Short Report: Temperature Effects on Plant Development Rate and Quality of Compact Container-grown Cucumber and Hot Pepper

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Abstract. **Mean daily temperature (MDT) effects on plant development rates and quality were evaluated for compact container-grown cucumber ('Patio Snacker') and pepper ('Taquito') grown at greenhouse set-points of 20.0, 22.5, 25.0, 27.5, and 30.0 °C. The number of days to first open flower and ripe fruit were measured and development rates calculated by taking the reciprocal (e.g., 1/d). Temperature effects were predicted by fitting a nonlinear exponential function, which included base temperature (T_{min}) and maximum developmental rate (R_{max}) parameters. Increasing the greenhouse MDT increased plant development rates and shortened crop timing for both crops. Estimated T_{min} was 18.2 °C for cucumber and 17.8 °C for pepper. Estimated R_{max} was 0.040 and 0.064 at flower and 0.035 and 0.016 at fruit for cucumber and pepper, respectively. Overall, these crops grown at ≈25 °C resulted in a relatively short crop time, large fruit size, and high fruit load per plant at finish. The information from this study can be used to help growers schedule compact cucumber and pepper alongside other containerized ornamental crops and determine the impacts of changing growing temperature on crop timing and quality.**

Compact varieties of edible crops such as pepper (*Capsicum* sp.) and tomato (*Lycopersicum solanum*) are grown in containers by greenhouse floriculture operations and produced for the home gardening market (Cruz et al. 2023). Greenhouse floriculture operations typically schedule production of container crops to finish and become saleable during specific market windows (Vargo and Faust 2022). Growers therefore require knowledge of the crop time needed to produce a marketable plant as well as how crop timing is influenced by environmental parameters that can be controlled, such as temperature.

This is a HortTechnology Short Report of a study conducted to 1) investigate the effects of mean daily temperature (MDT) on plant development rates and crop time for compact container-grown cucumber (*Cucumis sativa*) and pepper and 2) evaluate temperature effects on the number and mass of flowers and fruit per plant. Some methodology and certain data were referenced, presented in brief, or not presented as part of the Short Report format and may be available upon request to the corresponding author. Also, developmental rates were measured as the reciprocal of days (i.e., 1/d) for plants to reach stages of flowering and fruiting, which is common in container crop scheduling research (Dickson et al. 2024; Vargo and Faust 2022), and taking the inverse will convert these values into crop times (i.e., number of days).

Materials and methods

Overall, the experimental design, location, and methods were identical to those used to evaluate compact sweet and hot pepper varieties in another similar temperature study (Expt. 2 in Dickson et al. 2024). The exception was that cucumber seeds were sown directly into 6.5-inch containers (one seed per container) whereas pepper seedling plugs were transplanted into 6.5-inch containers at the start of the experiment. The cucumber vine per container was trellised vertically up a bamboo stake and pinched at 46 cm following commercial guidelines (personal communication, S. Padhye, PanAmerican Seed). The experiment began on 6 Mar 2023 and was repeated on 3 Apr 2023.

Six containerized plants of cucumber 'Patio Snacker' and hot pepper 'Taquito' (Kitchen Minis™; PanAmerican Seed, West Chicago, IL, USA) were grown in five identical and adjacent greenhouses with temperature set-points of 20.0, 22.5, 25.0, 27.5, and 30.0 °C. Each greenhouse compartment was individually controlled with an environmental control system (QCom Greenhouse Controls, Temecula, CA, USA) programmed to target each temperature set-point and record temperature data at the canopy level. The average daily temperatures for each set-point (from 20 to 30 °C) and during the experiments were (mean ± *SD*) 20.3 ± 0.5 °C, 23.5 ± 1.0 °C, 25.1 ± 1.9 °C, 26.9 ± 2.7 °C, and 28.7 ± 0.6 °C for the first replication and 21.6 ± 0.4 °C, 23.5 ± 1.3 °C, 25.1 ± 2.2 °C, 26.4 ± 1.4 °C, and 30.1 ± 0.1 °C for the second replication, respectively.

The date of the first open flower and first ripe fruit was recorded for each plant. The open flower was defined as the point of anthesis, and ripe fruit was the point where one fruit per plant had completely transitioned from green to red (pepper) or when fruit was 7.6 cm in length (cucumber). The number of days (i.e., time) from transplant to flowering and fruiting stages were then converted to flowering and fruiting rates by calculating the reciprocal (e.g., 1/d to flower or fruit).

