RESEARCH REPORT: TEMPERATURE MANIPULATION OF VEGETABLE STEM ELONGATION AND FLOWERING

John E. Erwin, Gerald Pierson, Mark Strefeler and Royal Heins
University of Minnesota and Michigan State University

Commercial management of vegetable transplant stem elongation has relied heavily on the use of synthetic plant growth retardants.

Abstract

Commercial management of vegetable transplant stem elongation has relied heavily on the use of synthetic plant growth retardants. Concern over the impact of these compounds on the environment and human health has limited their use and may limit their availability (Bidinotto, 1990). Indeed, the approval for use of daminozide (Alar) has been removed for all food crops. It is, therefore, imperative that methods for manipulating plant stem elongation which do not involve the application of chemical be developed.

Stem elongation is greatly affected by the day (DT) and night temperature (NT) plants are grown under.

Stem elongation is greatly affected by the day (DT) and night temperature (NT) plants are grown under (Went, 1952; Tageras, 1979; Karlsson, 1986). Stem elongation increases as the DT increases and NT decreases (Went, 1952; Tageras, 1979; Karlsson, 1986). Recent research identified that plant stem elongation was primarily a function of the difference (DIF) between DT and NT when temperatures ranged from 10 to 30C on *Lilium* (Erwin et al., 1989a; Erwin, 1991; Moe et al., 1991). Stem elongation increased linearly as DIF increased from -15 to +15C (Erwin et al., 1989a; Moe et al., 1991).

Stem elongation sensitivity to temperature varies within the photoperiod (Erwin et al., 1989b). Stem elongation was particularly sensitive to a cool temperature drop during the first 2-3 hours of the morning on *Lilium* (Erwin et al., 1989a). Almost as much inhibition of stem elongation occurred when plants were cooled to temperatures below the NT during the first 3 hours of the morning as if plants were cooled all day on *Lilium* (Erwin et al., 1989a; Erwin, 1991). Similar reductions in stem elongation from a -DIF during the first 3 hours of the morning have been reported on *Salvia* and *Impatiens* (Erwin, 1991).

Control of stem elongation via temperature manipulation has been applied on ornamental pot and bedding plants, but not vegetable crops.

Control of stem elongation via temperature manipulation has been applied on ornamental pot and bedding plants, but not vegetable crops. The reasons for this are twofold: 1) the concept of temperature manipulation for control of stem elongation is relatively new and was developed in the ornamentals industry first and 2) uncertainty as to how temperature manipulations for control of stem elongation during the seed to transplant stage may affect subsequent field production. The objectives of the research presented in this paper were to: 1) determine the potential for application of temperature manipulation for control of stem elongation on vegetable crops, 2) gain some insight into the physiological mechanism underlying responses of stem elongation to temperature and 3) determine the affect of temperature manipulations on other aspects of vegetable plant development such as flowering and sex expression.

Materials and Methods

Experiment 1: Seedlings of *Zea maize* 'Snow Bell', *Pisum sativum* 'Mars', *Citrullus lanatus* 'Crimson Sweet', *Phaseolus vulgaris* 'Blue Lake', *Lycopersicum esculentom* 'Sunny' and *Cucumis sativus* were planted in a soilless medium composed of 50% sphagnum peat, 25% perlite and 25% vermiculite and were placed in a controlled environment chamber maintained at constant 22C. When seedlings reached the first true leaf stage of development, they were moved into growth chambers maintained at: 1) continuous light, constant 20C, 2) 12 hr photoperiod, constant 20C, 3) 12 hr photoperiod, 23 DT/17C NT, or 4) 12 hr photoperiod, 17 DT/ 23C NT. All growth chambers had the same average daily temperature. Irradiance was maintained at 250 μmol $s^{-1}m^{-2}$ supplied with fluorescent (75% total wattage) and incandescent lamps (25% total wattage). Data were collected on internode length, flowering characteristics and leaf morphology after 3 months.

