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Vegetative Growth, Cold Acclimation, and Dormancy as Affected by Temperature and Photoperiod in Six Red Raspberry (*Rubus idaeus* L.) Cultivars

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Summary

The effects of temperature (4 or 20 °C) and photoperiod (9 or 18 h) on vegetative growth, cold acclimation and induction of dormancy in six red raspberry (*Rubus idaeus* L.) cultivars were studied in two experiments at different times of a year. Cane elongation and the number of new nodes were more strongly affected by temperature than by photoperiod. Photoperiod had very little effect on growth at 4 °C, but short day reduced growth at 20 °C. Cold hardiness of raspberry canes and buds was only affected by treatment temperature. In most cultivars deeper dormancy was induced at 20 °C than at 4 °C, and the effect of photoperiod was dependent on temperature. During spring experiment growth was more vigorous and the plants reacted more readily to changes in photoperiod than during fall experiment. However, greater cold hardiness and deeper dormancy were induced during fall experiment.

Zusammenfassung

Einfluss von Temperatur und Photoperiode auf vegetatives Wachstum, Kälteakklimatisierung, und Wachstumsruhe von sechs Himbeersorten (*Rubus idaeus* L.). Die Einflüsse von Temperatur (4 oder 20 °C) und Photoperiode (9 oder 18 h) auf das vegetative Wachstum, die Kälteakklimatisierung, und die Induktion der Wachstumsruhe von sechs Himbeersorten (*Rubus idaeus* L.) wurden in zwei Versuchsreihen in unterschiedlichen Jahrezeiten untersucht. Das Rutenwachstum und die Anzahl neuer Nodien wurden wesentlich stärker von der Temperatur als von der Photoperiode beeinflusst. Bei 4 °C hatte die Photoperiode einen sehr geringen Einfluss, allerdings verminderte der Kurztag das Wachstum bei 20 °C. Die Widerstandsfähigkeit der Ruten und Knospen gegen Kälte wurde nur von der Behandlungstemperatur beeinflusst. Bei den meisten Sorten wurde bei 20 °C eine tiefere Wachstumsruhe induziert als bei 4 °C, und die Wirkung der Photoperiode war von der Temperatur abhängig. Bei der Untersuchung im Frühjahr war das Wachstum stärker und die Pflanzen reagierten bereitwilliger auf die Wechsel der Photoperiode als im Herbst. Allerdings konnten im Herbst eine größere Widerstandsfähigkeit gegen Kälte und tiefere Wachstumsruhe induziert werden.

Key words. cane elongation – day length – hardiness – LT_{50} – rest

Introduction

Temperature is considered a critical factor determining the growth pattern of raspberry (*Rubus idaeus* L.) plants (HOOVER et al. 1989) with growth rate maximum being at about 22 to 24 °C (CAREW et al. 1999, 2003). Furthermore, growth is affected by photoperiod. In cv. 'Malling Promise' warm temperature (21 °C) induced vigorous growth and low temperature (10 °C) stopped cane elongation regardless of photoperiod (WILLIAMS 1959). However, at intermediate temperature (15.5 °C) short photoperiod (9 h) caused growth cessation and onset of dormancy, whereas at long photoperiod (14 h) growth continued in a similar manner to that at higher temperature. On the other hand, CAREW et al. (2003) found no evidence of the effect of photoperiod on vegetative growth of cv. 'Autumn Bliss' at temperature of 20/15 °C (day/night) although the time to flowering was decreased as photoperiod increased from 8 to 11 or 14 h.

Dormancy and cold hardiness in plants are interlinked, although their exact relationship is not clear. During the first stage of cold acclimation short photoperiod usually brings about growth cessation that is a prerequisite for cold acclimation (WEISER 1970). However, low temperature can stop growth and induce cold acclimation without inducing dormancy (IRVING and LANPHEAR 1967; WEISER 1970). Generally in woody plants photoperiod gives a signal for the initiation of hardening, but temperature has a major role in regulation of cold hardiness (JUNTTILA 1996). According to WILLIAMS (1959), both short days and low temperatures are responsible for dormancy induction in raspberry. Detailed studies on the effect of photoperiod and temperature on cold acclimation in raspberry are not available.

In this study, the response of six biennial raspberry cultivars to photothermal environment at different times of a year was examined. The effects of temperature (4 and 20 °C) and photoperiod (9 and 18 h) on cane elongation, node number, cold acclimation, and dormancy induction were studied.

