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Monochromatic Red LED Light Supplementation: A Dual Solution for Disease Resistance and Yield Enhancement in Glasshouse Production in New Zealand

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Summary

This paper explores the potential of monochromatic red-light supplementation as a sustainable and innovative solution to challenges in greenhouse production, including low winter yields and high disease pressure. Greenhouse cultivation systems, though efficient, often rely heavily on chemicals for disease control, posing environmental and health risks. Monochromatic red light, delivered through energy-efficient LED systems, has been shown to enhance plant immunity by inducing secondary metabolite production and activating defence pathways, reducing the need for chemical interventions. Drawing on recent studies and ongoing research at Lincoln University, this paper emphasises the need for further investigation into the role of red light in improving crop yield and quality while minimising environmental impact. Our preliminary trials with lettuce plants suggest promising outcomes, laying the groundwork for sustainable disease management strategies that align with New Zealand's goal of promoting environmentally responsible agriculture.

INTRODUCTION

Greenhouse (GH) cultivation systems are rapidly becoming essential components of modern agriculture due to their ability to maximise crop yields in controlled environments. These systems are especially beneficial in regions with challenging climates such as New Zealand, where off-season and year-round production are vital to meet domestic and international market demands. For example, New Zealand exports significant quantities of fresh produce, including capsicum and tomatoes, with 4,394 tonnes of fresh capsicum and 3,304 tonnes of fresh tomatoes exported in 2021 alone (Aitken & Warrington, 2020). Greenhouse cultivation allows for precise control over environmental factors such as light intensity, temperature, CO_2 levels, water, and nutrient supply, which are all essential for optimising plant growth and maximising crop yields.

However, despite the many advantages, greenhouse production faces several challenges, particularly during the colder winter months. The reduced natural light during this time, combined with the need for heating, makes off-season production expensive. Using supplementary LED (Light Emitting Diodes) lighting can help overcome the low crop yield in winter as LEDs are compact, energy saving light source that can provide specific wavelengths for plant photosynthesis as well as specific photoreceptor-mediated reactions, finally aimed at maximizing plant growth and light-driven metabolite accumulation (Landi et al., 2020). Many growers in New Zealand are already using this technique to extend photoperiod in winter months, for example, tomato grower Gourmet Mokai, are using Philips LED lighting to increase the production during winter (Vogrincic, 2018).

Another pressing issue in greenhouse production is pest and disease management. Greenhouses provide a controlled environment that can also be a haven for various pests, including whiteflies (*Trialeurodes vaporariorum*), aphids, and fungal pathogens such as *Botrytis cinerea* and powdery mildew (*Sphaerotheca fulginea*). These pests and pathogens thrive in the warm, humid conditions typical of greenhouses, posing a significant threat to crop health and yield. Integrated pest management (IPM) programmes, timely monitoring and use of biological control agents can help to reduce the insect pest population in the glasshouse, but the disease pressure is still majorly dealt with using chemical sprays. As per Manktelow et al. (2005) New Zealand agriculture uses around 3,400 tonnes of agrichemicals (including herbicides, fungicides and pesticides) active ingredients annually. And a huge amount of these (up to 51%) are presumed carcinogens that can increase the risk of cancer in people working closely with pesticides.

Considering these challenges, there is an increasing need to explore alternative, more sustainable methods for enhancing plant growth and protecting crops from diseases. One such promising solution is the use of monochromatic LED light supplementation. LED lighting allows growers to provide specific wavelengths of light that not only support photosynthesis but also influence plant physiology in ways that can enhance plant health and disease resistance (Landi et al., 2020). Recent research suggests that specific wavelengths of monochromatic light, particularly red and far-red light, can trigger plant responses that increase secondary metabolite production, which can strengthen the plant's natural defence mechanisms against pathogens (Gallé at al., 2021). For instance, studies have shown that exposure to far-red enriched light can protect tomatoes from *Botrytis cinerea* (Mihaly Cozmuta et al., 2016), similarly, red light has been found to reduce the incidence of fungal infections in strawberries (Lauria et al., 2023).

