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Balancing Yield & Quality in Greenhouse Strawberries

Josh Vander Weide, Nick Cooley & Roberto Lopez

For growers, yield is understandably one of the most important measures of success and profitability. Controlled Environment (CE) greenhouse production requires substantial investments in structures, heating, lighting and labor, so growers need yields high enough to justify those expenses.

But strawberries are somewhat different from many other greenhouse crops. Consumers aren't simply purchasing fruit—they're purchasing flavor. Aroma, sweetness, acidity, texture and berry size all contribute to whether someone enjoys a strawberry and, ultimately, whether they return to buy more.

That creates an important question for CE growers: Does the temperature that maximizes strawberry yield also produce the fruit consumers actually want?

Our recent research at Michigan State University suggests the answer is often no. Higher-yielding plants did not necessarily produce the most-liked fruit, and accounting for consumer preferences for berry size and firmness substantially changed what we considered "marketable yield."

Yield vs. quality

Strawberry fruit quality is complex. Soluble solids concentration (SSC)—commonly measured as °Brix—is often used as an indicator of sweetness, while titratable acidity (TA) represents fruit acidity. Consumers perceive these characteristics together, so the ratio of soluble solids to acidity (SSC/TA) can be more informative than either measurement alone.

Then there's aroma. Strawberries contain numerous volatile organic compounds (VOCs) that contribute to their desirable and characteristic smell and flavor. A berry can have plenty of sugar and still taste relatively bland if it lacks the right aroma compounds.

Firmness is also important. A berry can have excellent flavor, but if it's too soft, consumers may perceive it as overripe, and it becomes more difficult to harvest, package, transport and store.

Temperature influences all of these characteristics. Unfortunately, environmental conditions that promote faster development and higher production don't always favor fruit quality.

Study details

We evaluated six commercially relevant everbearing strawberry cultivars: Albion, Cabrillo, Monterey, Mara Des Bois, San Andreas and Seascape.

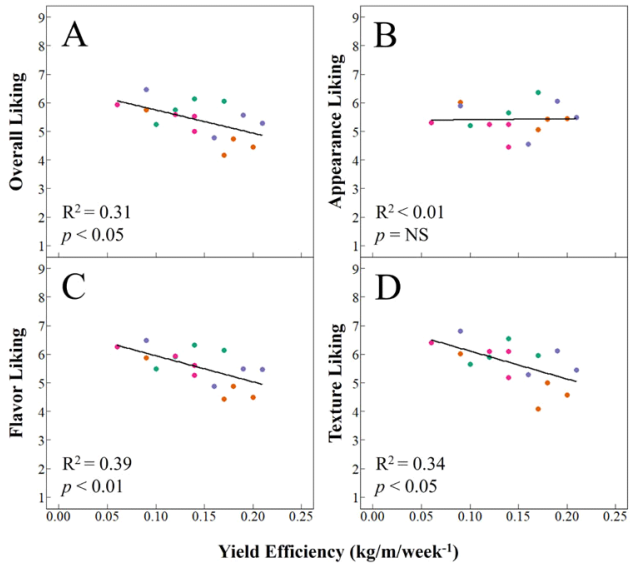
We grew bareroot plants in strawberry troughs under five day/night (D/N) temperature treatments: 59/45F (15/7C), 64/50F (18/10C), 70/55F (21/13C), 75/61F (24/16C) and 81/66F (27/19C) that gave us average daily temperatures (ADTs) of approximately 52, 57, 63, 68 and 73F (11, 14, 17, 20 and 23C), respectively. Plants received a 16-hour photoperiod with LED supplemental lighting to maintain a target daily light integral of 15 $mol \cdot m^{-2} \cdot d^{-1}$.

We harvested berries two to three times each week for 12 weeks. We measured SSC, TA, firmness, anthocyanin concentration and VOCs. We then combined these measurements with consumer sensory data to determine whether the temperatures that maximized production also maximized the amount of fruit meeting consumer expectations.

Cooler temperatures improved sweetness and firmness

One of the clearest responses was the effect of temperature on SSC/TA. Across all six cultivars, berries grown at lower ADTs had higher SSC/TA ratios. At the coolest temperatures, SSC/TA ranged from approximately 8.4 to 11.4 depending on cultivar. At warmer temperatures, values declined to roughly 5.6 to 6.2. In simple terms, fruit produced under cooler conditions generally had a more favorable balance between sweetness and acidity. Our results also indicate that cooler production temperatures favored the accumulation of strawberry VOCs associated with aroma.

Berry firmness responded similarly. Fruit produced at lower ADTs was generally firmer, while berries became considerably softer as temperatures increased. Firmness at the cooler treatments ranged from approximately 0.87 to 1.65 N, while values at warmer temperatures fell to 0.19 to 0.56 N. For growers, this response matters because firmness affects more than eating quality. Softer berries can also be more difficult to harvest and handle and may have reduced postharvest marketability.