Material and Methods

Plant material

Plants of red raspberry cvs. 'Maurin Makea' and 'Titan' propagated through tissue culture were grown outdoors during summer. Plants of cvs. 'Jatsi', 'Muskoka', 'Ottawa' and 'Preussen' propagated through root cuttings were received from a commercial nursery. All the plants were potted in 3 l plastic containers filled with peat-based potting mixture (Ruukutusmulta, Kekkilä, Tuusula, Finland) and placed in a greenhouse on 28 August 2000. Canes were cut down to soil level. Temperature was maintained at 20±1 °C and air relative humidity at 50 %. Daylength was 18 h (160 W m^{-2}). Plants were watered as needed, and after emergence of new shoots fertilised with 0.1 % complete fertilizer (NPK 12-5-27, Turve-Superex, Kekkilä, Eurajoki, Finland) weekly.

Fall experiment

A five-week experiment started on 15 November. Six canes were left in each pot and four pots per cultivar were randomly assigned into each of the four temperature-photoperiod treatments:
1) 4 °C short day (SD),
2) 4 °C long day (LD),
3) 20 °C SD, and
4) 20 °C LD.

SD corresponded to 9 h and LD to 18 h photoperiod. Low temperature treatments 1 and 2 were placed in two controlled-climate chambers (Weiss 2600/45, Weiss Umwelttechnik, Reiskirchen, Germany), and treatments 3 and 4 in separate greenhouse compartments equipped with darkening curtains. Light was provided by high-pressure sodium lamps with a photon flux density of 140 μmol m^{-2} s^{-1} at plant height for 9 h in all treatments. In LD treatments photoperiod was extended to 18 h by incandescent lighting (6–8 μmol m^{-2} s^{-1}).

The longest cane in each pot was used to observe vegetative growth; the length of a cane and the number of new nodes (leaves) were recorded weekly. Other canes in a pot were used for the determination of cold hardiness with controlled freezing tests at the beginning and at the end of the experiment, except for cultivars 'Maurin Makea' and 'Titan' once a week. For a freezing test, six one-node cane pieces from each treatment and replicate were sampled (one for each test temperature). Six test tubes per treatment each containing four cane pieces on moist paper towel were placed in a programmable refrigerated ethylene glycol bath (RK 20 KP, Lauda Gmb & Co, Lauda Königshofen, Germany) and kept at –2° C for one hour. To ensure ice nucleation in the samples, each culture tube was briefly touched with a spatula cooled in liquid nitrogen. Temperature was kept at –2 °C overnight and then the control samples were taken out. Bath temperature was lowered by 3 °C per hour and kept for 30 min at each test temperature. Test temperatures were at 3 °C intervals from –5 to –17 °C. One test tube per treatment was taken out, placed on ice and allowed to thaw overnight at 4 °C. After incubation in plastic bags at room temperature for one week samples were visually evaluated for freezing injury under a dissecting microscope. LT_{50} values (lethal temperatures for 50 % of the samples) for canes and buds separately were estimated using logit models (LINDÉN et al. 1996).

At the end of the experiment the state of bud dormancy in samples was determined. The canes were cut into one-node pieces (7 to 20 samples per treatment and replicate), inserted into perlite, and placed in a mist propagation bench. Relative humidity was 95 %, temperature 20 °C, and photoperiod 16 h (incandescent lighting). Number of broken buds was recorded weekly for six weeks, and DD_{50} values (days for 50 % bud break) were estimated using logit models (LINDÉN et al. 1996).

On 21 December all the plants were cut down to soil level and placed in a cold storage with temperature of 0 °C.

Spring experiment

On 23 March 2001 the plants of the previous fall experiment were transferred from storage into a greenhouse with growing conditions as described above. Spring experiment started on 9 May. The experimental conditions and measurements were as described above. A controlled freezing test was carried out weekly for all cultivars with an exception of week no. 4.

Statistical analysis

Experimental design was a 2 × 2 factorial experiment with four replicates. Data on vegetative growth (cane elongation, no. of new nodes) were subjected to a two-way analysis of variance using the procedure GLM in SAS to test the significance of the main effects of temperature and photoperiod and their interaction. Data on cold hardiness could not be statistically tested, because plant material from all four replicates had to be pooled for the determination of LT_{50}. The data on dormancy status were subjected to a three-way analysis of variance to test the significance of the main effects of cultivar, temperature, and photoperiod and their interactions.

