Unwrapping the soot assisted intra-pigment energy transfer in leaves through the thermal lens technique: Time series analysis in nanobiophotonics

Swapna MS[1,2]*, Sankararaman S[1]

(1) Department of Optoelectronics, University of Kerala Trivandrum, Kerala, 695581, India
(2) Laboratory for Environmental and Life Sciences, University of Nova Gorica, Slovenia

*Corresponding author's email: swapnams.opto@gmail.com

Background – The non-destructiveness of an analysing method is most important in the case of biological samples. Intriguing the energy-harvesting mysteries in plants, (photosynthesis) is important as it is the primary biological process that decides the life on earth. In one of our previous studies, the carbon nanoparticle assisted intra-pigment energy transport in leaves has been detailed through the single beam thermal lens (TL) technique [1]. The study revealed the thermal diffusivity variations of the chlorophyll system with varying concentrations of carbon nanoparticles. The present study is the first attempt of employing the mathematical and statistical tool – Time series analysis (TSA) to the novel interdisciplinary branch Nanobiophotonics. Here, the influence of soot nanoparticles in the energy transport mechanism of the leaf pigments is explored using the sensitive and non-destructive TL technique. The TL signal being a treasure of information regarding the medium of lens formation [2,3], it is found to have applications in studying the thermal diffusivity of materials, trace element and adulterant detection, quantum yield studies, biomedical analysis, pharmacology, and in thermal engineering [2,4,5].

Methods – The diesel soot containing carbon nanoparticles (CNPs) are prepared in different concentrations (0.10, 0.20, 0.60, 1.25, 2.50, 4.00, and 5.00 g/l) and are sprayed over the leaves of *Lablab purpureus (L.) sweet.* The chlorophyll pigments are extracted [6] from the leaves after ten days the UV-Vis absorption spectrum is recorded. The leaf extracts are subjected to laser-assited TL study, and the TL signals recorded are analysed by nonlinear time series and fractal techniques.

Results: The UV-Vis absorption spectrum of the samples shows a decrease in the intensity of the signature peaks (430 nm and 660 nm) of chlorophyll for the soot concentrations up to 0.60 g/l, increases up to 1.25 g/l and saturates after that. For the TSA of the TL signals of each sample, phase portraits are constructed after finding the optimal time delay and embedding dimension. A representative phase portrait for the soot concentration 5 g/l is shown in Fig. 1(a). The phase portrait, sample entropy (S), fractal dimension (FD), and Hurst exponent (H) show a variation in the randomness, disorder, complexity and antipersistence nature with the increase of soot concentration. The analysis becomes more easier when the graphs are divided into 3 regions based on the soot concentration (Fig. 1(b)). The range of soot concentrations 0 to 0.60 g/l, 0.60 to 2.5 g/l, and 2.5 to 5 g/l are considered as region 1, 2, and 3 respectively. Region 1 shows an increase of S and FD, in agreement with the phase portrait, due to the increased rate of out-flow of energy created due to thermal inequilibrium between the leaf system and the surroundings. In region 2, the values of S and FD decreases, indicating the energy trap by the soot nanoparticles in the chloroplast. The observed lowering of the spread of phase points agrees well with the reduced particle dynamics as revealed through S and FD. Here, the energy absorbed by the CNPs in soot is transferred to the leaf pigments, thereby facilitating intra-pigment energy transport among leaves. We have already reported the CNP assisted intra-pigment energy transport enhancing the photosynthesis rate [1]. In region 3, the UV-Vis absorption spectrum shows a near saturation, which gets reflected in the time series parameters and fractal dimension computed from the TL signal. The saturation of S and FD values for the concentrations in region 3 indicate the non-usefulness of such a CNP concentration in the intra-pigment energy transport. The rising and saturation of S and FD throw light into the intriguing particle/molecular dynamics resulting from increased energy dissipation.

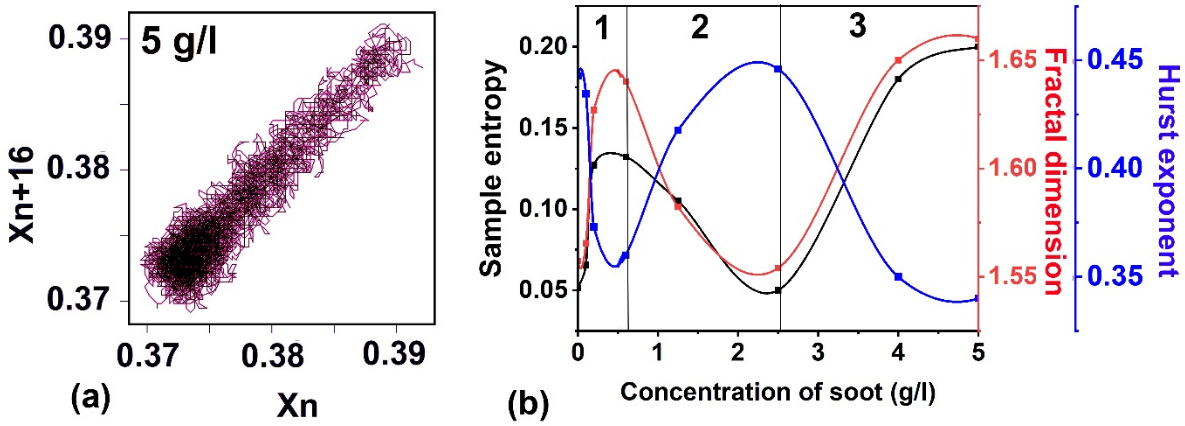

Fig. 1. (a) A representative phase portrait for the soot concentration 5 g/l and **(b)** variation of S, FD, and H with soot concentration.

Conclusions – Thus, the study proposes an optimum concentration of CNPs beneficial to leaves in the intra-pigment energy transport and suggests a possible yield enhancement method from crops. The entropy minimization and its analytical techniques open up its potential application in artificial photosynthesis and dye sensitized solar cells.

References

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