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Hot Pursuit: Searching for the Optimal Wasabi Greenhouse Growing Environment

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Abstract. **Understanding the optimal environmental conditions for wasabi (*Eutrema japonicum*) is key to expanding its cultivation. This study identifies key factors influencing wasabi's growth, including photosynthetic photon flux (Q_i), intercellular CO_2 concentration (C_i), soil moisture, and vapor pressure deficit (VPD). Results show that wasabi thrives with soil moisture $\geq$95% field capacity, VPD $\leq$ 2.0 kPa, and light levels between 500 and 830 $\mu mol \cdot m^{-2} \cdot s^{-1}$. Maximum net assimilation occurred at 828 $\mu mol \cdot m^{-2} \cdot s^{-1}$, with strong responses to increased CO_2, suggesting greenhouse target CO_2 at 1200 ppm. These findings provide initial soil moisture and VPD thresholds for wasabi cultivation in controlled environments, with further research needed on irrigation practices.**

Wasabi (*Eutrema japonicum*) is traditionally cultivated in cool, gravelly mountain streams in Japan's Nagano and Shizuoka regions (Chadwick et al. 1993), where it grows at elevations of 200 to 1000 m. Wasabi is grown in two systems: flooded systems that produce premium fresh herbs and upland systems for processing-vegetable products. Upland systems require cool temperatures (6 to 20 °C), with optimal growth at 8 to 18 °C; flooded systems perform best at 12 to 15 °C. When cultivated outside this native range, such as in the Pacific Northwest, where wasabi is a specialty horticultural crop grown in greenhouses, there are increased production challenges including root rot diseases, frost damage, and delayed maturity (Miles and Chadwick 2007). While propagation protocols have advanced (Hoang et al. 2019), optimal greenhouse production conditions, including light and soil moisture, remain uncertain.

Greenhouse systems may enable broader wasabi cultivation, expanding production outside of traditional areas; however, success depends on defining precise moisture and light conditions. Gas exchange and stomatal conductance (g_{sw}) provide insight into plant responses to environmental factors (Buckley 2019). Lysimeters synchronized with g_{sw} data can identify soil moisture thresholds for irrigation (McCauley et al. 2021). A/C_i and A/Q_i response curves further elucidate photosynthetic responses. The objective of this study was to use these tools to define optimal light conditions for container-grown wasabi.

Materials and Methods

The study was conducted at the North Willamette Research and Extension Center in Aurora, OR, USA (lat. 45.281009, long. 122.752512) in a heated, double-walled polyethylene greenhouse equipped with automated controls to maintain stable temperature and humidity. The structure provided diffuse light transmission and insulation suitable for cool-season crop production. Wasabi (cv. Daruma) was sourced from a commercial propagator and grown in 10.6-L air-pruning pots (#3 pots; RediRoot, Boring, OR, USA) filled with coconut fiber soilless substrate for greenhouse crops (Rio Coco PCM, Irving, TX, USA).

On 13 Mar 2024, 16 healthy plants were placed on a mini-lysimeter system controlling irrigation based on container weight. Irrigation was triggered at 90% container capacity), defined as the weight after full saturation and 1 h of drainage. The mini-lysimeter control system is discussed in detail in the work of McCauley and Nackley (2022).

Overhead lighting from 1000-W high-pressure sodium lamps were set to provide supplemental morning light at 750 $\mu mol \cdot m^{-2} \cdot s^{-1}$, operating daily from 8:00 to 11:00 AM, after which natural sunlight provided illumination for the remainder of the day.

Leaf-gas exchange. A portable photosynthesis system (LI-6800; LI-COR Biosciences, Lincoln, NE, USA) was used to generate light and CO_2 response curves on mature leaves of three different plants (n = 3). Photosynthetic light responses (A/Q) were measured under the following conditions: CO_2 concentration set to 400 ppm, temperature at 21 °C, relative humidity (RH) at 50%, fan speed at 10,000 rpm, and flow rate set to 500 $\mu mol \cdot s^{-1}$. Readings were taken at 2000, 1500, 1000, 800, 600, 500, 300, 200, 150, 50, and 0 photosynthetic photon flux density (PPFD).

Photosynthetic CO_2 response (A/C_i) were measured under the following conditions: incident light (Q_{in}) was maintained at 650 $\mu mol \cdot m^{-2}$, with a temperature of 21 °C, RH at 50%, fan speed at 10,000 rpm, and flow rate set to 600 $\mu mol \cdot s^{-1}$. Measurements were taken at CO_2 concentrations of 400, 300, 200, 100, 50, 0, 400, 600, 800, 1000, 1200, 1600, and 2000 ppm over a period of ~45 min.

