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A step forward towards advanced and self-sustainable greenhouse agriculture

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Abstract

It is now time for the future-generation and advanced greenhouse design practices to address a range of issues, from the energy and land use efficiency to providing plant-optimised growth techniques. In this Encyclopaedia record, we report on the practical development of spectrally selective and specialist-type advanced metal-dielectric thin-film filters that produce the optimized illumination spectrum when exposed to natural sunlight that can help maximize the biomass productivity of coated-glass greenhouse crops. Our experimental case study has been performed for the lettuce species, *Lactuca sativa*, L., yielding promising results.

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According to the United Nations Food and Agriculture Organisation (UN FAO), by the 2050, the world population can be 39% bigger than that of 2006, which can potentially lead towards a food crisis, due to large population along with other basic needs and requirements, such as energy and electric power. The world population, as well as the agriculture industry, will benefit, if the greenhouse crops could be mass-produced with minimal energy use, in an efficient manner, while maintaining the nutritional quality, simultaneously with achieving increases in the biomass growth productivity. Advanced growth technologies, such as innovative greenhouse production methods, e.g. spectrally-shaped illumination for plants, are widely expected to provide the practical solutions in the near future[1][2][3][4][5].

We experimentally determined the wavelength range(s) of visible electromagnetic radiation using an artificial combination-wavelength light source that are required to obtain improved biomass productivity in the plants like lettuce. After that, based on the obtained spectral illumination filtering results, we designed and developed thin-film optical filters for application to glass for use on the roof or walls of greenhouses. The thin-film optical filter will pass through only the solar spectral components required for optimized biomass growth of the sample plant (lettuce). Alternatively, the same thin-film components can be used to filter a range of broad-bandwidth artificial light sources used at night time, to further boost the overall greenhouse productivity, simultaneously with reducing the heat load inside greenhouses, due to reflecting the far-infrared wavelengths back into the atmosphere. Figure 1 (reproduced from Ref.[6]) shows a metal-dielectric thin-film filter developed at the Electron Science Research Institute's (ESRI) nano/micro fabrication cleanroom labs. This special type of spectral filter can usefully modify the incoming natural sunlight for plant growth applications.

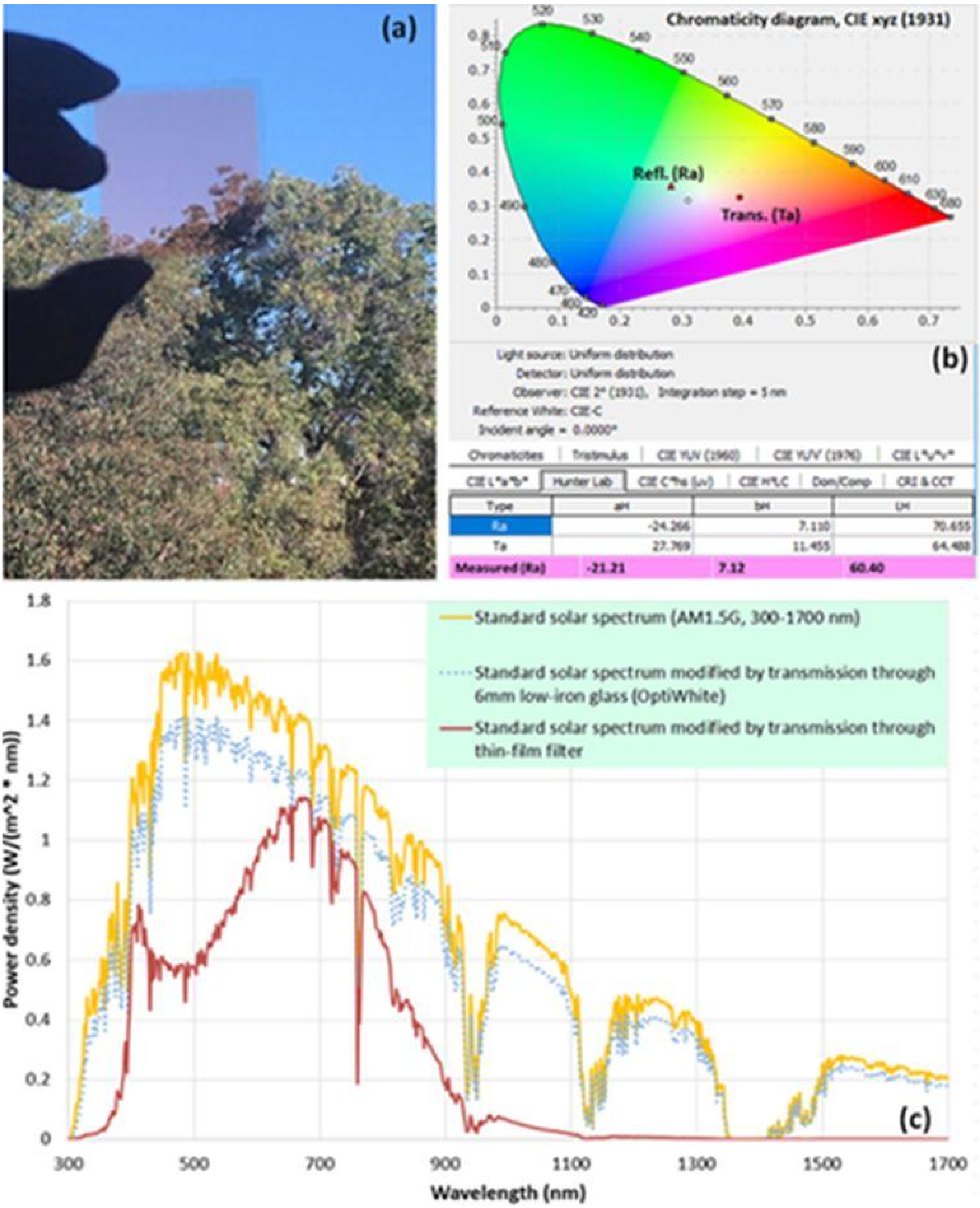

Figure 1: (**a**) filter image taken with the sample placed next to the glass of a conventional window; (**b**) filter chromaticity diagram, modeled in both the transmission and reflection; the measured reflected-colour Hunter Lab parameters (L, **a**, **b**) are also shown; (**c**) spectral modification of the natural sunlight (standard AM1.5G spectrum) on transmission through either the low-iron ultraclear 6mm glass, or through the thin-film filter developed.

