Scalable Light-managing Films for Enhanced Greenhouse Productivity

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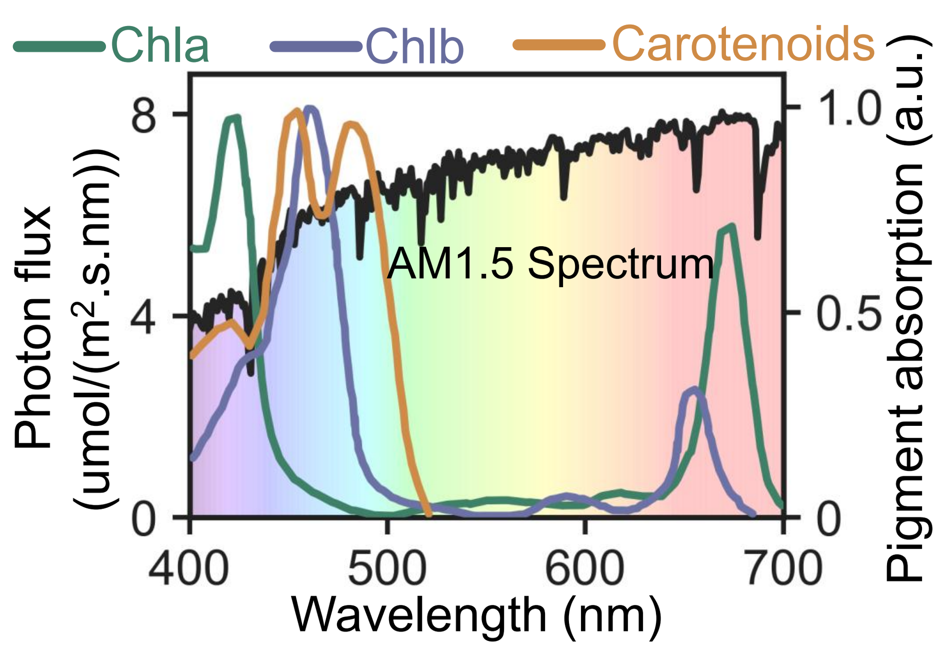
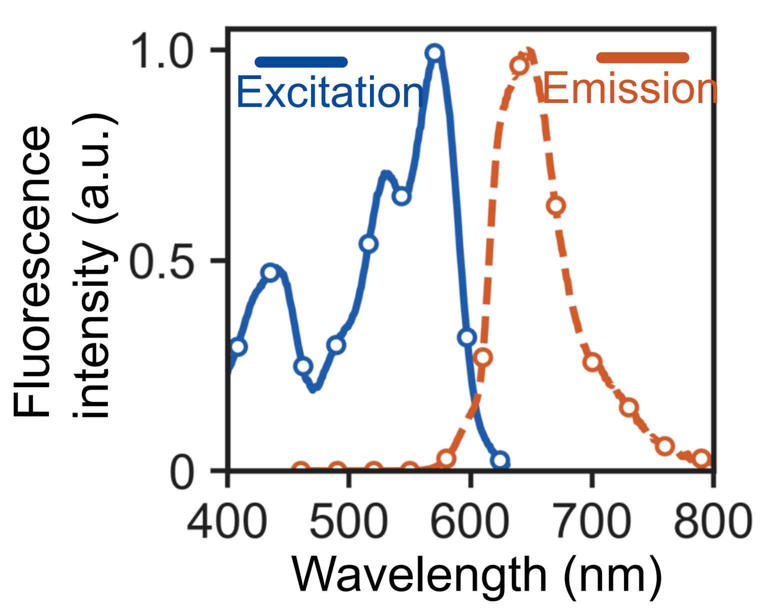
1. Introduction