Results

Growth

Temperature had a stronger influence on growth of six red raspberry cultivars than photoperiod. In both experiments, cane elongation was reduced at 4 °C compared to 20 °C in all cultivars (Fig. 1, 2). In fall experiment, the effect of photoperiod was significant ($P<0.05$) only in cv. 'Muskoka', whereas in spring experiment the effect of photoperiod was significant in all other cultivars except 'Ottawa'; growth was reduced

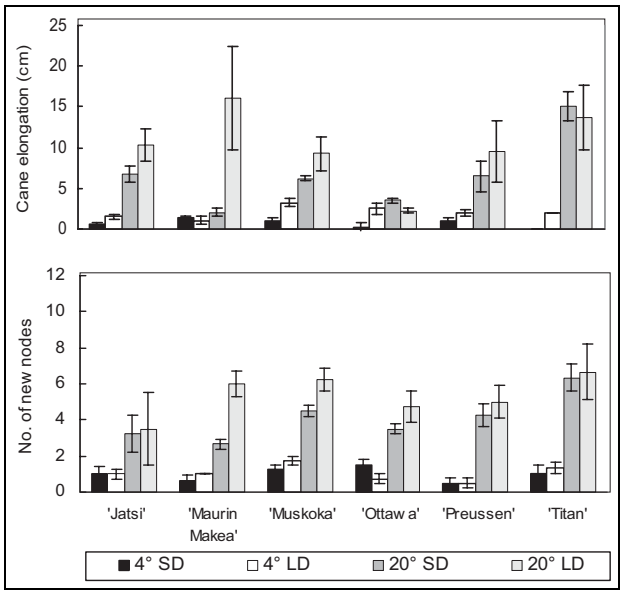


Fig. 1. Cane elongation and the number of new nodes in six raspberry cultivars exposed to different temperature and photoperiod treatments for five weeks in fall experiment. SD=9 h and LD=18 h. Vertical bars present ± SE, n=4. Notice that in cane elongation the scale in y-axis is different from that in Fig. 2.

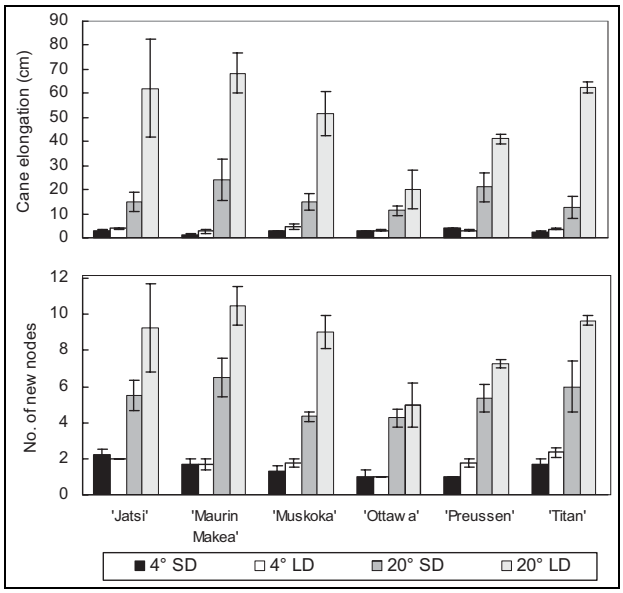


Fig. 2. Cane elongation and the number of new nodes in six raspberry cultivars exposed to different temperature and photoperiod treatments for five weeks in spring experiment. SD=9 h and LD=18 h. Vertical bars present ± SE, n=4. Notice that in cane elongation the scale in y-axis is different from that in Fig. 1.

at SD (9 h) compared to LD (18 h) (Table 1). Similarly, the number of new nodes was reduced by low temperature in all cultivars, but the effect of photoperiod was significant only in cvs. 'Maurin Makea' and 'Muskoka' in fall experiment, and in cvs. 'Maurin Makea', 'Muskoka', 'Preussen' and 'Titan' in spring experiment. An interaction between temperature and photoperiod in both cane elongation and the number of new nodes was also observed in some cultivars; the growth reducing effect of SD was more pronounced at 20 °C than at 4 °C.

In spring, experiment growth was more vigorous than in fall experiment (Fig. 1, 2). This was primarily due to longer internodes. In the fall, cane elongation during five weeks ranged between 0 and 3.3 cm (corresponding to 0.5 to 1.8 new nodes) at 4 °C, and between 2.0 and 16.0 cm (corresponding to 2.7 to 6.7 new nodes) at 20 °C. In spring, cane elongation was from

Table 1. Two-way ANOVA table presenting the P-values for the main effects of temperature (T) and photoperiod (P), and their interaction on growth of six raspberry cultivars in fall and spring experiments.

