Editor's Note: This is the final article in a six-part series based on the research being done by the Floriculture Research Alliance. The Alliance includes researchers that collaborate across universities and organizations on applied horticulture research. For more information, visit www.floriculturealliance.org.

FLORICULTURE & NURSERY RESEARCH INITIATIVE

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Environmental and Genetic Approaches to Lower Greenhouse Heating Costs

DISCOVER NEW STRATEGIES FOR REDUCING RISING ENERGY COSTS.

By Erik Runkle and Ryan Warner

Energy is typically the second largest overhead cost in the production of greenhouse ornamentals. For the past several years, one of our major research thrusts has been to reduce heating inputs as well as reduce electricity costs through more efficient lighting strategies and technologies. To lower energy costs for greenhouse heating, we have taken two approaches. Erik Runkle, former graduate student Matthew Blanchard, and current graduate student Tasneem Vaid have focused on reducing energy costs on a daily and per-crop basis by optimizing greenhouse temperature on a species- and seasonal-basis. Ryan Warner and former graduate students Aaron Walworth and Joseph Tychonievich have developed genetic resources to help facilitate the breeding of crops that flower earlier.

Managing Day/Night Temperature

Crops develop in response to the average daily temperature. Therefore, plants develop slower when the night temperature is lowered unless that decrease is compensated by raising the day temperature. Approximately three-fourths of the energy consumed for heating a greenhouse is at night, since the temperature outside is usually lower at night, and since there is no thermal gain

Table 1. Flowering time under 16-hour long days after transplant from plugs grown under long days. Time to flower is influenced by other factors, especially light quantity and photoperiod. Therefore, this information should be used as a guide only. Data based on research by Matthew Blanchard and Tasneem Vaid.

Common Name	Cultivar	Plug size	Days to first flower at: (°F)				
			57	63	68	73	79
Calendula	Bon Bon Orange	288	45	38	32	28	26
Diascia	Diamonte Mix	128	49	39	33	30	31
Gazania	Daybreak	128	89	69	57	48	40
Geranium	Pinto Red	288	81	71	61	51	41
Gerbera	Jaguar Deep Orange	128	68	60	52	44	36
Marigold (American)	Inca II Mix	288	62	50	41	35	32
Nemesia	Poetry White	128	38	34	29	25	20
New Guinea impatiens	Divine Cherry Red	128	59	53	46	39	32
Petunia	Bravo Blue	288	46	37	30	25	22
Portulaca	Margarita	128	70	47	35	28	23
Rudbeckia	Becky	128	82	64	53	45	38
Snapdragon	Liberty Classic Cherry	288	60	46	36	30	28
Verbena	Quartz	128	77	60	48	41	34
Vinca	Viper	128	--	56	38	29	22
Zinnia	Dreamland	128	78	55	43	35	28

from the sun. Therefore, a positive DIF (warmer day than night) can lower fuel costs on a daily basis. Using estimates from the computer software Virtual Grower (www.virtualgrower.net), approximately 10 to 25 percent less fuel is consumed by growing plants at a cooler night and warmer day than vice-versa. A potential negative consequence of this strategy is that a positive DIF promotes stem elongation. In addition, the relative humidity at night can increase when temperature is decreased, since air can hold less water vapor at a lower temperature.

Managing Temperature on a Per-Crop Basis

Flowering time depends on a number of factors, including the crop variety, maturity of the plug or liner at transplant, photoperiod, light quantity, application of growth regulators, and especially temperature. Until recently, surprisingly little research-based information has been available on how temperature influences crop timing of many of the major floriculture crops grown in the United States. Breeding companies often have culture sheets for their crops, but temperature recommendations and crop timing information are usually vague.

We have been quantifying how temperature influences flowering of a wide range of bedding plants (Table 1). For example, time from transplant of 288-cell plugs of snapdragon 'Liberty Classic Cherry' grown under long days took 46 days at 63° F but only 36 days at 68° F. This kind of information can help growers schedule crops so that they flower on time and, with Virtual Grower, enables one to determine the energy inputs for heating on a per-crop basis. The specific crop times can be especially useful for growers who have little or no experience growing that specific crop.

For growers with experience growing a crop, the relative differences in flowering time at different temperatures can be more useful. For example, a 5° F decrease in temperature, from 68 to 63° F, caused a 28 percent delay in flowering of snapdragon. If a grower typically produced this crop in flower in 30 days at 68° F (for example, if light levels were high or a larger plug was used), then a 28 percent delay in flowering time at 63° F would equate to eight days (flowering in 38 days at 63° F) under their growing conditions. The relative delay in flowering can be predicted for over 60 floriculture crops using Flowers OnTime, which is a decision-support tool that can be downloaded under the "Grower resources" tab at http://floriculturealliance.org.

Figure 1. *Average daily temperature and light integral (DLI) influence crop timing of floriculture crops, as seen here with petunia. Note the significant delay in flowering time when the DLI is low. Photo from Matthew Blanchard.*

We have also been investigating how the daily light integral (DLI) interacts with temperature to influence cropping time. Once the average DLI is at least 10 mol·m^{-2}·d^{-1}, additional increases in light have a relatively small impact on flowering time. However, without supplemental high-intensity lighting, light is a limiting factor for many crops until early spring (February in the South and March in the North). This means that, at the same air temperature, flowering is progressively delayed under lower light levels, as evident in petunia (Figure 1).

