it shows a linear response and serves as a calibration curve. It indicates that the pCO_2 level was about 342 ppmv during the deposition of the fossil. The result thus obtained is in good agreement with that obtained by means of geochemical methods[1] which point out CO_2 fluctuations between 280 and 360 ppmv. The above method of estimating pCO_2 may not be effective for pre-Cretaceous sites due to its species specific nature. According to Royer *et al.*[6], the error estimates for the Tertiary are ± 10–40 ppmv as stomatal density of trees and shrubs increases with altitude, and fossil leaves showing changes in SI through time are actually recording pCO_2 partial pressure. Therefore, for pCO_2 estimation using fossils from sites at higher altitudes, this technique may not be useful.

It is clear from the present study that SI of fossil angiosperm leaves presents an effective alternative method to measure pCO_2 concentration throughout the Cenozoic. Using the fossil cuticle of *T. catappa* from any time scale, it would be possible to deduce the pCO_2 level of that period. More such evidences, based on different fossil leaf compressions, would help in the accurate estimation of palaeoatmospheric CO_2 concentration.

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