Time	Cultivar	Cane elongation			Number of new nodes		
		T	P	T × P	T	P	T × P
Fall	'Jatsi'	<0.001	NS	NS	<0.001	NS	NS
	'MM'	0.034	NS	0.048	<0.001	0.003	0.009
	'Muskoka'	<0.001	0.032	NS	<0.001	0.014	NS
	'Ottawa'	0.006	NS	0.002	<0.001	NS	NS
	'Preussen'	0.011	NS	NS	<0.001	NS	NS
	'Titan'	<0.001	NS	NS	<0.001	NS	NS
Spring	'Jatsi'	0.006	0.041	0.046	0.002	NS	NS
	'MM'	<0.001	0.010	0.013	<0.001	0.056	0.056
	'Muskoka'	<0.001	0.007	0.012	<0.001	0.002	0.005
	'Ottawa'	0.009	NS	NS	<0.001	NS	NS
	'Preussen'	<0.001	0.008	0.005	<0.001	0.006	NS
	'Titan'	<0.001	<0.001	<0.001	<0.001	0.021	NS

NS: Non-significant at P<0.05 error level
'MM' = 'Maurin Makea'

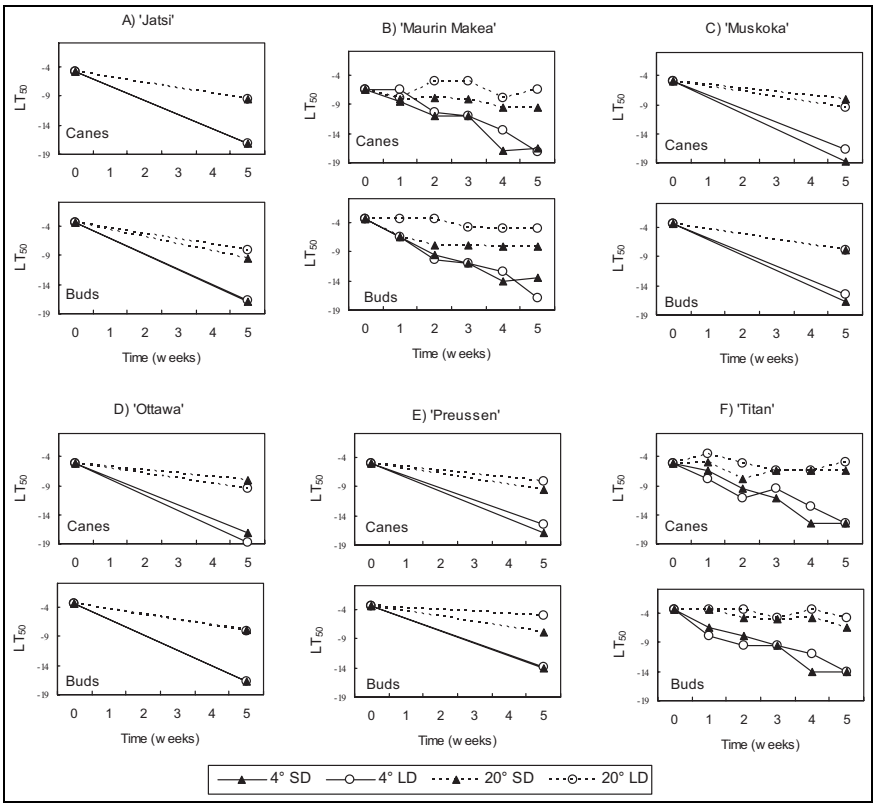


Fig. 3. Cold hardiness (LT_{50}, °C) in canes and buds of six raspberry cultivars exposed to different temperature and photoperiod treatments for five weeks in fall experiment. SD=9 h and LD=18 h. Notice that the scales in y-axes are different from those in Fig. 4.

