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Interactions between Far-Red Light and Blue–Red Spectra on Growth, Pigment Content, and Mineral Composition of Hydroponic Lettuce Cultivated in a Vertical Farming System

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INTRODUCTION & AIM

Lettuce is one of the most important economic vegetables in the world. It can be grown in vertical farm system, which is a promising alternative, especially in urban areas where space is limited. This system allows the production of high quality and nutritional value products with minimum water consumption, using LEDs as energy-efficient light sources (Budavári et al. 2024).

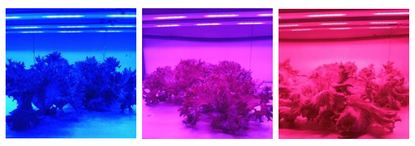
The use of LED lights in vertical farms emerges as an alternative to increase the nutritional parameters of horticultural plants by contributing to the production of nutraceutical compounds (Nájera et al. 2022). The most commonly used light spectra are blue (450-495 nm) and red (620-700 nm) (Nájera et al. 2022; Wong et al. 2020). Both directly impact photosynthesis and indirectly influence plant architecture that favors light interception, promoting photosynthesis (Lee et al. 2024; Wong et al. 2020). A higher blue light correlates with elevated phytochemicals, whereas red light enhances overall biomass (Van Brenk et al., 2025).

The inclusion of non-PAR light spectra such as far red (FR) light has shown promising results in improving crop yields. The addition or a higher fraction of FR in the spectrum enhanced fresh and dry biomass, leaf area (Kelly and Runkle 2024), and height of lettuce plants (Lee et al. 2019). However, FR light could have an inhibitory effect on the accumulation of chlorophyll (Wong et al. 2020) and polyphenols and on some micronutrients, although this effect would depend on the lettuce cultivar (Lee et al. 2019).

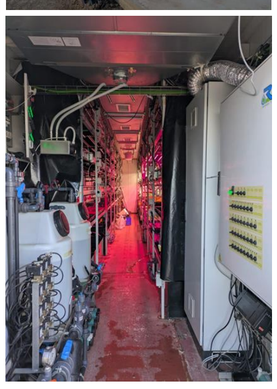
Despite the well-established roles of blue, red, and far-red light in plant development, their combined effects on biomass, pigment content and mineral accumulation in lettuce cultivars under vertical farming remain poorly understood. We hypothesize that the addition of FR enhances biomass accumulation at the expense of dry matter content. Conversely, blue-enriched spectra, with or without FR, will favor the accumulation of pigments and minerals. Thus, the aim was to evaluate the interactive effects of incorporating FR on the blue (B), red (R) and B+R spectrum on the growth, pigment content and mineral composition of two contrasting lettuce cultivars grown hydroponically in a vertical farming system.

