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Temperature and Humidity Affect Pillowy Fruit Disorder in Cucumber

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Abstract. **A study was designed to determine whether temperature alone or temperature and relative humidity (RH) interactions affect the development of pillowy fruit disorder (PFD) in cucumber *(Cucumis sativus* L.). Fruit of 'Calypso', 'Flurry', 'Carolina'? and inbred breeding line 39 were matured in four environments: cyclic and high (22 to 45C) and moderate (22 to 30C) temperatures at two RHs (35% and 75%). PFD symptoms were most severe at high temperature and RH; thus, both contribute to the development of this disorder. Line 39 had the highest PFD ratings, regardless of growing environment, a result indicating that cultigens respond differently to these imposed stresses.**

Pillowy fruit disorder (PFD) is a Ca-related anomaly that appears as styrofoam-like, white, porous-textured areas in the mesocarp of freshly harvested processing cucumbers (Staub et al., 1988). Following fresh-pack processing, "pillowed" tissue assumes a water-soaked, tan to grayish-brown color that reduces quality (Thomas and Staub, 1992). Pillowed tissue of processed fruit is significantly softer (33% to 39%) than nonpillowed tissue.

PFD incidence and severity was higher in fruit from plants subjected to high relative humidity (RH) or soil-moisture deficits (Staub et al., 1988; Thomas and Staub, 1992). Since higher PFD incidence also was observed in fruit harvested from non-water-stressed, field-grown plants under high temperatures (Thomas and Staub, 1992), a study was designed to determine whether temperature alone or temperature and RH interactions affect PFD development.

Cultigens that are particularly susceptible to environmental stress and differ in Ca uptake and accumulation are useful for testing hypotheses regarding PFD. Thus, the effects of temperature and RH. on PFD development were evaluated by comparing the response of various cultigens (inbred lines or cultivars) of cucumber to varying degrees of stress. Cultigen differences exist in tolerance to water, temperature, and RH, as measured by PFD incidence and severity (Navazio, 1993; Staub et al., 1988). For instance, 'Calypso' plants grown in solution culture are more susceptible (higher PFD incidence and severity) to RH and temperature stress than 'Tamer' (Staub et al., 1988). Likewise,' Carolina' and 'Calypso' are more susceptible (higher PFD) to water stress under field conditions than 'Flurry' (Navazio, 1992). European cucumber cultigens, such as Nunhems Seed Co.'s (Haelen, Holland) breeding line 39, also are susceptible to environmental stresses (e.g., low light and temperature) under glasshouse conditions (Franz Meddens, personal communication). Moreover, Ca deficiencies also have been observed in European glasshouse cucumbers grown under high RH and mineral stress (Bakker and Sonneveld, 1988).

Seeds of processing cucumber hybrids 'Calypso' (Campbell Institute of Research and Technology), 'Flurry' (Asgrow Seed Co., Kalamazoo, Mich.), and 'Carolina' (Peto Seed Co., Saticoy, Calif.) and breeding line 39 were germinated in plastic pots (13 cm in diameter; 700 ±50 ml) containing 1 sand: 1 compost soil :1 peat (by volume). In all experiments, plants in controlled environments received 14 h of light supplied by cool-white fluorescent and incandescent lamps with a photon flux (400 to 700 nm) maintained at the canopy level of 400 ± 20 $\mu mol \cdot m^{-2} \cdot s^{-1}$. Plants were germinated and grown to anthesis (flowering ≈ 45 days after planting) at 30C and 75% RH during the light period and 22C and 75%. RH during the dark period.

All cultigens flowered within 2 to 3 days of one another, and, at anthesis, some of the plants were transferred to two temperatures and RHs. Uniform plants (i.e., selected for similar height) were arranged in a randomized complete-block design with four replications in four controlled-environment rooms. Two rooms were designated as high- and two designated as moderate-temperature environments. In the two high-temperature environments, temperature was altered according to a sine function to simulate outside temperature changes. During the light period, the temperature was increased from 22C to a maximum of 45C from 0600 to 1600 HR (average 2.3C/h) and lowered to 22C from 1600 to 0600 HR (average 1.7C/h). In the moderate-temperature environments, temperature was raised from 22 to 30C from 600 to 630 HR and lowered to 22C from 2200 to 2230 HR. The RH in one room at each temperature was held constant at 35% and at 75% in the other room at each temperature. Thus, in the high-temperature rooms, the vapor pressure deficit (VPD) varied between 1.65 to 6.70kPa at 35% RH and 0.64 to 2.58 kPa at 75% RH. In the moderate-temperature rooms, the VPD varied between 1.65 to 2.69 kPa at 35% RH and 0.64 to 1.04 kPa at 75% RH. Plants were watered automatically to excess nine times daily in the high- and five times daily in the moderate-temperature environments with a complete nutrient solution (Hammer et al., 1978).

All flowers were hand-pollinated using pollen from 'Calypso' plants grown in the moderate-temperature environment at 35% RH. Pollination began 24 h after plants were transferred to treatment conditions. If abortion occurred, additional flowers were pollinated until one fruit set on each plant.