Developing Earlier Flowering Crops

Optimizing the production environment to minimize energy usage is critical for improving production efficiency of currently available varieties. Breeding varieties that flower earlier under 'suboptimal' environments, such as cool temperatures and low DLIs common in northern

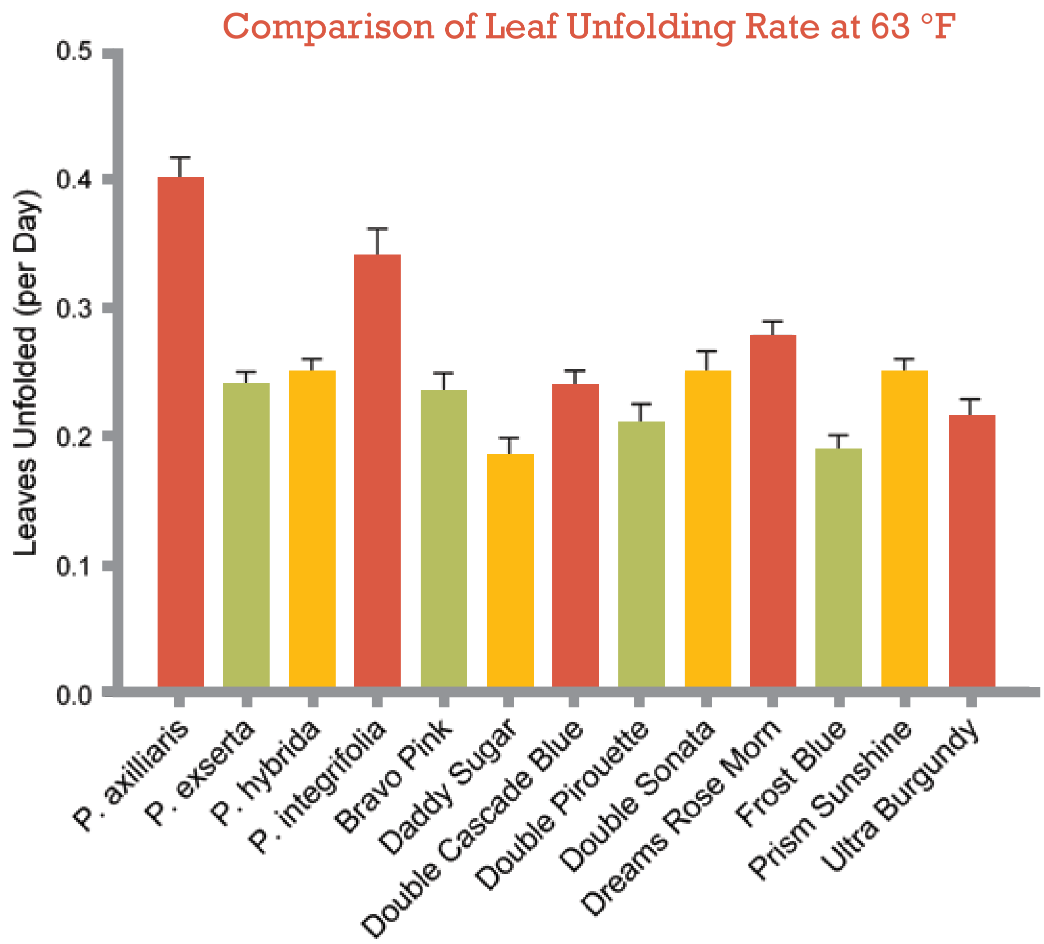

Figure 2. *Leaf unfolding rate of four petunia species and nine grandiflora-type cultivars at 63° F.*

temperate production areas, is a promising long-term strategy to improve the energy efficiency of greenhouse crop production. Crop production time is a function of the rate of development, i.e. leaf unfolding rate, and when the transition from vegetative growth to flowering occurs, which is usually dependent on unfolding a certain number of leaves and exposure to a particular photoperiod. Therefore, earlier flowering can be achieved either by increasing the leaf unfolding rate or by developing varieties that form fewer nodes before flowering (i.e. reducing the juvenile phase length).

Although lowering temperature reduces rate of development of all crops, not all species react similarly; some crops show more delay than others (Table 1). Even different cultivars within the same species exhibit different responses to temperature, suggesting a genetic basis for this trait that can be exploited to breed faster developing cultivars.

Petunia (*Petunia x hybrida*) is a hybrid between the species *Petunia axillaris* and *Petunia integrifolia*. We previously determined that both of these species have faster leaf unfolding rates than a broad panel of current grandiflora-type petunia cultivars, particularly at cooler production temperatures (Figure 2). For example, at 63° F, leaf unfolding rates of several petunia species and *P. x hybrida* cultivars varied between 0.18 and 0.40 leaves per day, with *P. axillaris* unfolding leaves at more than twice the rate of some cultivars! Leaf unfolding rates of both *P. axillaris* and *P. integrifolia* were considerably higher than any of the modern cultivars. Because modern garden petunias are a hybrid of *P. axillaris* and *P. integrifolia*, it is feasible to breed desirable traits from these species into commercial petunia genetics.

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We have developed interspecific hybrid populations between several petunia species and are using these populations to identify molecular genetic markers for fast leaf unfolding rate. We will be working with floriculture industry breeders to utilize these markers to develop earlier flowering varieties and to educate industry breeders in the use of marker-assisted breeding.

Developing crops with increased development rates will allow production at cooler temperatures, which has the potential to considerably reduce greenhouse fuel usage and costs. Alternatively, growth at warmer temperatures could allow for more crop turns through the greenhouse each season. While this research has been focused on earlier flowering under suboptimal environments, the genetic mapping populations we are developing will be useful for industry breeders to improve many other crop quality and performance traits.

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