METHOD

CEBAS Experimental Farm
Santomera, Murcia, Spain

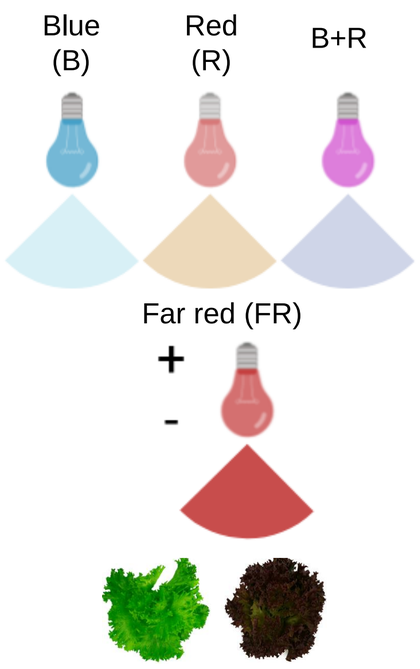


Horti-Blade BRWFR-4 dimmable lamps



Vertical Farm System

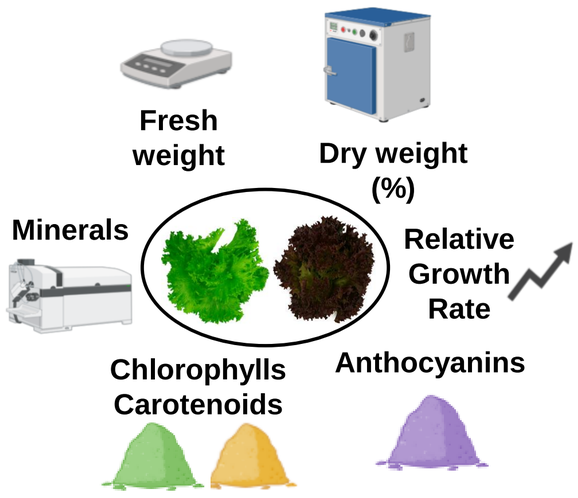
TREATMENTS



Lollo lettuce type

PPFD = ~150 µmol m⁻² s⁻¹; 16 h light
DLI = 8.64 mol m⁻² d⁻¹

MEASUREMENTS



EXPERIMENTAL DESIGN AND STATISTICAL ANALYSIS

Completely randomized design

Factorial structure

3 × 2

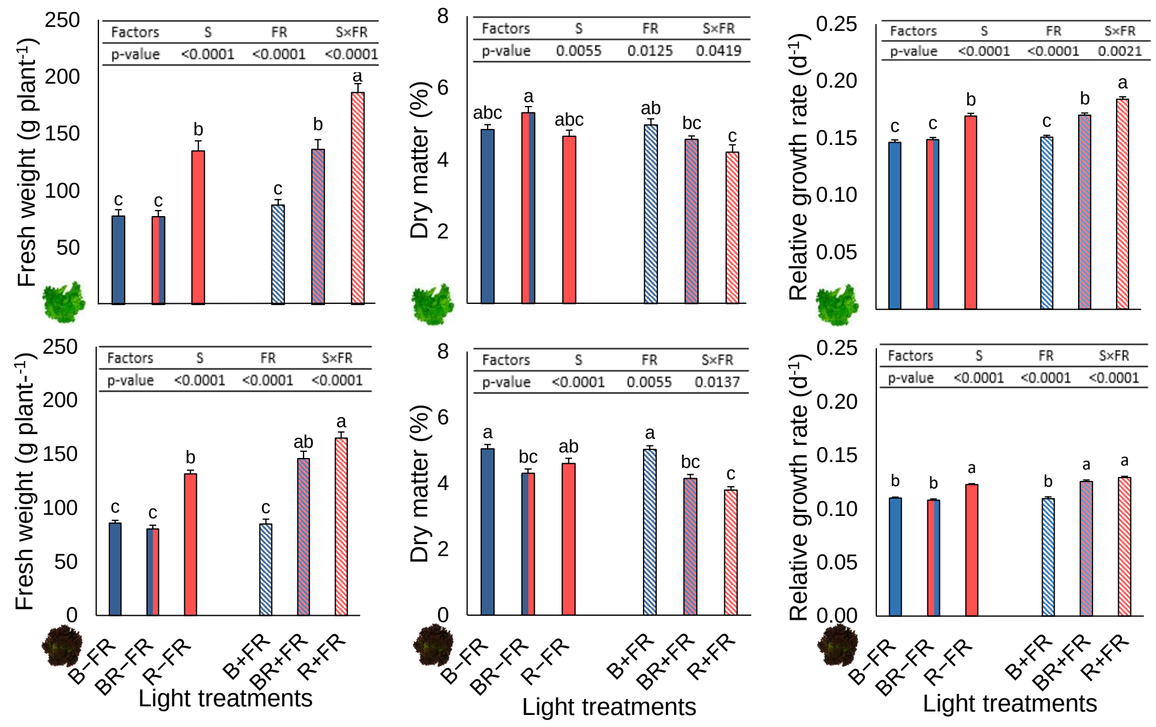
Light spectrum (S) | FR addition (FR)

Two-way ANOVA

Tukey's multiple comparison test ($p \leq 0.05$)