The exponential function described by (Larsen 1990) was used to describe the relationship between the flowering and fruiting rates and MDT for each crop:

$$1/\mathrm{d}\ \text{to flower or fruit} = R_{max} \times \left(1 - \exp\left(-C \times (\mathrm{MDT} - T_{min})\right)\right) \quad [1]$$

The function in Eq. [1] is appropriate when the relationship between

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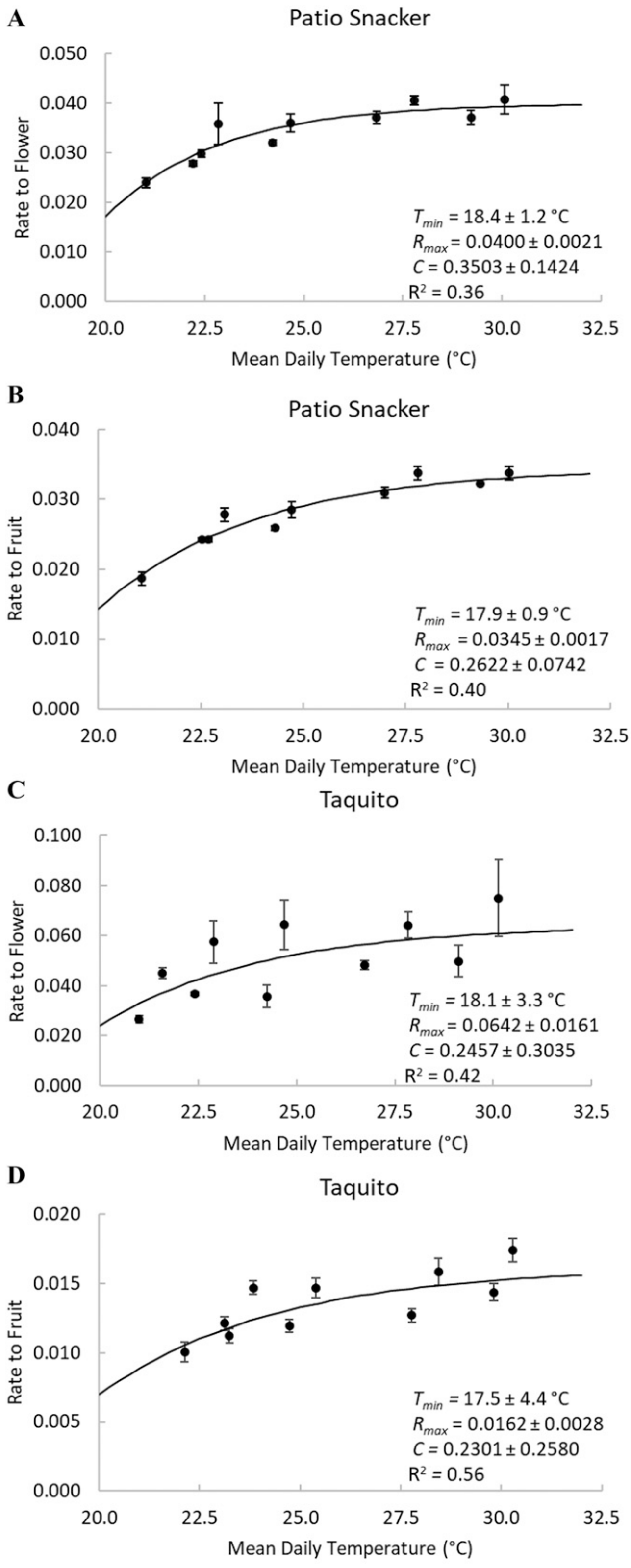

Fig. 1. Mean daily temperature effects on flowering and fruiting rates for cucumber and pepper using Eq. [1]. Regression slopes were nonsignificant ($P \geq 0.05$) between experimental replications, and therefore data were pooled for the statistical analysis. Each symbol (●) represents the treatment means across both replications, and error bars represent 95% confidence intervals. Trendlines are the predicted rates as a function of temperature. Base temperature (T_{min}) refers to the temperature at which the flowering or fruiting rate is zero. R_{max} refers to the maximum rate of development.

MDT and temperature follows an exponential curve and when T_{min} < MDT < T_{opt}. R_{max} has biological meaning and refers to the maximum rate of plant development at T_{opt}. T_{min} and MDT are measured in °C.

After collecting the data on crop timing, each plant remained in the greenhouse to allow for at least three fruits to ripen, which occurred within 10 d from the first ripe fruit. Once an individual plant developed three ripe fruits, additional plant quality data were collected consisting of individual ripe fruit weight, the total numbers of fruit (ripe and unripe), opened flowers, and unopened flowers following methods described by Dickson et al. (2024) and Humphrey et al. (2024). Data were analyzed using PROC NLIN and PROC GLIMMIX in SAS 9.4 (SAS Institute, Cary, NC, USA). Data on flower and fruit number and mass were log-transformed for homogeneity before analysis. Pairwise comparisons between temperature treatment set-points were performed on the final plant quality attributes using Tukey's honestly significant difference test at $\alpha = 0.05$.