Experiment 2: *Lycopersicum esculentum* cv 'Money Maker' seed were germinated in a soilless medium composed of 50% sphagnum peat, 25% perlite and 25% vermiculite and were placed in a controlled environment chamber maintained at constant 22C. When seedlings reached the first true leaf stage of development, they were moved into growth chambers maintained at constant 20C, 23 DT/17C NT, or 17 DT/23C NT. Irradiance and photoperiod were maintained at 250 $u$mol $s^{-1}m^{-2}$ and 12 hr, respectively. Plants were grown under fluorescent (75% total wattage) and incandescent lamps (25% total wattage).

At the 2nd true-leaf stage, plants in each chamber were divided into 3 groups of 5 plants each to receive growth regulator treatments. Growth regulator treatments consisted of spray applications of either ancymidol (52 ppm), GA_3 (12 ppm) or distilled water applied every 3 days for 21 days. Measurements were taken on internode length after 21 days.

Experiment 3: *Cucumis sativum* seed from EG11812-1 (gynoecious), EG29417-1 (androgenous), and EG6701-1 (hermaphroditic) lines were obtained from Dr. Jack Staub at the University of Wisconsin in 1990. Seed were germinated in a soilless medium composed of 50% sphagnum peat, 25% perlite and 25% vermiculite and were placed in a controlled environment chamber maintained at constant 22C on Feb. 14, 1990. Seedlings were moved into growth chambers maintained at constant 20C, 23 DT/17C NT, or 17 DT/23C NT at the first true leaf stage of development. Irradiance and photoperiod were maintained at 250 $u$mol $s^{-1}m^{-2}$ and 12 hr, respectively. Plants were grown under fluorescent (75% total wattage) and incandescent lamps (25% total wattage).

Data were collected on internode length, male flower number, female flower number and hermaphroditic flower number after 4 weeks. Data were collected on each plant on each of 3 representative nodes starting 2 nodes down from the shoot tip.

Results

Stem Elongation: Internode length increased as DT increased and NT decreased (Table 1). The

Table 1. The interaction between thermoperiod vs photoperiod on internode elongation of *Zea maize* 'Snow Belle', *Pisum sativum* 'Mars', *Citrullus lanatus* 'Crimson Sweet', *Phaseolus vulgaris* 'Blue Lake', *Lycopersicum esculentom* 'Sunny' and *Cucumis sativum*.

Crop	Cont. Light Fluct. Temp.	Cont. Temp. Fluct. Light (0C DIF)	23C Day 17C Night (+6C DIF)	17C Day 23C Night (-6C DIF)
Zea maize 'Snow Bell'	1.7 ± 0.5 [z]	3.9 ± 1.5	5.5 ± 0.8	1.7 ± 0.4
Pisum sativum 'Mars'	3.4 ± 0.4	2.0 ± 0.3	2.4 ± 0.3	2.3 ± 0.3
Citrullus lanatus 'Crimson Sweet'	3.7 ± 1.0	2.6 ± 1.1	2.5 ± 0.6	0.4 ± 0.1
Phaseolus vulgaris 'Blue Lake'	5.3 ± 0.6	4.2 ± 1.0	4.8 ± 0.8	3.6 ± 0.6
Lycopersicum esculentom 'Sunny'	2.3 ± 0.4	2.6 ± 0.3	4.6 ± 0.9	2.0 ± 0.3
Cucumis sativus	4.2 ± 2.2	7.6 ± 1.1	7.6 ± 1.4	4.7 ± 0.4

	r^{2} [y]	P	Significance
Zea	0.79	0.000	***
Pisum	0.03	0.455	n.s.
Citrullus	0.32	0.030	*
Phaseolus	0.32	0.020	*
Lycopersicum	0.78	0.000	***
Cucumis	0.51	0.001	***

z Numerals represent treatment means and standard deviations.
y Represents multiple r square of DIF response only.

***Lycopersicum esculentum* cv 'Money Maker' seed were germinated in a soilless medium composed of 50% sphagnum peat, 25% perlite and 25% vermiculite and were placed in a controlled environment chamber maintained at constant 22C.**

At the 2nd true-leaf stage, plants in each chamber were divided into 3 groups of 5 plants each to receive growth regulator treatments.

Table 2. The effect of fluctuating temperatures and light on vegetable plant flowering on *Pisum sativum* 'Mars', *Cucurbita pepo var. melopepo, Phaseolus vulgaris* 'Blue Lake' and *Lycopersicum esculentom* 'Sunny'.

