clude the costs of facility construction of about \$15,000 (Donoghue, 1994b).

The pattern exhibited by the BE of the strains varied only slightly from the pattern of the overall mushroom yields per log (Figs. 3). WR46 was not as biologically efficient as its yield would indicate. Although it had the highest yield per log, it ranked only fourth highest in BE. With the exception of CW25, all strains were suitable for the wood species on which they were grown. However, for optimized commercial production, only the white and red oak should be considered as a substrate based on the results of this experiment, which is not to the exclusion of wood species not evaluated in this research. These strains were selected based on their fruiting temperature requirements.

At the end of 36 months, the most productive log species were red oak and white oak. The most productive strains were WR46, WW44, WW70, V3, WR85, and Twice Flowering. Although the wood species and strain interactions were not significant, BE attained from these interactions ranged from 0% (WW70, CW25, and WR85 on sycamore) to 8.8% (WW44 on red oak) in an outdoor uncontrolled environment. The gross per cord value (\$8.14/kg) of shiitake harvested from white oak was \$1332. Since white oak trees harvested for shiitake are not large enough to be considered for timber, they have a pulpwood value of only \$6 per cord. The costs, from inoculation to production, for one cord of shiitake are about \$6.44 per log in a small-scale operation (Sabota, 1993). A larger operation would have most of the same costs and would reduce the actual production costs per log. The costs include the following: one cord of logs, \$100; spawn, \$88; wax, \$6; shade cloth, \$75; high-speed drill, \$300; two spawn guns, \$44; two drill bits, \$24; two metal wax basters, \$16; four drilling stands or saw horses, \$50; stove to melt wax, \$20; propane fuel, \$12; 1135-L soaking tank, \$116; irrigation hoses and sprinklers, \$40; and inoculation labor, \$225. Assuming a \$2475 return (150 logs yielding 0.5 kg per year for 3 years and selling for \$11/kg) and a cost of production of about \$966 per cord, a net return of \$1509 per cord is realistic and includes the cost of preharvest labor. However, it is important to note that many produc-

ers have gone out of shiitake production due to limited markets in their growing areas and the labor requirements for harvesting, grading, soaking, marketing, and delivery. The success of the shiitake mushroom industry in Alabama is due, in part, to the cooperation among growers in merging product to meet large market demands. This allows producers to maintain markets even when one producer falls short on production occasionally.

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Temperature and Photoperiod Affect Grafted Cactus Scion Necrosis

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ADDITIONAL INDEX WORDS.

Chamaecereus silvestrii, *Hylocereus trigonus*, irradiance, rootstock, axillary branching

SUMMARY. The interaction among temperature, photoperiod, and irradiance on survival of *Chamaecereus silvestrii* (yellow sport) flat-grafted onto *Hylocereus trigonus* Haw. rootstock was studied in an effort to understand the basis for elevated scion necrosis during winter. Plants were placed in glasshouses maintained at 12, 16, 20, or 24 °C under either daylight (moles per day), 66% daylight or daylight + 100 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ irradiance levels. Plants were grown with an 8-hour (short day) or 8-hour + 4-hour night interruption (long day) photoperiod. Cactus scion necrosis increased under short days and a growing temperature of 12 °C and was nearly eliminated by long-day conditions and a growing temperature of 16 °C. Irradiance did not affect scion necrosis. Plant quality rating was highest when plants were grown under long-day conditions at 16 °C.

Grafted cacti are sold as a novelty crop throughout the world. A common rootstock for grafted cacti is *Hylocereus trigonus* Haw. (Night Blooming Cereus) (Lamb and Lamb, 1976), an epiphytic cactus native to tropical America (Cullman et al., 1984). *Gymnocalycium mihanovichii* var. *friedrichii* 'Hibotan' (red) and *Lobivia* (*Chamaecereus*) *silvestrii* Br. and R. (yellow sport) commonly are grafted onto *H. trigonus* because of

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their unique colors (Carter, 1973). Both of these cacti are incapable of independent survival; they reportedly lack chlorophyll (Mabe, 1974). Wild-type *C. silvestrii* and *G. mihanovichii* are native to a dry, grassy region east of the Andes in Argentina (Cullman et al., 1984; Meadow, 1976).

Significant *C. silvestrii* cultivars and *G. mihanovichii* var. *friedrichii* 'Hibotan' scion necrosis occurs on established grafted cacti during winter months in commercial production; crop losses can be as great as 30% to 50% (Luco Pasan, Nurseryman's Exchange, personal communication). Scion death is characterized by an ini-

tial loss of color, development of necrotic spots (on *C. silvestrii* cultivars), and eventual dehydration and complete scion necrosis (personal observation). Scion death usually requires 2 to 3 months (personal observation). *Hylocereus trigonus* (rootstock) axillary shoot development often occurs simultaneously with scion necrosis. I conducted this study to ascertain the effect of photoperiod, irradiance, and temperature on scion necrosis in an effort to identify a possible environmental basis and to develop alleviation techniques to limit cacti scion necrosis during the winter in commercial production-holding facilities.