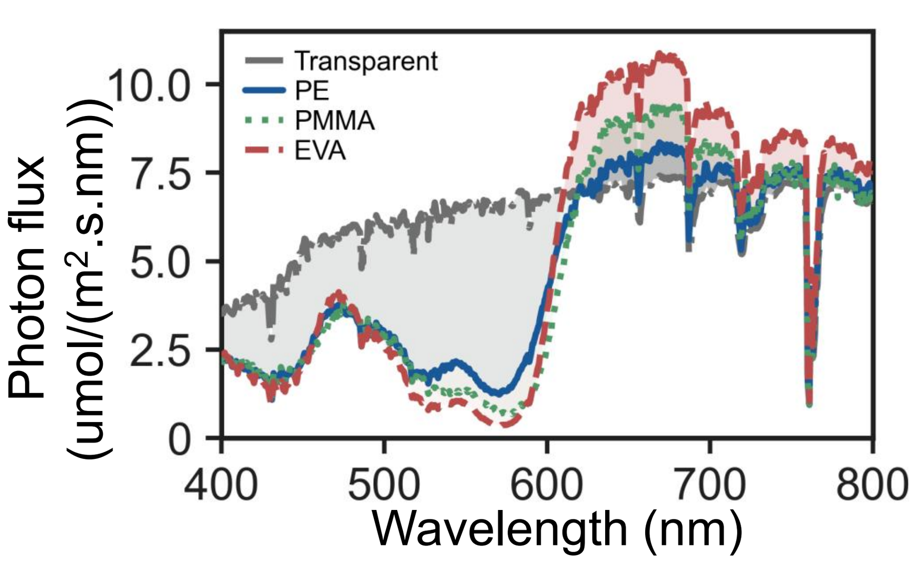
Not all spectral components of sunlight contribute equally to photosynthesis. The primary light-harvesting pigments in plant leaves absorb strongly in the blue and red regions, with red light being particularly effective. However, green light, which accounts for approximately 35% of incident photosynthetically active radiation (PAR), is less efficiently utilized and largely reflected.
Spectral-shifting materials that convert green light into more photosynthetically active red light therefore offer a passive strategy for enhancing crop photosynthesis. However, previously reported light-converting films have been limited by total internal reflection, which traps emitted photons within the films.
We previously demonstrated a microstructured photonic film fabricated using a facile solution-based method. Nevertheless, the rigid matrix and mold-based structuring process hindered its large-scale greenhouse integration. Here, we demonstrate a scalable pathway toward agricultural light-management films by combining a sandwich-structured material design with randomly textured surfaces.