Crop	Cont. Light Fluct. Temp.	Cont. Temp. Fluct. Light	23C Day 17C Night	17C Day 23C Night
Pisum sativum 'Mars'				
Flowers/node	1.7 + 0.5 [z]	2.0 + 0.0	2.0 + 0.0	1.2 + 0.4
Cucurbita pepo var. *melopepo*				
Male flowers	5.6 + 2.3	1.3 + 0.8	5.6 + 2.1	2.0 + 1.4
Female flowers	2.7 + 2.1	1.7 + 0.5	0.4 + 0.5	2.0 + 0.7
male/female ratio	2.07	0.8	14.0	1.0
Phaseolus vulgaris 'Blue Lake'				
Flowers/node	2.5 + 0.6	3.6 + 0.5	1.8 + 0.8	1.3 + 0.5
Lycopersicum esculentom 'Sunny'				
Flowers/cluster	4.7 + 1.0	4.7 + 1.0	4.3 + 0.5	4.0 + 0.0

[z] Numerals represent treatment means and standard deviations about the treatment mean.

Species responded differently to DIF.

effect of DT and NT on internode elongation could best be described as a function of the difference (DIF) between DT and NT (DT-NT) (Table 1, Table 2, Figure 1). Internode length increased linearly as DIF increased from -6 to +6C when temperatures ranged from 12 to 24C in Experiment 1 and 2 (Figure 1). For instance *Zea* internode length increased from 1.7 to 5.5 cm as DIF increased from -6 to +6C in Experiment 1 (Table 1). Similarly, *Lycopersicum* internode length increased from 1.4 to 2.1 cm as DIF increased from -6 to +6C in Experiment 1 (Table 1; Figure 1) and increased from 1.0 to 2.1 cm as DIF increased from -6 to +6C in Experiment 2 (Table 2).

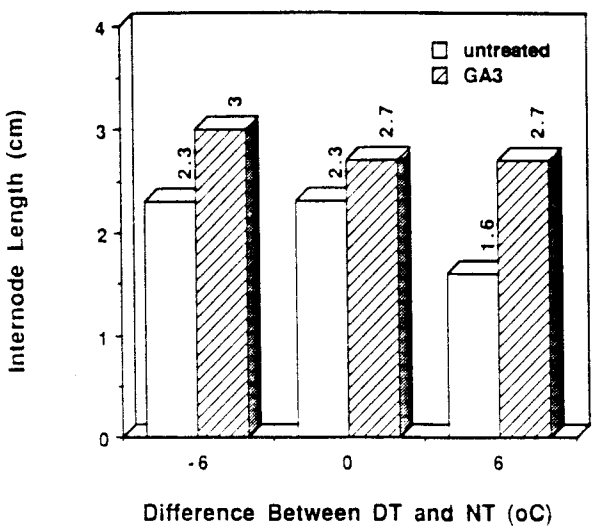


Figure 1. Stimulation of elongation of *Lycopersicum* internode elongation of plants grown in 23 DT/17C Nt versus 17 DT/23C NT environment before and after GA_3 application (Erwin and Pierson, 1992).

The response of *Cucumis* to DIF varied among experiments and among different genetic lines.

Species responded differently to DIF. The degree of correlation of internode length data with DIF (r^2) was greatest on *Zea* and *Lycopersicum* and least on *Pisum*, *Citrullus* and *Phaseolus* (Table 1). *Pisum* showed no response to DIF (r^2 = 0.03; P = 0.455) (Table 1). *Cucumis* elongation showed an intermediate response to DIF; although correlation was not high (r^2 = 0.51) a significant trend between DIF and internode length was evident (P=0.001) (Table 1).

The response of *Cucumis* to DIF varied among experiments and among different genetic lines (Tables 1 and 3). *Cucumis* internode length increased linearly as DIF increased from -6 to +6C in Experiment 1 (Table 1). Internode lengths on plants from the gynoecious line of *Cucumis* responded to DIF as in Experiment 1, i.e. internode length increased linearly as DIF increased (Table

3). In contrast, internode length was greatest in androgenous and hermaphroditic lines when DT and NT were constant (Table 3), i.e. the standard increasing linear response to DIF was not evident.