Air and fruit temperatures were recorded daily. Fruit temperatures and the length and diameter of one fruit each from a 'Calypso' and breeding line 39 plant in each room was measured every hour during one 24-h cycle. Thermocouple wires (0.003 mm in diameter) were located in the air ≈ 14 cm beneath the top of the canopy and in the fruit by inserting them into the midsection 2 to 5 mm below the epidermis. Fruit that had been pollinated on the same day and were 40 ± 5 mm in diameter (between 3 to 5 days postpollination, depending on growing environment) were measured.

When fruit attained a diameter of 50 mm, they were harvested, halved longitudinally, and examined for the presence of PFD. Fruit were classified as pillowed if an opaque-white, porous-textured tissue was observed in the mesocarp region 2 to 6 mm under the epidermis. Fruit were given a percent PFD value (percentage of longitudinal area showing pillowed tissue) according to Staub et al. (1988) and Thomas and Staub (1992). PFD symptoms were rated visually on a four-point scale, where 1 is 0% to <10% PFD, 2 is 10% to <20% PFD, 3 = 20% to <40% PFD, and 4 is> 40% PFD.

Analyses of variance of PFD ratings were performed separately for each environment, and means were separated using a least significant difference test at $P \leq 0.05$. Different RHs in contrasting temperatures were not compared because of differing VPDs between environments. Thus, comparisons are valid only within each RH or temperature, at the same RH at different temperatures, and for cultigens within an environment.

Significant differences in PFD were detected among plants grown in the same RHs at different temperatures, among RHs within the same temperature, and among cultigens within the same temperature (data not presented). . Significant cultigen × RH and cultigen × temperature two-way interactions were detected.

Comparisons among fruit grown in the moderate- and high-temperature environments indicated that temperature increased PFD severity (Table 1). The PFD ratings of all culti-

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gens were higher at high than moderate temperatures at the same RH. PFD severity increased under high RH (Staub et al., 1988) and was greater at high RH at both temperatures (Table 1). This increase in PFD most likely is associated with decreased transpiration rate under high RH (Nagaoka et al., 1984; Thomas and Staub, 1992).

The average daily VPDs for moderate and high temperatures at 35% and 75% RH were 2.2 and 0.9, and 3.0 and 1.5 kPa, respectively. The rank order of PFD severity observed in the treatments were high temperature (35% RH) > high temperature (75% RH) > moderate temperature (35% RH) > moderate temperature (75% RH). These results indicate that temperature and RH affect PFD seventy.

Increased PFD severity at higher temperatures may be attributable to increased fruit growth rate. Tazuke and Sakiyama (1986) reported that cucumber growth rate is related linearly to increased fruit temperature. Fruit temperatures of 'Calypso' and breeding line 39 were similar at any given temperature and RH. Fruit temperatures were an average of 1.3 (0600 HR) to 5.6C (1600 HR) lower than air temperatures in 35% RH and 0.1 (0600 HR) to 3.2C (1600 HR) lower than ambient in 75% RH (Fig. 1). These temperature differentials, as influenced by RH, may be due to shading, transpirational cooling, or both, of the fruit. Fruit temperatures predictively lagged behind air temperatures because of the additional energy required to heat fruit mass to similar air temperatures over a given period.

At moderate temperatures and 35% RH, increases in fruit length of breeding line 39 (7.0 mm) were greater than those of 'Calypso' (6.2 mm) during the period measured (600 to 2200 HR). At high temperatures and 75% RH, this difference in growth rate was more pronounced (breeding line 39 = 10.9 mm and 'Calypso' =2.7 mm). Regardless of RH, growth

Table 1. Visual ratings of pillowy fruit disorder (PFD) taken after growth at two temperatures and relative humidities (RHs).

	Temp[z]			
	Moderate (22-30C)		High (22-45C)	
	RH (%)			
Cultigen	35 [y]	75	35	75
Flurry	0.0	[x] 0.4	0.0	2.2
Carolina	0.0	0.4	0.9	1.9
Calypso	0.2	0.4	0.7	2.8
Line 39	1.2	2.8	1.5	3.2
LSD $_{(0.05)}$	0.5	0.8	0.8	1.1

[z]Temperature cycled between 22 to 30C in the moderate- and 22 to 45C in the high-temperature environment.

[y]Vapor pressure deficits in moderate temperature at 35% and 75% RH were 2.69 and 1.04 kPa, respectively, and in high temperature at 35% and 75% RH were 6.70 and 2.57 kPa, respectively.

[x]Fruit ratings of the percentage of pillowed tissue present, where 1 is 0% to <10% PFD, 2 is 10% to <20% PFD, 3 is 20% to <40% PFD, and 4 is >40% PFD.