Results and discussion

Increasing MDT resulted in fewer days to flower and fruit for both cucumber and pepper (Fig. 1). The time to flower ranged from 22 to 44 d for cucumber and from 11 to 40 d for pepper, while the time to fruit ranged from 29 to 57 d and 56 to 109 d, respectively. The flowering rate ranged from 0.023 to 0.045 for cucumber and from 0.025 to 0.091 for pepper (Fig. 1A, 1C), whereas the fruiting rate ranged from 0.018 to 0.034 for cucumber and from 0.009 to 0.018 for pepper (Fig. 1B, 1D).

The estimated T_{min}, R_{max}, and C parameters from Eq. [1] are shown in Fig. 1. Estimated T_{min} for cucumber and pepper averaged 18.2 and 17.8 °C, respectively (Fig. 1). Varietal differences in T_{min} were reported for container edibles plant species by Dickson et al. (2024) and Humphrey et al. (2024), and therefore T_{min} values estimated for cucumber and pepper may be specific to 'Patio Snacker' and 'Taquito' varieties.

The coefficients of determination generated for the nonlinear equations (R^2) ranged from 0.36 to 0.56 for cucumber and pepper (Fig. 1) and reflect the accuracy of Eq. [1] and the

Table 1. **Temperature set-point effects on individual fruit weight, total fruit (ripe and unripe), open flowers, and unopened flowers per plant for compact container cucumber and pepper. Data are least-square means of six observational units per treatment and experiment replication. Trend analysis used a linear model.**

		Temp set-point (°C)					
	Repl.	20.0	22.5	25.0	27.5	30.0	Trend
Cucumber 'Patio Snacker'							
Individual fruit weight (g)	1	36.5 a	36.7 a	30.2 a	19.2 b	20.1 b	***
	2	68.5 ab	74.4 a	49.2 ab	33.2 b	33.1 b	**
No. of total fruit	1	30 a	18 b	17 b	12 b	12 b	***
	2	22	24	21	19	19	NS
No. of open flowers	1	3	8	6	9	8	NS
	2	4	2	17	1	2	NS
No. of unopened flowers	1	29 b	53 ab	62 a	40 ab	68 a	**
	2	34 b	33 b	66 a	39 b	58 a	**
Hot pepper 'Taquito'							
Individual fruit weight (g)	1	2.3 b	4.0 a	2.5 b	2.9 ab	2.3 b	***
	2	2.6	2.8	2.3	1.8	19	NS
No. of total fruit	1	46 a	39 a	36 ab	29 b	19 c	***
	2	42 a	32 a	28 ab	12 b	6 b	***
No. of open flowers	1	3	0	4	0	1	NS
	2	3	7	4	4	9	NS
No. of unopened flowers	1	10 a	1 ab	6 ab	0 b	14 a	**
	2	5 ab	9 ab	2 b	7 ab	21 a	**

NS, *, **, and *** indicate nonsignificant and significant at $P < 0.05$, < 0.01, and < 0.001, respectively.
Means within rows followed by the same letter are not significantly different by Tukey's honestly significant difference test at $\alpha = 0.05$.

parameters in Fig. 1 at predicting temperature effects on flowering/fruiting times. These R^2 values were comparable to those reported for compact pepper and tomato varieties by Humphrey et al. (2024) and Dickson et al. (2024), which ranged from 0.33 to 0.85. However, the relatively low values ($R^2 < 0.7$) also indicated considerable variability, which negatively influenced the model accuracy. A potential source of variability may have been changes in the daily light integral (DLI), which naturally increased during this experiment and resulted in slightly different DLI values between replications and temperature set-point treatments for each crop (data not shown).

Increasing the temperature set-point from 20 to 30 °C decreased the total fruit per plant at finish for both crops (Table 1). Similarly, increasing temperature decreased individual fruit mass for cucumber, but there was less of an effect for pepper (Table 1). In contrast, higher temperature set-points tended to result in greater numbers of open and closed flowers per plant for both crops (Table 1).

Conclusions

As temperature increased from 20 to 30 °C, the developmental rates for flowering and fruiting increased for container-grown 'Patio Snacker' cucumber and 'Taquito' hot pepper. Results suggest these crops grown at ≈25 °C would result in near optimal combination of a relatively short crop time, large fruit size, and a high number of fruits per plant at finishing. This study incorporated estimates for crop T_{min} and R_{max}, which have biological meaning and can be used to draw inferences regarding crops optimal growing temperatures. Information from this study can be used to help growers schedule compact cucumber and pepper alongside other containerized ornamental crops and determine the impacts of changing growing temperature on crop timing and quality.

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