Continuous light and alternating thermoperiod promoted internode elongation on some species but not others (Table 1). For instance, *Zea*, *Lycopersicum* and *Cucumis* elongation was inhibited by continuous lighting whereas *Pisum*, *Citrullus* and *Phaseolus* elongation were promoted by continuous lighting (Table 1). Interestingly, elongation on those crops which were most responsive to DIF were most inhibited by continuous lighting (Table 1). In contrast, elongation on species which were not responsive to DIF was promoted by continuous lighting. In fact, percent stimulation of elongation by continuous lighting was highly correlated with responsiveness of species to DIF (Figure 2). Experiments are currently underway studying the relationship between thermo- versus photosensitivity of plants with respect to stem elongation.

Continuous light and alternating thermoperiod promoted internode elongation on some species but not others.

Flower Development: Flower formation was affected by the DT/NT environment which plants were grown under and plant species. For instance, *Cucumis* sex expression was dramatically altered by DT/NT regime. Maleness was promoted by a +DIF environment whereas femaleness was promoted by a 0 or -DIF environment in Experiment 1 (Table 3; Figure 3). These findings are consistent with data which suggests that +DIF environments promote gibberellin biosynthesis. Increased levels of gibberellins have been associated with promotion of maleness in *Cucurbitae*.

Conflicting results were found in Experiment 3 (Table 3). Maleness was promoted in an androgenous line in Experiment 3 on *Cucumis* when plants were grown under constant 20C. Hermaphroditic flowers were promoted when temperatures fluctuated with a + or -DIF compared to plants grown at constant 20C (0C DIF) (Table 3). Gynoecious lines of *Cucumis* produced female flowers regardless of DT/NT environment (Table 3).

Flower formation was affected by the DT/NT environment which plants were grown under and plant species.

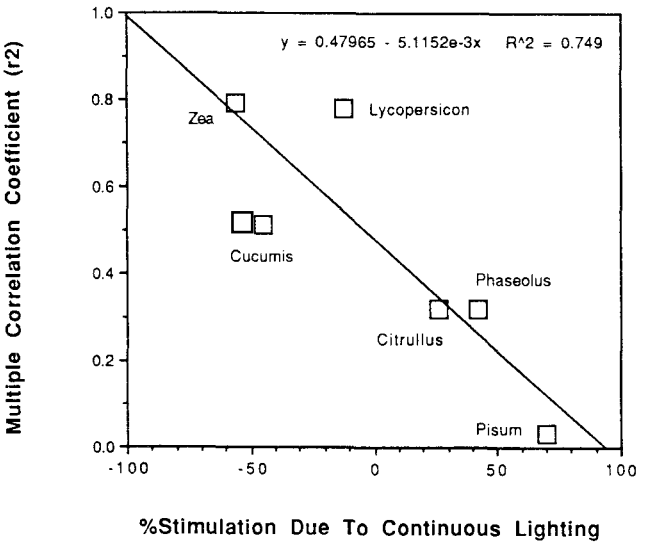
Table 3. The effect of day/night temperature relationship on flower sex expression of *Cucumis sativum* EG11812-1, EG29417-1 and EG6701-1 lines. Data were collected on internode length, male flower number, female flower number and hermaphroditic flower number after 4 weeks. Data were collected on each plant on each of 3 representative nodes starting 2 nodes down from the shoot tip.

	Temperature Treatment		
Cultivar Characteristic	**+ DIF**	**0 DIF**	**- DIF**
EG11812-1 (gynoecious)			
Internode length	5.3 ± 1.2 [z]	4.7 ± 1.5	3.4 ± 1.0
Female flowers	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0
Male flowers	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Hermaphroditic	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
EG29417 -1 (androgenous)			
Internode length	4.9 ± 0.7	8.5 ± 0.8	3.8 ± 1.2
Female flowers	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Male flowers	0.0 ± 0.0	5.6 ± 0.9	0.0 ± 0.0
Hermaphroditic	4.8 ± 1.0	0.7 ± 0.6	5.3 ± 1.0
EG6701-1 (hermaphroditic)			
Internode length	5.3 ± 1.1	7.7 ± 1.3	5.1 ± 1.2
Female flowers	0.0 ± 0.0	0.0 ± 0.0	0.0 + 0.0
Male flowers	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Hermaphroditic	6.4 ± 1.9	9.6 ± 2.4	8.6 ± 2.2

[z] Numerals represent treatment means and standard deviation about the mean.

