Temperature Cycling Periods Meet Growth and Tuberization in Potatoes under Continuous Irradiation

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Abstract. Plants of the potato (*Solanum tuberosum* L.) cultivars Denali, Norland, Haig, and Kennebec were grown for 42 days under three temperature cycling periods (thermoperiods) with continuous irradiation in two repeated experiments to help determine if temperature cycling might be varied to optimize tuber development of potatoes in controlled environments. Thermoperiods of 6/6 hours, 12/12 hours and 24/24 hours were established with the same temperature change of 22/14C and same controlled vapor pressure deficit of 0.60 kPa. The thermoperiod of 24/24 hours significantly promoted tuber initiation but slowed tuber enlargement in all four cultivars, compared to the thermoperiods of 6/6 hours and 12/12 hours. 'Denali' produced the highest tuber and total dry weights under the 6/6 hours thermoperiod. 'Kennebec' produced the highest tuber dry weight under the 12/12 hours thermoperiod. Thermoperiods had no significant effect on shoot and root dry weights of any cultivars. The major effect of thermoperiod was on initiation and enlargement of tubers.

Temperature plays a key role in regulating growth and yield in potatoes (Bodlaender, 1963; Ewing, 1981; Gregory, 1965; Tibbitts et al., 1989). Growth at 17C maximizes tuberization (Gregory, 1965), whereas growth at 25C maximizes top growth (Benoit et al., 1983). In another study, 20C produced the highest plant dry weights with high tuber yields (Wheeler et al., 1986). Also, a day/night temperature fluctuation (thermoperiod) is considered to be necessary for maximum tuber yields (Benoit et al., 1986; Bodlaender, 1963; Ewing, 1981; Gregory, 1965). High day and low night temperature cycle of 22/14C with a 12-h photoperiod promoted growth and tuberization in potatoes as compared to a constant 18C, although the amount of promotion from temperature fluctuation varied with cultivar (Bennett et al., 1991). However, low day and high night temperature cycles of 12/24C with 10- or 14-h photoperiod produced less growth than high day and low night temperature cycles of 24/12C at the same photoperiods (Steward et al., 1981).

Temperature fluctuations of 22/14C in 12/12-h cycles effectively prevented leaf necrosis and growth stunting in 'Kennebec' and 'Superior' potatoes when grown under continuous irradiation (Tibbitts et al., 1990). However, temperature fluctuations have not been found to be required for healthy growth of 'Denali' and 'Haig' under continuous ir-

radiation (Cao and Tibbitts, 1991; Tibbitts et al., 1989). The objective of the study we now report was to establish the effects of various durations of temperature cycling on growth and tuberization of potatoes under continuous irradiation. This study was designed to help determine if temperature cycling might be varied to optimize yields of potatoes in life support systems being developed for long-term space bases (Tibbitts et al., 1989).

The experiment was conducted in controlled-environment rooms at the Biotron, Univ. of Wisconsin-Madison, with 'Denali', 'Norland', 'Haig', and 'Kennebec' potatoes. 'Norland' and 'Haig' are early maturity cultivars that tuberize readily under various growing conditions. 'Denali' is a mid-maturity and 'Kennebec' a late-maturity cultivar. Also, 'Kennebec' is injured under continuous light when temperature is kept constant, while the other three cultivars are not sensitive to continuous light (Cao and Tibbitts, 1991; Wheeler et al., 1986). Plants of the four cultivars were raised from micropropagated stem cuttings grown in sterile agar culture (Tibbitts et al., 1989). Uniform single plantlets were transplanted into the centers of 8-liter plastic pots containing 1 commercial peat : 1 vermiculite (v/v) that had a pH of 6.5. The transplants were covered with glass beakers for the first 3 days to minimize transplant shock. An additional 3 cm of medium was added to the pots 14 days after transplanting to cover the lower plant nodes. Plants were watered to excess four times daily, using a complete nutrient solution (Hammer et al., 1978).

Three temperature cycling periods were established at 6/6 h, 12/12 h and 24/24 h with a temperature regime of 22/14C. Relative humidity levels of 76% at 22C and 62% at 14C were provided to maintain a constant

vapor pressure deficit (VPD) of 0.60 kPa at both temperatures. The three thermoperiod treatments were maintained in three separate growth rooms. In each growth room, the four cultivars were arranged in six randomized blocks. Temperature and vapor pressure were monitored continuously by computer and checked daily using a thermocouple psychrometer. The ranges of room averages in the first study were 22.0/14.0 $\pm$ 0.2C and 0.60 $\pm$ 0.02 kPa VPD. Continuous irradiation was provided by metal halide lamps at a photosynthetic photon flux (PPF) of 385 $\pm$ 7 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ (range of room averages). The PPF was measured weekly at the top of the canopy with a LI-COR quantum sensor (LI-185; LI-COR, Lincoln, Neb.). Carbon dioxide levels were ambient at 350 $\mu\text{l}\cdot\text{liter}^{-1}$.

