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FEATURES

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The Complexity of Greenhouse Strawberries

Josh Vander Weide, Nick Cooley & Roberto Lopez

Strawberries are the most popular berry fruit in the United States and one of the top fruits consumed overall, with per-capita consumption reaching over 7.5 lbs. in 2023. Consumer demand is driven by flavor, aroma, versatility and perceived health benefits, fueling expanded production. While most strawberries are still produced in open fields in California and Florida, controlled environment (CE) production—using greenhouses and indoor farms—is expanding rapidly to supply fruit during the off-season from November to April (Figure 1).

A significant advantage of greenhouse production is the ability to control environmental and cultural parameters, such as temperature, light, humidity and pollination to improve yield and fruit quality. However, they entail much higher production costs. Energy inputs—especially heating and lighting—account for a significant share of operating expenses in greenhouse strawberry production systems, often second only to labor. As a result, many growers operate with narrow profit margins. Minor improvements in energy-use efficiency could have a substantial impact on profitability.

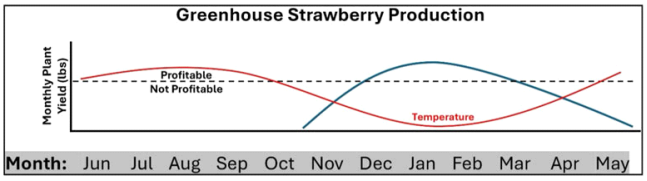


Figure 1. Monthly greenhouse yield efficiency of everbearing strawberry production. During late fall, winter and early spring months, day/night temperature (red line) can easily be controlled, leading to more profitable production (blue line). Meanwhile, during late spring, summer and early fall months, day/night temperatures cannot easily be controlled, leading to less profitable production.

One often overlooked opportunity to improve returns is cultivar selection. Many operations rely on familiar everbearing or day-neutral cultivars used in field production, particularly Albion, due to its flavor and large berry size. However, cultivars such as Albion were not explicitly developed for greenhouse systems and often yields only moderately in CEs. Our recent research at Michigan State University suggests that other cultivars may be better suited to greenhouse production, particularly when combined with an appropriate temperature strategy.

Why temperature matters

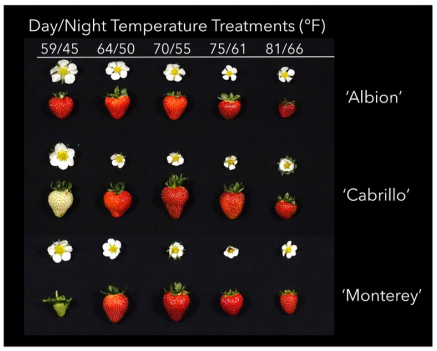
Average daily temperature (ADT) is one of the most critical drivers of development and fruit quality. Temperature influences the timing of leaf unfolding, flowering and fruit harvest, as well as yield and quality

components, including berry number, color, firmness and size.

Crop developmental responses to ADT can be graphed along a temperature-response curve: the base temperature indicates the lowest temperature at which development begins; a linear increase in development rate occurs until an optimal temperature range is reached, followed by a decline until development halts at the maximum temperature. Therefore, low temperatures can slow plant development and reduce fruit set, while excessively high temperatures can reduce berry size, sweetness and overall quality.

Additionally, cultivars don't respond similarly to temperature. This means there's no single "best" greenhouse temperature for strawberry growth and development—environmental conditions are going to be cultivar-dependent, as well as dependent on the grower's production goals.

Despite this, few, if any studies have provided clear guidance on determining the base, optimum and maximum temperature ranges for modern everbearing cultivars under greenhouse conditions. To address this gap, we evaluated six everbearing cultivars—Albion, Cabrillo, Monterey, Mara Des Bois, San Andreas and Seascape—across a wide range of day/night (D/N) temperatures in a greenhouse.



Study details

Plants were grown in trough systems under five D/N temperatures: 59/45, 64/50, 70/55, 75/61 or 81/66F (15/7, 18/10, 21/13, 24/16 or 27/19C), representing average daily temperatures (ADT) from approximately 52 to 73F (11 to 23C). A 16-hour photoperiod was maintained using high-intensity light-emitting diode (LED) fixtures to achieve a target daily light integral of 15 $mol \cdot m^{-2} \cdot d^{-1}$.

Figure 2. Representative flowers and fruit of Albion, Cabrillo and Monterey grown at different day and night temperatures for seven weeks.