Gynoecious lines of *Cucumis* produced female flowers regardless of DT/NT environment.

Figure 2. *P*ercent stimulation due to continuous lighting of *Zea maize* 'Snow Bell' *Lycopersicum esculentom* 'Sunny', *Cucumis sativus*, *Citrullus lanatus* 'Crimson Sweet', *Phaseolus vulgaris* 'Blue Lake' and *Pisum sativum* 'Mars' when compared with DIF treatments.



Pisum flower number per node decreased when plants were grown in a -DIF environment.

Phaseolus flower number per node decreased if temperatures were fluctuated at all.

Lycopersicum flower number per cluster was unaffected by temperatures between 12 and 24C.

Pisum flower number per node decreased when plants were grown in a -DIF environment (Table 3). *Phaseolus* flower number per node decreased if temperatures were fluctuated at all (Table 3). *Lycopersicum* flower number per cluster was unaffected by temperatures between 12 and 24C (Table 3).

Literature Cited

Bidinotto, R.J. 1990. The great apple scare. Reader's Digest, October 1990.

Erwin, J.E., R.D. Heins and M.G. Karlsson. 1989a. Thermomorphogenesis in *Lilium longiflorum* Thunb. Amer. J. Bot., 76:47-52.

Erwin, J.E., R.D. Heins, R.D. Berghage, B.J. Kovanda, W.H. Carlson and J.A. Biernbaum. 1989b. Cool mornings can control plant height. GrowerTalks, 52(9):73-74.

Erwin, J.E. 1991. Thermomorphogenesis in plants. Ph.D. Thesis. Michigan State University.

Erwin, J.E., R.D. Heins and R. Moe. 1991. Temperature and photoperiod effects on *Fuchsia x hybrida*. J. Amer. Soc. Hort. Sci., 116:955-960.

Erwin, J.E. and G. Pierson. 1992. Interaction between diurnal temperature fluctuations and gibberellins on *Lycopersicum* stem elongation and chlorophyll content. HortScience, 27(6):657.

Karlsson, M.G. 1986. Temperature and irradiance effects on *Dendranthema grandiflorum* cv 'Bright Golden Anne' growth and development. PhD Thesis. Department of Horticulture, Michigan State University.

Moe, R., R.D. Heins and J. Erwin. 1991. Effect of day and night temperature alterations, and plant growth regulators on stem elongation and flowering of the long-day plant *Campanula isophylla* Morettii., Scient. Hort., 48:141-151.

Tageras, H. 1979. Modifying effects of ancymidol and gibberellins on temperature induced elongation in *Fuchsia x hybrida*. Acta Hort., 91:411-417.

Went, F. 1952. The effect of temperature on plant growth. Ann. Rev. Plant Physiol., 362.

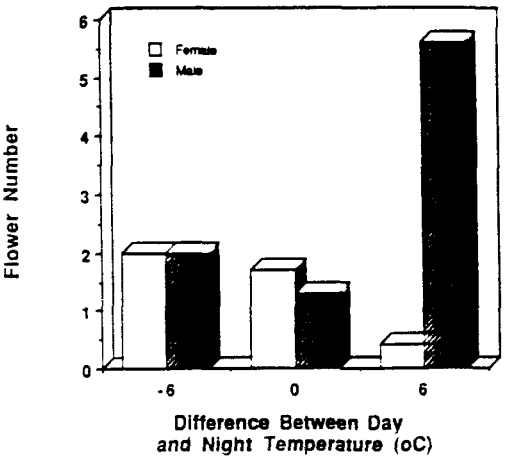


Figure 3. Effect of difference (DIF) between DT and NT on *Cucurbita* of male versus female flower number (Erwin, 1991).