2. Methods

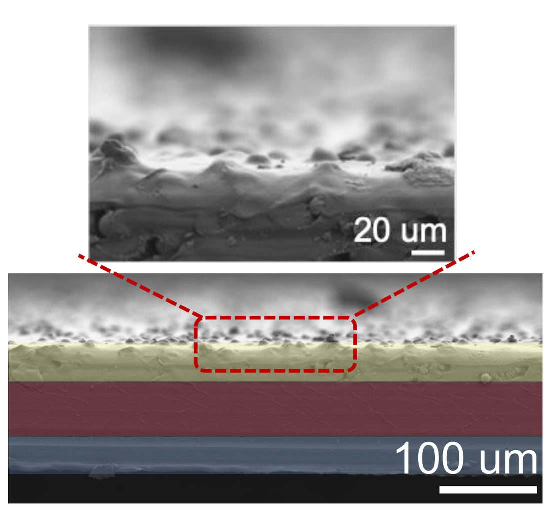


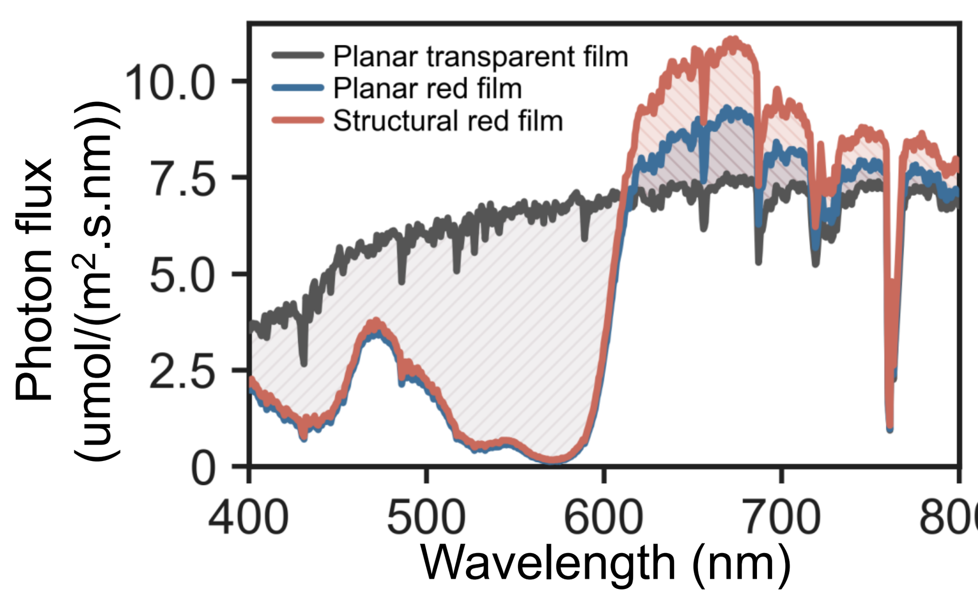


- An obvious mismatch between the natural light spectrum and the absorption spectra of light-harvesting pigments in plant leaves.
- Fluorescence converts less efficiently utilized green light into more active red light, thereby enhancing photosynthesis.



- The matrix environment significantly influences the emission of organic dyes.
- Identifying EVA as the optimal matrix for red-light emission, outperforming PMMA, a commonly used material in fluorescence applications.