Materials and methods

Fifty thousand established *C. silvestrii* (yellow sport) plants flat-grafted onto *H. trigonus* were received at Nurseryman's Exchange (Half Moon Bay, Calif.) from Japan on 9 Aug. 1993. Plants were held at constant 20 °C under ambient daylight conditions. One hundred ninety-two plants were selected for uniformity and were shipped overnight to St. Paul, Minn. (lat. 45°N), on 24 Dec. 1993. On arrival, plants were unpacked and placed in a 12 °C glasshouse under ambient daylight conditions. After 4 d, plants were placed in glasshouses maintained at a constant 12, 16, 20, or 24 ± 2 °C under either ambient daylight + 100 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ (supplied using high-pressure sodium lamps), daylight only, or 66% daylight irradiance levels (using 33% reduction saran). Plants were covered with opaque cloth from 1600 to 0800 HR each day to provide an 8-h photoperiod. Half of the plants in each treatment received night interruption lighting from 2200 to 0200 HR (supplied with incandescent lamps, 2 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$). Plants were watered as needed. No fertilizer was applied.

Data were collected on the percent plants with scion necrosis, the percent plants with axillary rootstock shoots (≥ 5 mm long), and appearance

Table 1. Interaction between temperature and irradiance on percent scion necrosis of *Chamaecereus silvestrii* (yellow) flat grafted onto *Hylocereus trigonus*

Irradiance	Temp (°C)			
	12	16	20	24
66% daylight	25 a (a) ^z	25 a (a)	40 a (a)	35 a (a)
Daylight	55 a (ab)	15 b (a)	25 b (a)	11 b (a)
Daylight + 100 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$	75 a (b)	15 b (a)	40 a (a)	35 a (a)
Term	Significance			
Temperature	***			
Irradiance	NS			
Photoperiod	***			
Temperature × irradiance	*			
Irradiance × photoperiod	NS			

^zTreatment means are presented. Letters not in parentheses denote mean comparisons across temperature; letters in parentheses denote mean comparisons across irradiance.

NS, *, ** Nonsignificant or significant at $\alpha = 0.05$ or $P < 0.05$ or 0.0001, respectively.

Fig. 1. Effect of photoperiod on percent scion necrosis and rootstock axillary shoot development of *Chamaecereus silvestrii* (yellow) flat-grafted onto *Hylocereus trigonus*. Letters above symbols denote significant differences between means as determined using Tukey's HSD test for mean separation.

after 60 d. Plant quality (appearance) was evaluated based on scion and rootstock color, presence or absence of complete scion necrosis or necrotic spots, and presence or absence of axillary rootstock shoots. Plant quality ratings varied from 1 to 5, with 5 = excellent and 1 = poor.

The experiment was organized as a $4 \times 3 \times 2$ factorial design with temperature, irradiance, and photoperiod, respectively, as the main factors. Four plants were used in each of the two replicates. Replication was achieved by blocking within a greenhouse section. Data were analyzed using an analysis of variance (ANOVA) procedure. Percentage data were arcsine-transformed before ANOVA. Mean separation was conducted using Tukey's test (HSD). An alpha level of 0.05 was used throughout analysis to identify statistical significance among treatments.

Results

Temperature and irradiance interacted to affect the percentage of plants with complete scion necrosis. Percent scion necrosis decreased from 55% to 15% as temperature increased from 12 to 16 °C when plants were grown under ambient daylight conditions across photoperiod (Table 1). Percent scion necrosis was unaffected by temperature when plants were grown under 66% daylight conditions across photoperiod (Table 1). Percent scion necrosis increased from 25% to 75% as irradiance increased from 66% daylight to daylight + 100 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ when plants were grown at 12 °C (Table 1). In contrast, irradiance did not affect percent scion necrosis when plants were grown at 16, 20, or 24 °C (Table 1).

Photoperiod affected percentage of plants with scion necrosis. Scion necrosis decreased from 53% to 11% when plants were grown under long-day vs. short-day conditions across temperature and irradiance treatments (Fig. 1).

Axillary shoot development was affected by temperature and photoperiod. Percentage of plants with axillary shoots decreased from 53% to 8% when plants were grown under long-day vs. short-day conditions across temperature and irradiance levels (Fig. 1). Percentage of plants with axillary rootstock shoots decreased from 49% to 14% as temperature increased from 12 to 24 °C across irradiance and photoperiod treatments (Fig. 2).

Irradiance and photoperiod interacted to affect overall plant quality. Quality was unaffected by irradiance when plants were grown under short-

day conditions (Table 2). In contrast, plant quality was higher when plants were grown under supplementary lighting or 66% daylight irradiance levels

Fig. 2. Effect of temperature on percent rootstock axillary shoot development and plant quality rating of *Chamaecereus silvestrii* (yellow) flat-grafted onto *Hylocereus trigonus*. Plant ratings varied from 1 to 5, with a rating of 5 considered excellent and 1 considered poor. Letters above symbols denote significant differences among means as determined using Tukey's HSD test for mean separation.