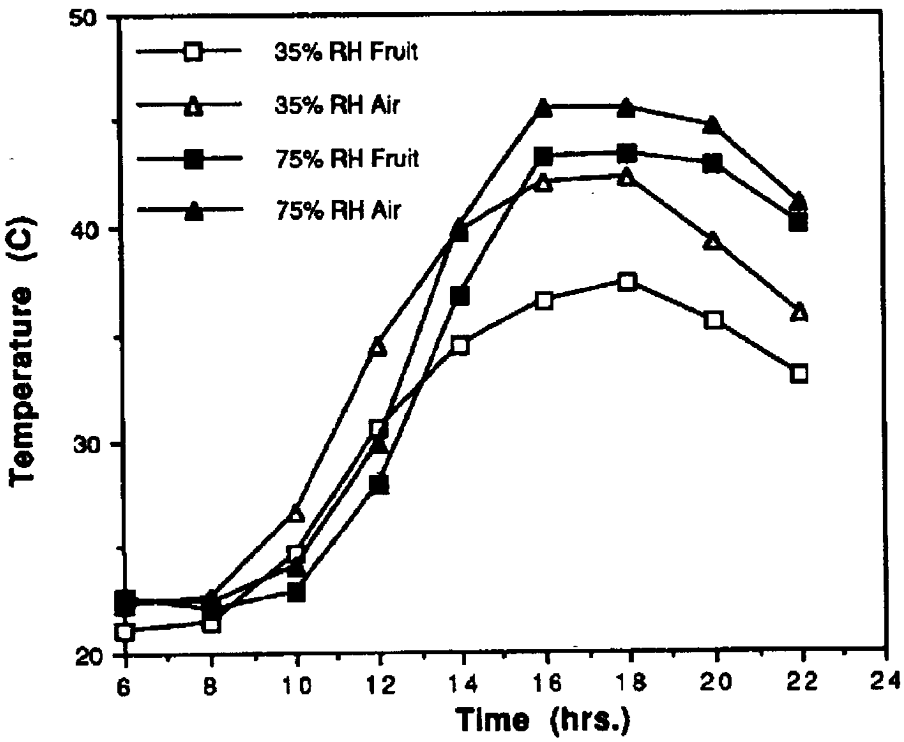

Fig. 1. Combined mean air and fruit temperatures of 'Calypso' and breeding line 39 cucumbers grown at 45C at two relative humidities (RHs).

rate was greatest at high temperature (data not presented). At high temperature and low RH, percent daily change in fruit length was 5.3% and 10.3% for 'Calypso' and breeding line 39, respectively. At high temperature and RH, percent change in fruit length was 11.4% and 15.6% for 'Calypso' and breeding line 39, respectively.

Differences in PFD severity between cultigens were found in each growing environment. Line 39 had the highest PFD ratings, regardless of growing environment (Table 1). Its sensitivity is demonstrated by the high PFD ratings recorded at moderate temperatures and 35% RH compared to that of other cultigens. This sensitivity may be attributed partially to a faster fruit growth rate than other cultigens.

The high temperatures and RHs we used in this research are reached in growing areas of the southern United States (North Carolina, Florida, and Texas), where PFD is most common (Gary Mader, personal communication). Given that PFD is increased by soil-moisture deficits (Thomas and Staub, 1992), our data indicate that PFD intensity resulting from plants subjected to soil-moisture deficits will be exacerbated by high temperatures and RHs.

The results of this study suggest that temperature and RH contribute to PFD development. However, no differences in PFD severity were detected among U.S. processing cucumber cultigens at high temperature and RH. Yet, differential response to water stress has been observed among 'Flurry', 'Calypso', and 'Carolina' under field conditions (Navazio, 1993). We therefore hypothesize that, although stress imposed by elevated temperature and RH can play a role in PFD development, a cultigen's ability to withstand soil-moisture deficits is more important in reducing PFD incidence and severity. Regardless, PFD incidence and seventy can be reduced by growing cucumbers in locations with moderate temperatures and low RHs and using watering procedures that minimize water stress.

Literature Cited

Bakker, J.C. and C. Sonneveld. 1988. Calcium deficiency of glasshouse cucumber as affected by environmental humidity and mineral nutrition. J. Hort. Sci. 63:241–246.

Hammer, P. A., T.W. Tibbitts, R.W. Langhans, and J.C. McFarlane. 1978. Baseline growth studies of' Grand Rapids' lettuce in controlled environments. J. Amer. Soc. Hort. Sci. 103:649-655.

Nagaoka, M., K. Takahashi, and K. Arai. 1984. Effects of environmental factors on photosynthesis and transpiration of tomato and cucumber plants. Veg. and Ornamental Crops Res. Sta., A. Ano Mie, Japan. 12:97–1 17.

Navazio, J.P. 1993. The effects of soil moisture and postharvest handling on pillowy fruit disorder in cucumber *(Cucumis sativus* L.). MS Thesis, Univ. of Wisconsin–Madison.

Staub, J.E., P. Rousos, and B.E. Struckmeyer. 1988. Anatomical characterization and possible role of calcium in "pillowy", a fruit disorder in processing cucumber. J. Amer. Soc. Hort. Sci. 113:905–909.

Tazuke, A. and R. Sakiyama. 1986. Effect of fruit temperature on the growth of cucumber fruits. J. Jpn. Soc. Hort. Sci. 55:62-68.

Thomas, R.S. and J.E. Staub. 1992. Water stress and storage environment affect pillowy fruit disorder in cucumber. J. Amer. Soc. Hort. Sci. 117:394-399.