Here in this paper, I briefly discuss the potential of monochromatic red-light supplementation as a promising and sustainable approach to greenhouse disease management and crop production. Drawing on insights from recent studies and ongoing research at Lincoln University, the work underscores the need for further investigation into the role of red light in enhancing plant immunity and reducing reliance on chemical pesticides.

Monochromatic red-light supplementation: A sustainable approach

In greenhouse environments, the primary challenge is often maintaining optimal light conditions for plant growth. Light intensity and photoperiod (the duration of light exposure) are critical factors influencing plant growth, yield, and overall health. During the winter months, when natural light is limited, it becomes necessary to supplement the light supply using artificial lighting. While conventional grow lights, such as high-pressure sodium (HPS) or metal halide lamps, have been used extensively in this role, they are energy-inefficient, produce significant heat, and are not always tailored to the specific light needs of plants (Katarzyna et al., 2020).

In contrast, LED lighting provides a highly energy-efficient alternative. LEDs consume less energy while offering precise control over light intensity, spectrum, and duration, all of which can be optimized for plant growth. The ability to use specific wavelengths is particularly important. For instance, blue light (around 450–495 nm) is known to enhance photosynthesis and regulate plant growth, while red light (around 640–680 nm) has been found to promote flowering, fruiting, and secondary metabolite accumulation (Human, 2023; Landi et al., 2020) (**Fig. 1**).

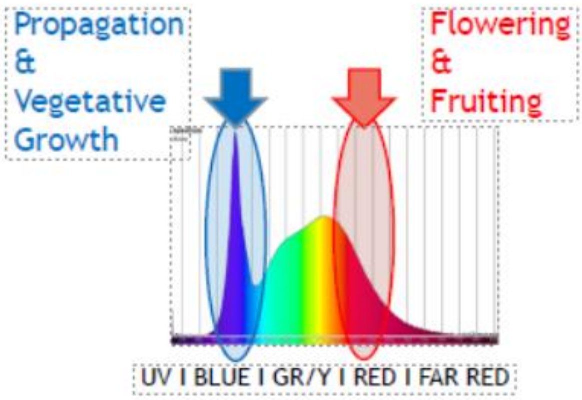

Figure 1. Monochromatic light spectrum and its influence on plant growth. Source: Human, 2023.

Beyond the energy savings, one of the most promising aspects of monochromatic LED light supplementation is its ability to influence plant immunity and disease resistance, particularly red light. Plants have various photoreceptors that perceive light as an informational signal, such as red/far-red light sensing phytochromes, blue light sensing cryptochromes, and phototropins and UV-B receptor UVR8 (Gallé et al., 2021; Landi et al., 2020). When plants are exposed to red light, the cytosol localised inactive phytochrome (Pr) changes to active far-red light absorbing form (Pfr), which can induce physiological responses in plants through the transcriptional regulation of various genes (Gallé et al., 2021). These physiological responses can enhance plant defence by activating signalling molecules such as salicylic acid and induce the production of secondary metabolites like flavonoids and phenolic compounds, which are known for their antioxidant properties (Su et al., 2017).

Several studies have shown that red light supplementation in green house crops can improve disease resistance, for instance, (Hui et al., 2017) showed that *B. cinerea* induced lesion development was significantly reduced in detached tomato leaves when exposed to red light for 4 days as compared to leaves in dark. Additionally, red light exposure significantly decreased the superoxide and H_2O_2 content and enhanced antioxidant enzyme activity of SOD, CAT and POD after 2 days of *B. cinerea* infection in detached tomato leaves (Hui et al., 2017). Similarly, (Meng et al., 2019) showed that strawberry leaves when developed under red light are more resistant to *Botrytis* infection as compared to when developed under white, blue, and blue+red lights. A recent study by (Lauria et al., 2023) showed that strawberry plants exposed to red light supplementation showed higher fruit yield, and lower disease severity in harvested strawberries at 36 hours post inoculation as compared to white, blue, green or no light supplementation treatments. Enhanced disease resistance in post-harvested strawberries was linked to induction of secondary metabolites and the upregulation of defensive genes in plants exposed to red light supplementation (Lauria et al., 2023). Thus, monochromatic light supplementation offers a two-fold advantage: increasing crop yield while simultaneously reducing disease incidence and the need for chemical pesticides.