Lactuca sativa L. was considered as a reference plant for use in the experimental investigation, since it is a quantitative long-day plant at high temperatures and a day-neutral plant at low temperatures[7]. Lettuce can be cultivated in long day growth mode, although it is a long-day plant, because premature flowering effects can be controlled by using an appropriate air temperature. Production yields can be maximized, provided that both the irradiation timing and the ambient temperature are optimally controlled, when the length of day exceeds the length of night that the plant is detecting. A detailed background literature study together with all relevant experimental procedures and test results are explained in detail, and are available in the recently published preprint[6]. Figure 2 shows a presentation of raw data on the dry biomass obtained from each of the samples in each of the grow tents, together with the graphical analysis of the relevant data distributions and statistical analysis parameters.

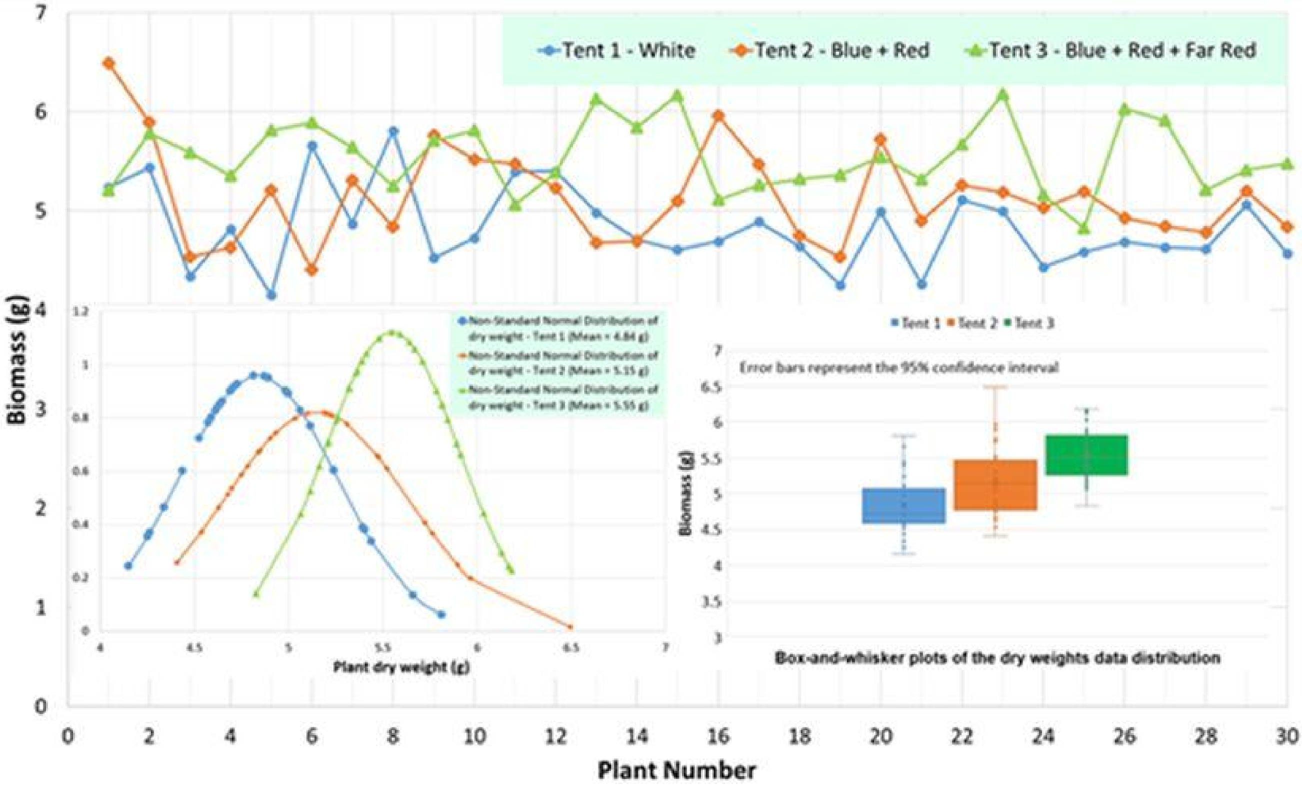

Figure 2. A graphical presentation of relevant statistical data analysis results for each of the grow tents, and the biomass distributions obtained from each plant within each tent (a total of 90 plants used in the study).

A comprehensive study has been conducted to optimize the wavelength range of the visible light that can improve the biomass growth of the sample plant *Lactuca sativa,* L.

A passive solar thin-film filter design suitable for use in existing low-emissivity energy-harvesting solar window products has been prototyped for use in agricultural greenhouses. It can be expected that future lettuce growth experiments in advanced photovoltaic pilot greenhouses using spectrally-optimized solar windows will reconfirm the biomass improvement results reported.

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Keywords

Greenhouse agriculture; Lactuca sativa; spectral optimization; energy efficiency