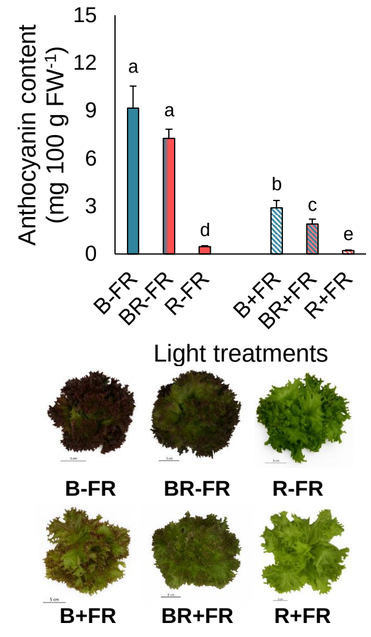
RESULTS

GROWTH



PIGMENTS

Factors	Chlorophyll a		Chlorophyll b		Carotenoids	
	mg 100 g⁻¹ FW					
B	5.78b	20.7a	8.29b	11.5a	5.75	6.76a
BR	6.57a	19.0b	9.46a	7.95b	5.98	5.71b
R	5.62b	16.5c	8.56ab	5.46c	6.15	4.72c
−FR	5.65b	19.4	8.31b	8.56	6.64a	6.09a
+FR	6.33a	17.4	9.22a	8.06	5.27b	5.37b
B −FR	5.61	20.6	7.50	10.8ab	5.85bc	7.12
BR −FR	5.83	20.0	8.99	8.95bc	7.10a	6.09
R −FR	5.51	17.7	8.46	5.93d	6.98ab	5.04
B +FR	5.95	21.2	9.08	12.2a	5.65c	6.39
BR +FR	7.31	18.2	9.92	6.96cd	4.85c	5.33
R +FR	5.73	15.2	8.67	5.00d	5.32c	4.40
S	0.003	<0.00	0.029	<0.00	0.327	<0.00
FR	0.005	0.120	0.015	0.249	<0.00	0.00
S × FR	0.052	0.166	0.297	0.007	0.002	0.955



MINERALS

Factors	$P^{2+,5+}$		K^+		Ca^{2+}		Cu^{2+}		Mn^{2+}		$Fe^{2+,3+}$	
	mg 100 g⁻¹ FW						µg 100 g⁻¹ FW					
B	59.8a	48.8a	343.0a	284.6a	54.2a	72.9a	8.91b	74.9b	362.3a	342.9a	484.4	466.4
BR	52.6b	42.6b	280.9b	217.2b	48.8a	65.8a	12.5a	88.2a	312.3b	310.2a	428.3	498.7
R	42.5c	38.5c	281.3b	201.3b	40.4b	50.5b	9.47b	74.1b	259.5c	250.0b	463.5	478.4
−FR	54.7a	44.1	286.7b	221.6b	48.7	65.8	12.12a	91.9a	309.5	308.6	514.9a	526.0a
+FR	48.7b	42.5	316.8a	247.2a	46.8	60.4	8.44b	66.3b	313.3	293.4	407.4b	440.2b
B −FR	61.9	47.7a	346.1	284.8	53.5	68.9ab	9.19c	77.9bc	372.9	340.6	505.7	488.9
BR −FR	57.9	43.2b	254.2	195.1	50.1	76.6a	15.9a	109.1a	302.2	334.0	501.2	546.9
R −FR	44.2	41.4b	259.7	184.8	42.6	51.7c	11.3b	88.7b	253.3	251.3	535.5	538.1
B +FR	57.7	49.8a	339.9	284.4	54.9	76.9a	8.64cd	71.9bcd	351.8	345.1	463.2	447.7
BR +FR	47.5	41.9b	307.5	239.2	47.3	54.9bc	9.04c	67.4cd	322.4	286.3	367.6	450.5
R +FR	40.8	35.6c	302.9	217.9	38.2	49.3c	7.64d	59.5d	265.8	248.7	391.5	418.7
S	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	0.002	<0.00	<0.00	0.177	0.485
FR	0.000	0.050	0.008	0.004	0.310	0.090	<0.00	<0.00	0.794	0.251	<0.00	0.00
S × FR	0.081	0.002	0.064	0.083	0.440	0.002	<0.00	0.000	0.480	0.223	0.112	0.329

CONCLUSION

- The addition of FR resulted in faster but less dense growth of lettuce plants, especially when combined with red light, by significantly improving fresh weight and reducing dry matter content.
- In general, spectra with a higher proportion of blue light were confirmed as a key modulator of the intrinsic quality of both types of lettuce, increasing the concentration of pigments and macro- and micronutrients.
- Overall, the results show that blue light optimizes the biochemical quality of lettuce, while red light combined with FR maximizes yield. This provides clear guidelines for the design of lighting strategies according to the production objective: biomass versus functional quality.

FUTURE WORK / REFERENCES

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