Following the first study, the experiment was repeated, but treatments were switched among growth rooms. The ranges of room averages for environmental conditions in the second study were 22.0/13.9 $\pm$ 0.1C, 0.60 $\pm$ 0.02 kPa VPD, and 350 $\pm$ 3 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ PPF.

Plants were harvested 42 days after transplanting. Number of tubers was counted for each cultivar. All plant material was oven-dried at 70C for 2 days, and then tuber and total dry weights were determined. Analysis of variance was performed for each cultivar separately in a randomized block design with three thermoperiod treatments and two replications between growth rooms.

The number of tubers increased with increasing thermoperiod in all four cultivars, although the difference between 6/6 h and 12/12 h was significant only for 'Denali'

Table 1. Number of tubers of four potato cultivars grown for 42 days under three thermoperiods.

Cultivar	Thermoperiod (h) ^a		
	6/6	12/12	24/24
	No./plant ^b		
Denali	16.1 c	20.1 b	24.3 a
Norland	24.2 b	28.8 b	44.2 a
Haig	30.1 ab	25.6 b	38.7 a
Kennebec	7.3 b	8.3 ab	11.4 a

^aThree temperature cycling periods with temperature regime of 22/14C.

^bMeans of 12 replicate plants. Mean separation in each row by Duncan's multiple range test, $P = 0.05$.

Table 2. Tuber dry weights of four potato cultivars grown under three thermoperiods.

Cultivar	Thermoperiod (h) ^a		
	6/6	12/12	24/24
	g/plant ^b		
Denali	32.1 a	25.5 b	24.4 b
Norland	9.0 a	7.3 a	7.3 a
Haig	12.8 a	13.2 a	12.6 a
Kennebec	3.3 ab	5.3 a	2.1 b

^aThree temperature cycling periods with temperature regime of 22/14C.

^bMeans of 12 replicate plants. Mean separation in each row by Duncan's multiple range test, $P = 0.05$.

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(Table 1). The promotive effect of 24/24 h thermoperiod on tuber initiation was especially marked in 'Denali' and 'Norland'. Number of tubers for all cultivars averaged 48% higher with 24/24 h thermoperiod than with other thermoperiods. These results indicate that thermoperiod can significantly affect tuber formation in potatoes.

The effects of thermoperiod on tuber dry weights varied with cultivar (Table 2). Tuber dry weights of 'Norland' and 'Haig' were similar under the three thermoperiods. However, tuber dry weight in 'Denali' was significantly higher under the 6/6 h thermoperiod than under 12/12 h or 24/24 h thermoperiods. Tuber dry weight in 'Kennebec' under the 12/12 h thermoperiod was higher than under 24/24 h and not significantly different from that under 6/6 h. The 24/24 h thermoperiod increased number of tubers (Table 1) but did not increase tuber dry weight (Table 2) relative to the 6/6 h or 12/12 h thermoperiods. Thus, the average dry weight per tuber was lowest under the 24/24 h thermoperiod, suggesting that this thermoperiod slows tuber enlargement in potatoes.

Total plant dry weights for each cultivar were similar under the three thermoperiod, except that 'Denali' produced significantly higher total dry weight under 6/6 h thermoperiod than under 12/12 h (73.0 vs. 64.4 g; $P = 0.05$). The differences in total dry weight for 'Denali' were apparently related to the significantly higher tuber dry weight under the 6/6 h thermoperiod (Table 2). Shoot and root dry weights of each cultivar were similar under the various thermoperiods (data not shown).

Plants of 'Kennebec' grown under three thermoperiods did not exhibit any typical continuous light injury that was observed un-

der constant light and temperature conditions (Cao and Tibbitts, 1991; Tibbitts et al., 1990). Thus, continuous irradiation injury in 'Kennebec' plants can be prevented by temperature fluctuation, not only with a 12/12 h temperature cycling period, as reported by Tibbitts et al. (1990), but also with 6/6 h and 24/24 h cycles.

The response of 'Kennebec' to thermoperiods was different than the response seen in the other cultivars. Tuber dry weights in 'Kennebec' were lower under both shorter (although not significantly) and longer temperature cycles than under the 12/12 h thermoperiod (Table 2), a consistent response in both replications. 'Kennebec' is also the most sensitive cultivar to continuous light under constant temperature (Cao and Tibbitts, 1991; Tibbitts et al., 1990). Apparently, 'Kennebec' has less plasticity in response to extremely short or long temperature cycles.

This study demonstrates that the major effect of thermoperiods under continuous irradiation was on the tuber development of potatoes. A 24/24 h thermoperiod promoted tuber initiation but slowed tuber enlargement in some cultivars as compared with 6/6 h and 12/12 h thermoperiods. The results suggest that it may be possible to use long thermoperiods during early growth to promote tuber initiation, and then use short thermoperiod during late development to promote tuber enlargement. Thus, it seems likely that a careful control of thermoperiods at some growth stages would increase yields of potatoes in controlled growing facilities.

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