CO_2 response data were analyzed using the Farquhar–von Caemmerer–Berry (FvCB) model (Farquhar et al. 1980) adjusted for temperature and CO_2 (Bernacchi et al. 2001). Parameters included $V_{c\ max}$, J_{max}, R_d, and triose phosphate utilization (TPU) (Sharkey et al. 2016). Parameters were estimated using nonlinear least squares in MATLAB constrained within biological ranges and evaluated with linear modeling (Supplemental Fig. 1).

Starting on 18 Mar 2024, irrigation was stopped, and the pots were allowed to dry down. During a 4-day dry-down, leaf gas-exchange parameters (g_{sw}, VPD_{leaf}, and Q_{amb}) (Table 1) were measured from each plant (n = 16) every 60 to 90 min starting at 9:00 AM until around 4:00 PM with a portable porometer–fluorometer (LI-600; LI-COR Biosciences). Attention was focused on sampling the newest, fully developed mature leaves.

Results and Discussion

The automatic misting and irrigation systems in the greenhouse were used to

Table 1. Environmental data recorded on the 4 days when soil moisture content and transpiration measurements were taken.

	PPFD ($\mu mol \cdot m^{-2} \cdot s^{-1}$)		VPD (kPa)		Temp (°C)			
Day	Mean	Max	Mean	Max	Min	Mean	Max	Mean field capacity (%)
Mar 18	201.96	1080	1.10	2.45	9.13	18.31	27.05	95
Mar 19	234.82	1136	0.85	1.72	9.17	16.90	24.00	90
Mar 20	261.22	1006	0.79	1.87	11.81	16.89	23.22	86
Mar 21	257.79	1347	0.84	2.24	12.16	17.49	25.79	82

Max = maximum; Min = minimum; PPFD = photosynthetic photon flux density; Temp = temperature.

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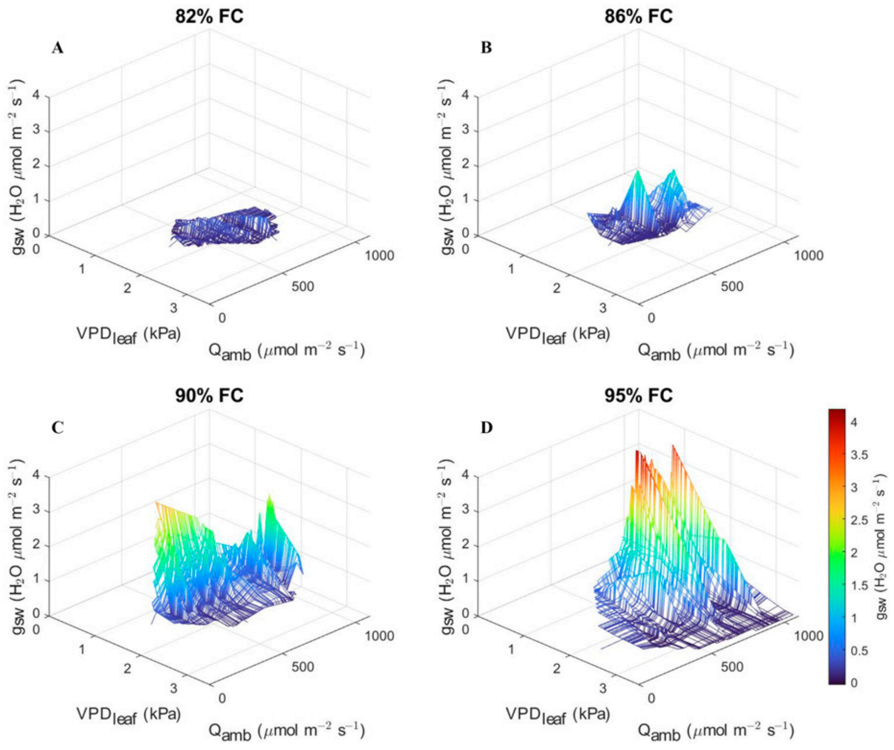

Fig. 1. Stomatal conductance (g_{sw}) over a range of field capacities (FC), VPD$_{leaf}$, and light. (**A**) 82% FC (n = 112). (**B**) 86% FC (n = 96). (**C**) 90% FC (n = 112). (**D**) 95% FC (n = 96). All axes are scaled the same, with the x-axis showing VPD$_{leaf}$, the y-axis Q_{amb}, and the z-axis g_{sw}. The color scale for all is scaled the same. Red represents a high g_{sw} of ~4, while orange is ~3, green is ~2, and blue is ≤1 µmol H$_2$O m^{-2}·s^{-1}. At 95% FC, plants maintained high g_{sw} even under less favorable atmospheric conditions, whereas at 82% FC, g_{sw} remained suppressed despite optimal light and VPD$_{leaf}$.