Table 2. Effect of photoperiod and irradiance on plant quality rating of *Chamaecereus silvestrii* (yellow) flat-grafted onto *Hylocereus trigonus*. Plant ratings varied from 1 to 5, with 5 considered excellent and 1 considered poor.

Photoperiod	Irradiance ^z		
	66% Daylight	Daylight	Daylight + 100 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$
Short day	2.5 a (a) ^y	3.1 a (a)	2.3 a (a)d
Long day	4.0 b (a)	3.8 a (a)	4.5 b (a)
Term	Significance		
Temperature	**		
Irradiance	NS		
Photoperiod	***		
Temperature $\times$ irradiance	NS		
Irradiance $\times$ photoperiod	*		

^ySupplemental lighting supplied with high-pressure sodium lamps.

^zTreatment means are presented. Letters not in parentheses denote mean comparisons across irradiance; letters in parentheses denote mean comparisons across photoperiod.

NS, *, **, *** Nonsignificant or significant at $\alpha = 0.05$ or $P < 0.05, 0.01, \text{ or } 0.0001$, respectively.

under long-day conditions (Table 2). Temperature also affected plant quality. Plant quality was highest, across irradiance and photoperiod treatments, when plants were grown at 16 °C compared to other temperatures (Fig. 2).

Discussion

Scion necrosis probably is related to photoperiod and temperature effects on cacti reproductive development, apical dominance, or both. Factors controlling flowering in many cacti are unclear. Many cacti have an obligate or facultative vernalization requirement (Cullman et al., 1984; personal observation). Furthermore, flowering is increased when cacti are vernalized and then placed under short-day vs. long-day conditions (Cullman et al., 1984). Some cacti, notably *Schlumbergera truncata* (Thanksgiving cactus) and *Rhipsalidopsis rosea* (Easter cactus), will flower under short days without receiving any cold treatment (i.e., they may not have any vernalization requirement). If *C. silvestrii* or *H. trigonus* are short-day plants, data presented here suggest that flat-grafted cacti must be grown under apparent vegetative conditions (long days and warm temperatures) to inhibit scion necrosis.

The association between rootstock axillary shoot development and scion necrosis suggested that necrosis might be related to loss of apical dominance and subsequent axillary shoot development on the rootstock. Reduction in apical dominance of many plants often is associated with reduced daylength (Phillips, 1969). *Chamaecereus silvestrii* (yellow sport) scion necrosis may be an artifact of rootstock behavior if necrosis has occurred when the rootstock failed to translocate needed assimilates to the scion. Carbohydrate translocation often is correlated positively with irradiance (Christy and Swanson, 1976; Hartt, 1965; Troughton

and Currie, 1977). Differences in my study probably are associated with photoperiod effects on apical dominance and/or reproductive state only since there was no effect of irradiance on scion necrosis. However, it cannot be assumed that scion necrosis is associated exclusively with rootstock effects because axillary shoot development and scion necrosis occur nearly at the same time; removal of a sink (death of the scion in this case) promotes axillary shoot development (Tamas, 1987).

Graft necrosis is reduced greatly and plant quality was greatest when plants received night interruption lighting with incandescent lamps from 2200 to 0200 HR and when plants are grown at a constant 20 °C. In addition, although not statistically significant, supplemental lighting increased overall plant quality by intensifying of scion color and apparent size.

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Response of Four Vegetable Crops to Fluridone-treated Irrigation Water

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ADDITIONAL INDEX WORDS. nontarget effects, aquatic herbicide, Sonar, 1-methyl-3-phenyl-5-[3-(trifluoromethyl)phenyl]-4(1H)-pyridinone, soil type, tomato, *Lycopersicon esculentum*, sweet corn, *Zea mays*, bell pepper, *Capsicum annuum*, cucumber, *Cucumis sativus*

SUMMARY. Greenhouse studies examined the effects of an aquatic herbicide (fluridone) in irrigation water on four vegetable crops growing on two soils. Tests on Fuquay loamy sand (0.3% humic matter) and Portsmouth fine sandy loam (4.1% humic matter) examined fluridone concentrations $\leq 250 \mu\text{g}\cdot\text{L}^{-1}$. Injury to sweet corn (*Zea mays* L.), cucumber (*Cucumis sativus* L.), bell pepper (*Capsicum annuum* L.), and tomato (*Lycopersicon esculentum* L.) on these soils varied with soil type and stage of plant growth. Seedlings or new transplants were more susceptible to fluridone damage than older plants. All plants showed more injury on Fuquay loamy sand, which had the lowest humic matter content. Injury to cucumber occurred only to seed-

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