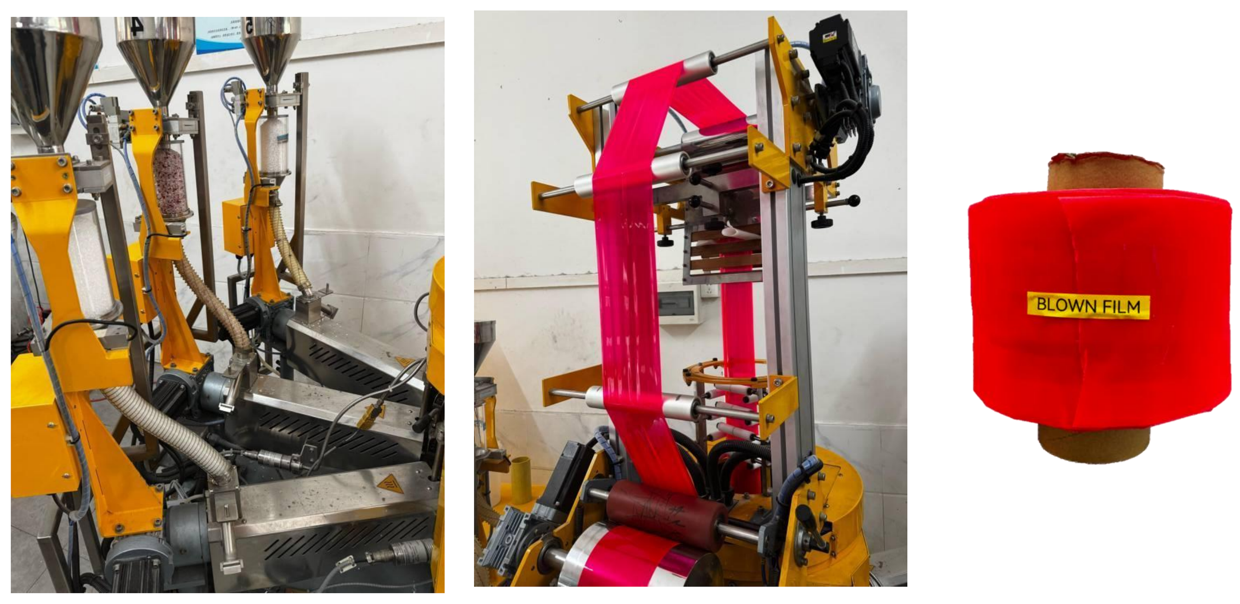




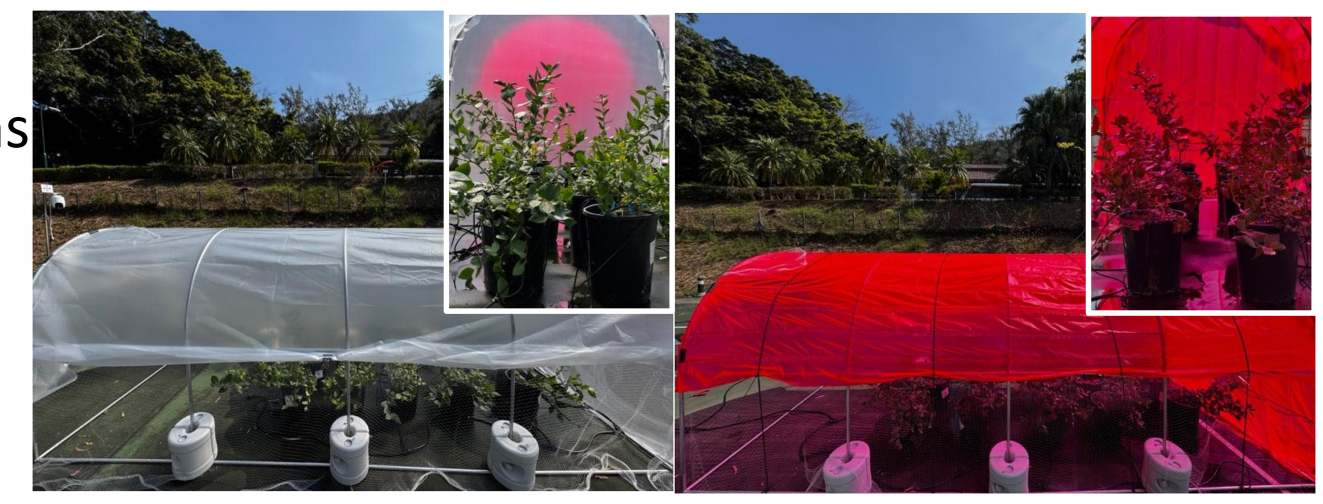
- Previous mold-based structuring limits film width and throughput.
- Particulate additives create randomly distributed surface structures, enabling efficient photon extraction.
- This approach is compatible with blown-film processing and readily scalable for large-scale production.

3. Mass Production & Field Deployment

Multilayer co-extrusion blown-film processing.

