High-temperature Inhibition of Seed Germination and Seedling Emergence of Broccoli

Marshall K. Elson[1], Ronald D. Morse[2], Dale D. Wolf[3], and David H. Vaughan[4]

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Summary. High summer temperatures may reduce plant stands of direct-seeded fall broccoli *(Brassica* oleracea var. italica Plenck). The influence of constant and diurnally alternating temperatures in the range of 5 to 42C on germination and emergence of 'Packman' broccoli was evaluated. Germination was defined as protrusion of the radicle from the seedcoat, and emergence as 10 mm elongation of the radicle. The range of constant temperatures from 10 to 30C for 14 days was satisfactory for 90% germination and 75% emergence. However, alternating temperatures extended the acceptable emergence range to 5/17 through 20/32C. Since soil temperatures in warm climates often exceed 20/32C during the summer, high-temperature inhibition of seed germination and seedling emergence is a potentially important factor limiting direct-seeded broccoli stands.

[1]*Graduate Student, Department of Horticulture, Michigan State University East Lansing MI 48824.*

[2]*Associate Professor, Department of Horticulture, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061.*

[3]*Professor, Department of Crop and Soil Environmental Science, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061.*

[4]*Professor, Department of Agricultural Engineering Virginia Polytechnic Institute and State University, Blacksburg, VA 24061.*

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Efforts to produce direct-seeded fall broccoli in Virginia and other warm climates have resulted in poor stand establishment. Many factors affect stand establishment of a direct-seeded crop, including soil temperature, soil moisture, planting depth, seed size, and seed vigor. Since fall broccoli is direct-seeded in July and August, when soil surface temperatures often exceed 35C, high soil temperatures may have a significant influence on germination and emergence of broccoli.

Harrington and Minges (1956) and Wagenvoort and Bierhuizen (1977) evaluated the influence of temperature on many vegetables. However, neither of these studies included broccoli.

Wagenvoort and Bierhuizen (1977) defined the "practical" germination temperature range as the temperature extremes (Tp_{min}, and Tp_{max},) between which a predetermined acceptable germination percentage is achieved in a limited period of time. For example, the germination percentage of red cabbage *(Brassica oleracea* var. *purpurea)* was ≥75% between 5 and 25C after 2 weeks. Below the Tp_{min} (5C) and above Tp_{max} (25C), germination was reduced to <75%.

Hegarty (1975, 1977, 1978) investigated numerous aspects of broccoli germination and emergence. However, his temperature studies did not exceed 25C. If the "practical" germination temperature maximum of 25C for red cabbage (Wagenvoort and Bierhuizen, 1977) approximates the limits for other *Brassica oleracea* varieties, high soil temperatures would limit stand establishment of fall broccoli during hot weather.

Hegarty (1975) has shown that diurnally alternating temperatures increased the germination of broccoli. Alternating temperatures are more representative of field conditions and have been shown to increase germination in many crops (Ellis et al., 1982; Hegarty, 1975; Logendra, 1984; Probert and Smith, 1986; Thompson and Fox, 1976). As a result, alternating temperatures may increase germination and emergence at high temperatures.

The objective of this study was to determine the constant and diurnally alternating temperature limits for acceptable germination and emergence of broccoli. Germination does not necessarily equate with emergence,

because germination may proceed at a temperature that inhibits growth (Hegarty, 1975). The acceptable levels for this study were set arbitrarily at 90% germination and 75% emergence within 14 days. Germination was defined as protrusion of the radicle from the seedcoat, and emergence as 10 mm elongation of the radicle.

Seeds of 'Packman', graded to 1.75 to 2.00 mm (#5) and treated with tetramethylthiuramidisulfide (thiram) and methyl-1-(butylcarbamoyl)-benzimidazol-2-yl carbamate (benlate), were obtained and stored at 5C for this study. The seed label indicated 90% germination under commercial seed-testing procedures. Twenty seeds were placed in two rows on a single layer of moistened Whatman #1 filter paper in 10-cm petri dishes.

The petri dishes were placed at temperatures from 5 to 42C on a 100 × 100-cm aluminum thermogradient table in a dark, unheated growth chamber. The desired temperatures were maintained by pumping heated or cooled water through reservoirs at either end of the table. The top, bottom, and sides of the table were insulated with 2.5.cm Styrofoam, and the entire table was set at a 25% incline to produce geotropic response in the seedlings and provide access to water without submerging the seeds. Temperatures were monitored with two calibrated thermocouples located at each treatment temperature, plus one for ambient temperature in the growth chamber. The largest temperature variation was ± 1.0C at 42C.

Three single-factor temperature studies (constant, high, and alternating) were conducted with replications over time. A fourth study was conducted to determine the effects of short term exposure to high temperatures. Petri dishes containing seeds were placed at the assigned temperatures, and 10 ml ofdistilled water was added. Germination and emergence percentages were recorded every 10 to 14 h for 14 days, which was considered the practical germination period. The rate of emergence was determined by the number of days to 50% emergence. The data were tested by analysis of variance and linear regression (SAS Institute, 1985). Least significant difference values were calculated from the pooled variances of the treatments.