effectively mimic natural conditions of the mountain stream beds with abundant moisture and low heat stress. During the initial phase, when moisture was abundant, leaf gas exchange revealed a maximum assimilation rate (A_{max}) of 11.08 ± 0.42 µmol·m^{-2}·s^{-1} at 828 µmol·m^{-2}·s^{-1} Q_{amb} (Supplemental Fig. 1). Model fitting showed a strong correlation between light levels and net assimilation (R^2 = 0.906), with adequate PPFD setting for greenhouse growers to target between 500 and 800 µmol·m^{-2}·s^{-1}. The A/C_i curve (Supplemental Fig. 1B) showed an A_{max} of 22.84 ± 1.82 µmol·m^{-2}·s^{-1} at 1600 µmol·mol^{-1} CO$_2$, indicating a strong response to CO$_2$ but with diminishing returns at higher CO$_2$ concentrations. Key parameters such as $V_{c\ max}$ (74 µmol·m^{-2}·s^{-1} at 21 °C) and J_{max} (108 µmol·m^{-2}·s^{-1} at 21 °C) suggest that photosynthesis in wasabi is constrained by both Rubisco activity and RuBP regeneration at lower CO$_2$, with a triose phosphate utilization (TPU) limitation at higher concentrations. The FvCB model fit strongly (R^2 = 0.959). The higher V_{cmax} and J_{max} values suggest that wasabi has the potential to benefit from elevated CO$_2$ conditions, making greenhouse cultivation with CO$_2$ enrichment targeting 1200 ppm CO$_2$ a viable option for future cultivation.

During the dry-down period, when irrigation was limited, the drying substrate caused rapid reductions in stomatal conductance (g_{sw}), indicating a sensitivity to dry soils. While g_{sw} was positively correlated with both Q_{amb} and VPD$_{leaf}$, field capacity (FC) emerged as the dominant control. For example, at 95% FC, g_{sw} remained robust (~3 to 4 µmol H$_2$O m^{-2}·s^{-1}) even as VPD$_{leaf}$ approached 2.0 kPa (Fig. 1). In contrast, at 82% FC, g_{sw} remained low (<1 µmol H$_2$O m^{-2}·s^{-1}) across all VPD$_{leaf}$ and ambient light (Q_{amb}) conditions. Plants at 95% and 90% FC showed a clear positive response to increasing light, with peak g_{sw} observed around 800 µmol·m^{-2}·s^{-1}. However, plants at 86% and 82% FC displayed minimal g_{sw} response to changing light levels, indicating that light alone could not overcome the limitations imposed by lower soil moisture. Our work is among the very few studies of wasabi photosynthesis, with essentially no direct comparisons available. A couple of titles from the early 2000s suggest that photosynthesis work was conducted in Korea, but these studies were published in Korean in reports that are not readily accessible outside that region. A more recent publicly available study examined the effects of light quality on wasabi growth (Ruamrungsri et al. 2025). However, according to our findings, their research was conducted at light intensities (35, 60, 90, and 140 µmol·m^{-2}·s^{-1} PPFD) that were suboptimal. These are unusually low light intensities for any plant. We identified an optimal target of 800 ± 50 µmol·m^{-2}·s^{-1} PPFD, which supported assimilation rates of ~10 µmol·m^{-2}·s^{-1}, increasing to >20 µmol·m^{-2}·s^{-1} with CO$_2$ enrichment (Supplemental Fig. 1). By comparison, their reported assimilation rates of ~2 µmol·m^{-2}·s^{-1} (Ruamrungsri et al. 2025) were consistent with our measurements at ~100 µmol·m^{-2}·s^{-1} PPFD. Given the scarcity of wasabi research, indirect comparisons to other Brassicaceae root crops provide a useful benchmark. For example, red radish (*Raphanus sativus* L.) A_{max} was between 15 and 18 µmol·m^{-2}·s^{-1} and was sensitive to irrigation deficit (Alsadon et al. 2023). These findings underscore the critical role of soil moisture in maintaining stomatal function and suggest that irrigation strategies for wasabi should prioritize keeping FC above 90% to sustain physiological activity under fluctuating environmental conditions.

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