We tracked plant development (flowering and harvest timing), weekly yield, berry size and berry soluble solids content and titratable acidity. Yield efficiency was calculated as the number of pounds of fruit produced per yard row per week over 12 weeks.

Temperature strongly affected phenology

As expected, across all cultivars, warmer temperatures significantly accelerated crop development. Time to open flower and harvest were both longest under the coolest ADTs and shortest under the warmest ADTs.

In practice, plants grown at the highest ADT reached harvest four to six weeks earlier than those grown under the coolest ADT. However, ADT or D/N temperatures had little effect on the timing of visible bud formation, suggesting that early floral initiation in everbearing strawberries is relatively insensitive to temperature. At the same time, later stages of flower and fruit development are much more temperature dependent.

For growers aiming to shorten crop cycles or hit specific market dates, this highlights the importance of temperature management, particularly during flowering and fruit development.

Figure 3. Average daily temperature optimum (T_{opt}; F) for yield efficiency (lbs/yard row/week), the yield efficiency at the optimum temperature and yield efficiency of five cultivars compared to Albion across five day/night temperature conditions.

Cultivar	Average daily temperature (F) optimum (T_{opt})	Yield efficiency at T_{opt} (lbs/yard/week)	Yield efficiency compared to Albion
Albion	64.2	0.36	---
Cabrillo	64.4	0.46	27% ↑
Monterey	64.9	0.58	60% ↑
Mara Des Bois	68.9	0.46	27% ↑
San Andreas	69.1	0.45	27% ↑
Seascape	72.9	0.32	7% ↓

Yield efficiency depends on cultivar and temperature

Yield efficiency showed a clear temperature response, but the optimal temperature differed by cultivar. Across the six cultivars, peak yields generally occurred between 64/50 and 75/61F (18/10 and 24/16C), corresponding to ADTs of roughly 57 to 68F (14 to 20C).

At their optimal temperatures:

- Monterey was the highest-yielding cultivar, producing ≈60% more fruit per week than Albion.
- Cabrillo, San Andreas and Mara Des Bois also outperformed Albion, producing roughly 25% to 30% higher yields.
- Seascape consistently produced lower yields than Albion under most conditions.

Yields declined sharply in the coolest ADT across all cultivars. When ADT fell near 52F (11C), weekly production was reduced by more than 80% in some cases. This indicates that maintaining your greenhouses near the base temperature to minimize heating costs can dramatically reduce productivity, increase timing and may be counterproductive.

Bigger berries don’t always mean higher yields

Berry size responded differently to temperature than yield. Across all cultivars, berry mass declined steadily as temperature increased. The largest berries developed at the coolest ADTs, while the smallest berries developed at the warmest ADTs (Figure 2).

However, total yield was reduced at the coolest ADT due to limited fruit set, resulting in fewer berries despite larger individual berries. This confirms that berry size alone isn’t a reliable indicator of overall productivity.

At the optimal ADT for yield efficiency, Cabrillo, Monterey and San Andreas produced berries that were equal to or larger than those of Albion, while Mara Des Bois and Seascape produced smaller berries (Figure 2).

Practical takeaways

This study highlights three key points for greenhouse strawberry producers:

1. **Cultivar selection matters.** Several cultivars outperformed Albion in yield efficiency, particularly Monterey, San Andreas and Cabrillo. Meanwhile, Seascape produced lower yield efficiency than Albion

(Figure 3).

2. **Moderate temperatures maximize yield efficiency.** Small differences (5 to 10F) in temperature can significantly alter yield efficiency for most everbearing strawberry cultivars. ADTs that are too cool can severely reduce yield through a lack of flower bud development, while excessively warm ADTs reduce yield through smaller berry size.
3. **Balance yield and fruit quality.** For strawberries, cultivars or production temperatures that lead to high yield aren't always synonymous with highly flavorful berries. It's critical to allow flavor—and not just yield—to guide cultivar selection and management decisions.

As greenhouse strawberry production continues to expand, matching the right cultivar with the right temperature strategy will be essential for maintaining profitability in an increasingly competitive market. **IG**

Nick Cooley is a former M.S. student at Michigan State University (MSU), Joshua Vander Weide is an Assistant Professor and Berry Fruit Extension Specialist, and Roberto Lopez is an Associate Professor and Controlled Environment/Floriculture Extension Specialist in the Department of Horticulture at MSU.
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