Constant temperatures. Treatments consisted of 5, 10, 15, 20, 25, 30, 35, or 40C. Three petri dishes of 20 seeds each were placed at each treatment for a total of 60 seeds/ treatment. Four replicationswere completed over time.

Germination at constant temperatures showed only slight differences from 5 to 30C (Fig. 1). However, germination was only 63% at 35C and zero at 40C. Emergence followed a similar pattern, although the percentages generally were lower than germination. For example, germination at 25C was 93%, but emergence was only 85%. Emergence at the temperature extremes was very low. At 5C germination was 90%, but emergence was only 4%. At 35C germination was 63% and emergence was 6%. The range of temperatures from 10 to 30C was satisfactory for ≥90% germination and ≥75% emergence ofbroccoli within 14 days. Although 5C was satisfactory for 90% germination, the growth rate was so slow that the radicles did not reach 10 mm within 14 days. In the field, such slow growth rates could expose the seedlings to unfavorable emergence and survival conditions.

High temperatures. Treatments of 30, 32, 34, 36, or 38C were used to define further the upper temperature limit for germination and emergence of broccoli. One petri dish was placed at each temperature for 20 seeds/ treatment. Four replications were completed over time.

Germination and emergence generally decreased as the temperatures increased from 30 to 38C (Fig. 2). Both germination and emergence were nearly linear (r^2 = 0.87 and 0.88, respectively), although 30C was the only treatment in the acceptable emergence range. High temperatures limited radicle growth more than germination, as demonstrated by the larger number of seedlings with terminated radicles. Logendra (1984) also reported that temperature limits growth more than germination in soybeans germinated at 40C. The influence of high temperatures was most evident at 36C, where germination of broccoli seed continued at a low level (31%), but emergence was zero. As a result, 36C may be the upper limit for survival of 'Packman' broccoli seedlings.

Alternating temperatures. Diurnally alternating temperatures of 12C magnitude were simulated by placing the petri dishes at a low temperature for 12 h, then moving them to a higher

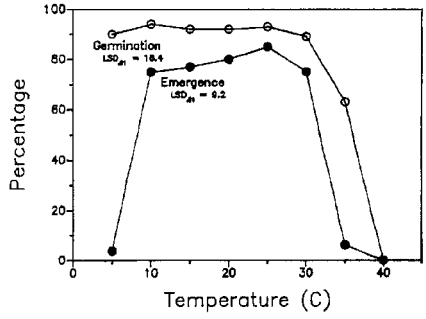

Fig. 1. *Germination and emergence of 'Packman' broccoli at selected constant temperatures from 5 to 40C. Eachpoint represents the mean of four replications of 60 seeds after 14 days.*

temperature for 12 h (Vazquez-Yanes and Orozco-Seqovia, 1982). Treatments consisted of the following combinations: 5/17, 10/22, 15/27, 20/ 32, 25/37, or 30/42C and vice versa. Two petri dishes were placed at each treatment for a total of 40 seeds/ treatment with three replications over time. For example, two petri dishes were placed at 5C and two at 17C, then they were switched after 12 h. Two-sample *t* tests showed no significant difference between imbibition at a high or a low temperature; therefore, the data were pooled before analysis.

The germination and emergence percentages showed only slight differences in the range of alternating temperatures from 5/17 to 20/32C (Fig. 3). However, the percentages were below the acceptable levels at the higher temperature regimes, similar to the constant temperature results. At 25/ 37C, germination averaged 72% and emergence was 10%. At 30/42C, germination averaged only 10% and emergence was zero.

Alternating temperatures may extend the acceptable range for emer-

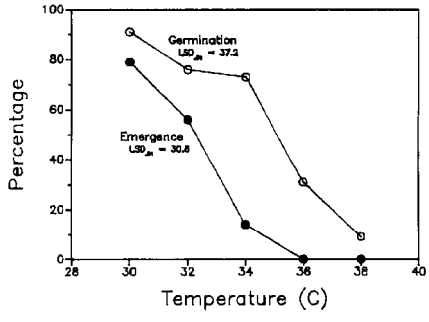

Fig. 2. *Germination and emergence of 'Packman' broccoli at selected high temperatures from 30 to 38C. Each point represents the mean of four replications of 20 seeds* after *14* days. *The regression equations are: germination, y = 406.0 - 10.3x,* r^2 *= 0.76 ± 0.01; emergence, y = 395.75 - 10.75x,* r^2 *= 0.77 ± 0.01.*