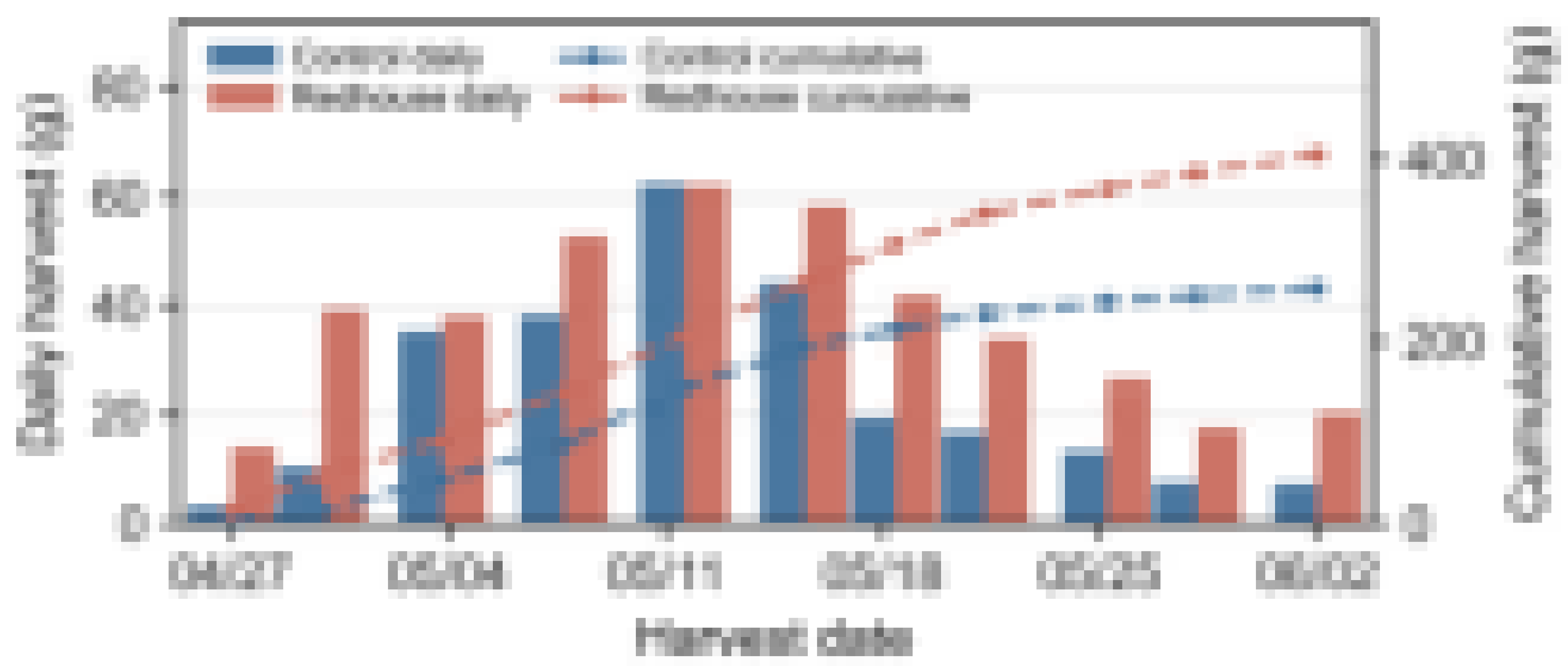


Freestanding films for low-tunnel deployment over blueberry crops.



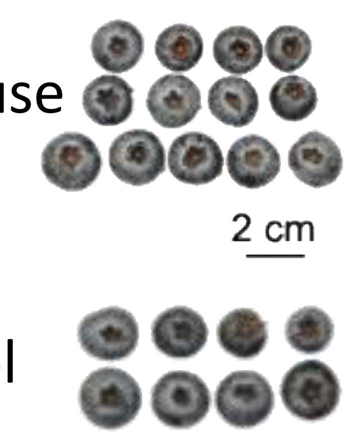
- High-throughput multilayer coextrusion blown-film manufacturing
- Low-tunnel field trials for blueberries
- Direct scalability to industrial production

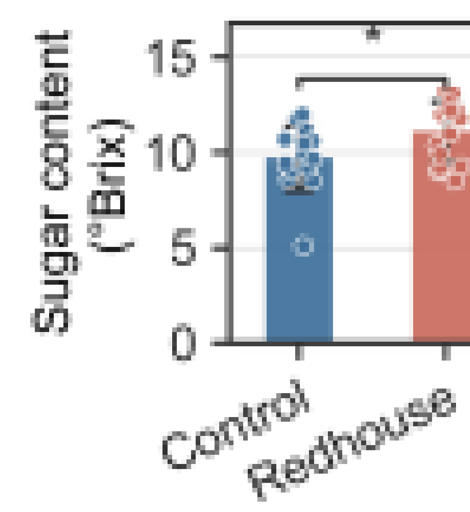
4. Results

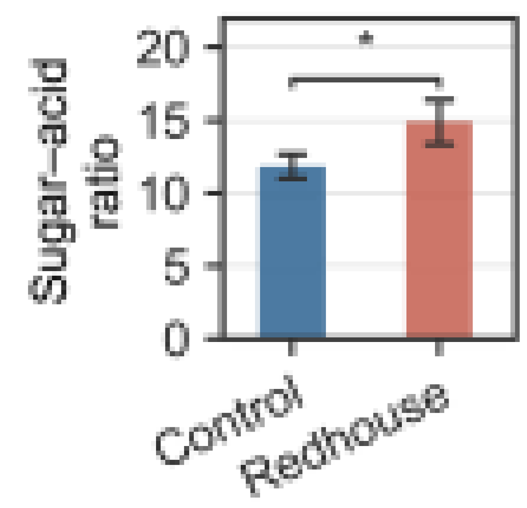


Redhouse

Control







- Earlier coloration and ripening with an extended harvest period
- Over 50% increase in cumulative yield
- Significantly higher sugar-to-acid ratio and improved fruit flavor

5. Conclusions

In this work, we demonstrate enhanced photosynthesis and biomass production in plants, including blueberries, through fluorescence-based spectral conversion and improved interfacial light extraction. In particular, the film can be fabricated using a scalable blown-film process, enabling large-scale production and subsequent deployment in greenhouse applications. Its performance was also preliminarily validated in a low-tunnel cultivation system. This film offers an efficient and scalable strategy for increasing crop productivity, highlighting its potential for practical agricultural applications.

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