More fruit didn't mean happier consumers

Consumers gave the highest overall liking scores to strawberries produced under the two coolest ADTs. These berries received average overall liking ratings between 5.8 and 6.5 on a nine-point hedonic scale. Fruit harvested from plants grown under the warmest ADT received scores between approximately 4.2 and 5.3.

Figure 1. Relationship between strawberry yield efficiency and consumer ratings for overall liking, appearance, flavor and texture. Overall liking, flavor liking and texture liking declined as yield increased, while appearance liking remained relatively

unchanged.

Flavor and texture followed similar patterns. As yield increased, overall, flavor and texture liking all declined significantly. Interestingly, appearance liking didn't follow this trend. Consumers didn't necessarily think the higher-yielding treatments produced worse-looking strawberries—they simply didn't like eating them as much.

This distinction matters. If growers optimize production parameters solely for pounds of fruit harvested, they could unintentionally set day and night temperatures away from those that produce the flavor and aroma consumers prefer.

One likely explanation is the balance between crop load and the plant's source-sink relationship. Mature leaves act as carbohydrate "sources," while developing flowers and fruit are strong "sinks." As crop load increases, more fruit compete for a limited supply of carbohydrates. The result can be more berries, but fewer resources available to each individual berry.

Total yield isn't necessarily marketable yield

This led us to another question: What happens if, instead of counting every harvested berry as yield, we count only berries that meet consumer expectations?

In our previous consumer sensory work, participants identified a preferred berry mass range of approximately 13 to 27 grams. When we applied this range to our production data—depending on cultivar and temperature—only 4.9% to 68.6% of berries fell within it. Most unacceptable fruit was too small.

Firmness had an even greater effect in some cases. Consumers indicated an acceptable firmness range of approximately 1.7 to 6.0 Newtons. When only berries within that range were counted, just 3.9% to 75.5% of fruit qualified, again depending on cultivar and greenhouse production temperature.

In contrast, SSC/TA was much less limiting. Most berries remained above the consumer acceptance threshold of >4.0 SSC/TA, meaning adjusting yield based on SSC/TA had relatively little effect on either marketable yield or the calculated optimal production temperature.

The important message is that berry size and firmness—not simply the number or weight of berries harvested—were the biggest constraints separating total yield from consumer-defined marketable yield.

The "best" production temperature changes when quality matters

Accounting for these consumer thresholds also shifted the temperature associated with maximum marketable production. For most cultivars, the ADT needed to optimize consumer-acceptable fruit was cooler than the temperature that maximized total yield.

The response was especially large for some cultivars. For Mara Des Bois and San Andreas, for example, accounting for berry mass shifted optimum temperatures lower. Similar responses occurred when we applied firmness standards.

These cooler temperatures came with a cost: lower total yield. That's the central challenge. Simply lowering greenhouse temperatures isn't automatically the answer because excessively low production temperatures can reduce flower and fruit development enough to substantially limit production.

Instead, our results point toward a compromise. Across the fruit quality parameters we measured, a D/N temperature near 70/55F (21/13C) provided a reasonable balance. Above this range, SSC and firmness generally declined while acidity increased. Responses weren't identical among cultivars, however, growers should consider temperature management and cultivar selection together.

Growers shouldn't select a cultivar based on yield —or flavor alone. The ideal cultivar should produce enough fruit to support profitability while maintaining berry size, firmness, sweetness and aroma that consumers desire and that entice repeat purchases.

Practical takeaways

This study highlights four key points for greenhouse strawberry producers:

- Maximum yield isn't necessarily maximum marketable yield. Higher-yielding treatments received lower overall, flavor and texture liking scores from consumers.
- Temperature strongly affects eating quality. Strawberry firmness and SSC/TA generally increased at cooler ADTs, while warmer temperatures produced less favorable, softer fruit.
- Berry size and firmness deserve special attention. When we applied consumer acceptance thresholds, these two traits caused much larger reductions in marketable yield than SSC/TA.
- Aim for balance rather than an extreme. Very low temperatures can suppress productivity, while warm conditions can sacrifice fruit quality. Under our greenhouse conditions, approximately 70/55F (21/13C) provided a useful starting point for balancing these competing responses, although the ideal temperature remains cultivar dependent.

For CE strawberry production to be profitable long-term, growers ultimately need to sell more than just strawberries—they need to sell strawberries consumers want to buy again and again. Optimizing harvested yield matters, but optimizing marketable, high-quality yield in pounds may be the more meaningful target. The next step may be finding ways to break this tradeoff rather than choosing one side. **IG**

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 Michigan State University (MSU). Nick Cooley is a former M.S. student at MSU. *The authors gratefully acknowledge the USDA Hatch Multistate Fund, USDA National Institute of Food and Agriculture, Hatch project nos. MICL02472 for funding.*

Update to Autumn Issue Article

Editor's Note: It was discovered after publication that updated information for a portion of the vapor pressure deficit research in strawberries had been omitted in the Autumn issue article. Click here for the full updated article.