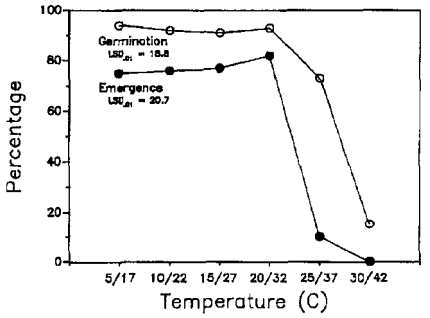

Fig. **3.** *Germination and* emergence of *'Packman' broccoli with selected 12C alternating temperatares every 12 b for 14 days. Each point* represents *the* mean *of three replications of 80 seeds.*

gence at both extremes (Fig. 3). For example, exposure to 17C for 12-h intervals promoted sufficient radicle growth so that seedlings could be exposed to 5C and still emerge within 14 days. At the high-temperature regimes, 82% emergence at 20/32C compared with 52% at a constant 32C indicated that broccoli is capable of withstanding higher temperatures when accompanied by a more optimum cooler temperature. However, final emergence of only 29% at 25/37C compared with ≈65% at a constant 31C suggests that exposure to 37C for just 12 h was sufficient to severely limit emergence.

Alternating temperatures modified the rate ofemergence at both low- and high-temperature regimes when their mean temperatures are compared with constant temperatures (Fig. 4). Hegarty (1975) found that alternating temperatures stimulated the rate of emergence of 'Rex' broccoli. However, our study suggests that alternating temperatures increased the rate of

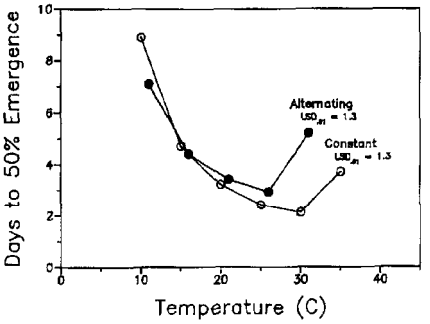

Fig. 4. *Days to 50% emergence of 'Packman' broccoli at selected constant and alternating temperatures. Alternating temperatures presented as the average of the high and low temperature. Constant temperature points represent the mean of four replications. Alternating temperature points represent the mean of three replications.*

emergence only slightly at the lower temperatures. At the other extreme, high alternating temperatures delayed emergence, as demonstrated by 5.2 days to 50% emergence at 25/37C compared with 2.1 days to 50% emergence at a constant 30C.

Short-term high temperatures. Continuous high temperatures seldom would occur over a 14-day period in normal field situations. To test the effects of short-term exposure to high temperatures, broccoli seeds were imbibed in petri dishes on the thermogradient table at 40C, then moved to 25C at 0, 2, 4, 6, 12, 18, or 24 h. One petri dish was moved at each time treatment for a total of 20 seeds/ treatment. Five replications were completed over time.

Germination and emergence decreased as the time of exposure increased from 2 to 24 h (Fig. 5). Both germination and emergence were nearly linear (r^2 = 0.73 and 0.79, respectively) over the 24-h period. Exposure for 2 h did not reduce germination and emergence much below the acceptable levels; however, a single exposure of 4 h at 40C reduced emergence to 60%. Summer broccoli plantings in warm climates frequently experience one or more days with soil temperatures around 40C for 4 to 6 h. During hot weather, air temperatures often reach 40C, and surface soil temperatures could be >40C, particularly in dry soil. Thus, growers should plant at the coolest time possible and use cultural practices to reduce soil temperature and accelerate emergence.

Interpretive summary. Summer soil temperatures in warm climates are likely to limit the establishment of direct-seeded fall broccoli. 'Packman' can produce 90% germination and 75% emergence in the alternating temperature range of 5/17 to 20/32C. Temperatures ≥ 35C severely limited emergence. Short-term exposure to 40C for a single, 4-h period reduced emergence to 60%.

Temperature-reducing cultural practices are recommended to improve stand establishment of broccoli under high-temperature conditions. Planting in the evening would allow the seeds to imbibe water and initiate germination processes during the cooler night temperatures. Frequent, light irrigations and organic mulches also reduce soil temperature during hot weather.

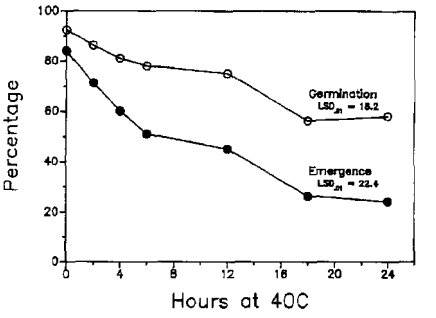

Fig. 5. *Germination and* emergence *of 'Packman' broccoli imbibed at 40C and transferred to 25C after* a *selected number of hours. Each point represents the* mean *of five replicationsof* 20 seeds after 10 days. The regression *equations are: germination, y = 87.45 - 1.375x,* r^2 *= 0.54 ± 0.01;* emergence, y = *70.25 - 2.15x,* r^2 *= 0.63 ± 0.01.*

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