In response to the growing need for sustainable disease management in New Zealand's greenhouse production, researchers at Lincoln University, including Prof. Rainer Hoffmann and Dr. Gagan Jain, are collaborating with Assoc. Prof. Marco Landi from the University of Pisa. Together, they are investigating the potential of red-light supplementation in greenhouse production systems. This project is supported by the Royal Society Catalyst Grant (Grant reference number: 23-LIU-002-CSG).

The objectives of this project are to:

- Develop a collaborative research and development plan with the University of Pisa to explore the effects of monochromatic light on disease management in greenhouse crops.
- Identify and standardise optimal supplementary lighting techniques for controlling specific pests and diseases across various greenhouse cropping systems in New Zealand.
- Translate these findings into an innovative and sustainable mechanism for managing diseases in greenhouse production.

An initial experimental trial has been established in the nursery glasshouse at Lincoln University. In this study, lettuce plants are subjected to two treatments: supplementary red light and no supplementary light, over a period of 10 weeks. The supplementary red light is provided at an intensity of 250 µmol/m²/s for 5 hours daily (from 11:00 a.m. to 4:00 p.m.).

Preliminary results indicate that lettuce plants exposed to supplementary red light, for four weeks, have accumulated **20% more biomass** compared to those without supplementary light (**Fig. 2**, results unpublished). In the next phase, these plants will be inoculated with a *Botrytis* spore solution to assess disease severity in the red light-treated plants versus those grown under standard conditions without supplementary light.

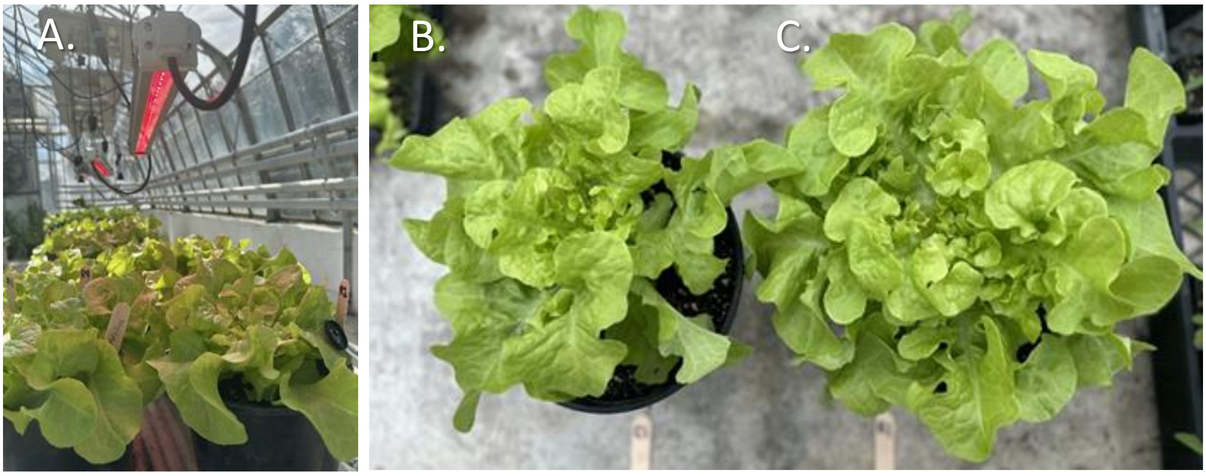

Figure 2. A) Plants exposed to supplemented red light, in Lincoln University glasshouse. **B**) Plants exposed to no light supplementation, and **C**) red-light supplementation for four weeks.

CONCLUSION

In conclusion, monochromatic LED red light supplementation can present a sustainable and innovative approach to addressing some of the key challenges in greenhouse production. It can offer a viable solution to increase crop yield and quality while reducing disease pressure, minimizing pesticide use, and promoting environmental sustainability, which aligns with New Zealand's broader goal of sustainable agriculture. Further research and practical implementation of this technology could pave the way for transformative advances in greenhouse production systems.

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