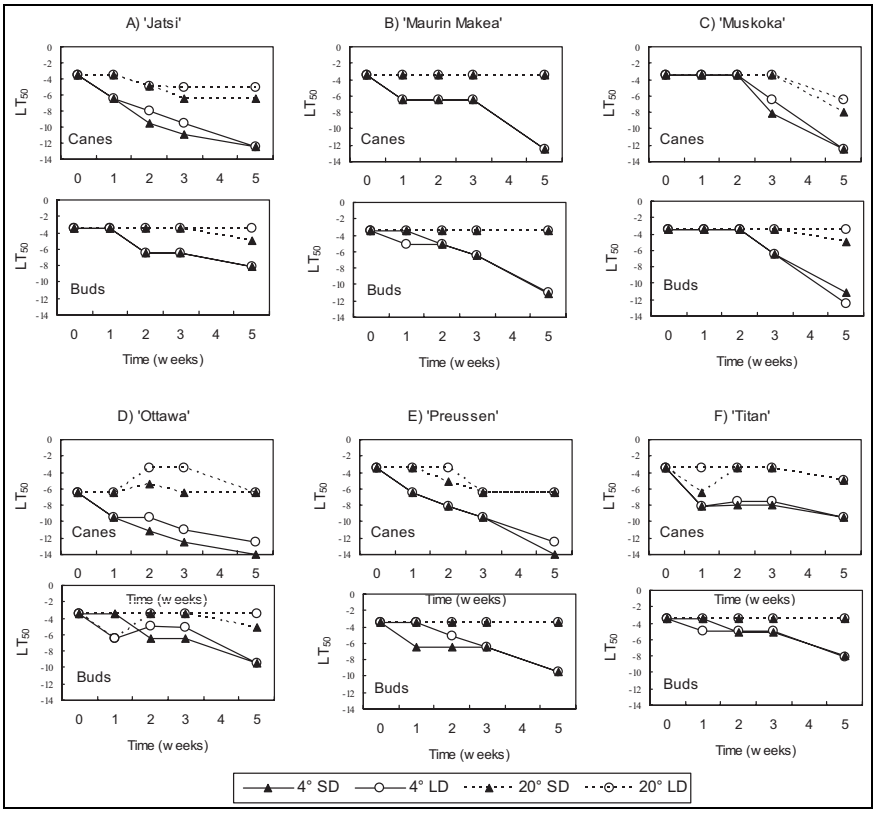


Fig. 4. Cold hardiness (LT_{50}, °C) in canes and buds of six raspberry cultivars exposed to different temperature and photoperiod treatments for five weeks in spring experiment. SD=9 h and LD=18 h. Notice that the scales in y-axes are different from those in Fig. 3.

1.3 to 4.5 cm (1 to 2.3 new nodes) at 4 °C, and from 11.3 to 68.5 cm (4.3 to 10.5 new nodes) at 20 °C. The effect of photoperiod on growth was more pronounced in spring experiment than in fall experiment.

Cold hardiness

Cold hardiness (LT_{50}) of canes and buds was only affected by treatment temperature (Fig. 3, 4). However,

in fall experiment SD was observed to slightly increase cold hardiness of cv. 'Maurin Makea' at 20 °C. Generally, during fall experiment plants acquired greater cold hardiness than during spring experiment. When grown at 4 °C in the fall, LT_{50} for canes was between –18.8 and –15.5 °C, and that for buds between –17.1 and –13.5 °C. In spring, LT_{50} for canes was between –13.9 and –8.1 °C and that for buds between –12.5 and –7.9 °C.

Dormancy status

When, all the cultivars were analysed together, dormancy status at the end of fall experiment was affected by cultivar (P<0.001), temperature (P<0.001), and photoperiod (P=0.034). Generally, dormancy was deeper after incubation at 20 °C than at 4 °C, and SD induced deeper dormancy than LD (Table 2). When cultivars were analysed separately, the effect of temperature was significant in all cultivars except 'Jatsi' and 'Titan', but the effect of photoperiod was not significant in any cultivar.

When all the cultivars were analysed together, dormancy status at the end of spring experiment was affected by cultivar (P<0.001), temperature (P<0.001) and by photoperiod (P=0.028). There was also an interaction between temperature and photoperiod (P<0.001) and between cultivar and temperature (P=0.048). When cultivars were analysed separately, the effect of temperature was significant in all cultivars except 'Jatsi'; dormancy was deeper after incubation at 20 °C than at 4 °C (Table 2). An effect of photoperiod was observed only in cv. 'Maurin Makea'. An interaction between temperature and photoperiod was also observed in some cultivars; at 4 °C dormancy was deeper in LD conditions, but at 20 °C deeper dormancy was induced by SD. Generally axillary buds were in deeper dormancy after fall experiment (DD_{50} between 16.1 and 30.2 d) than after spring experiment (DD_{50} between 8.4 and 19.0 d) (Table 2).

Discussion

Temperature (4 °C compared to 20 °C) had a stronger influence on growth of red raspberry cultivars than photoperiod (9 or 18 h). Accordingly, WILLIAMS (1959) observed that growth of raspberry cv. 'Malling Promise' was influenced by photoperiod only at intermediate temperature. In cloudberry (*Rubus chamaemorus* L.) vegetative growth was reduced under short days (12 h) compared to long days (24 h) (KAURIN et al. 1982). Cane growth rate of *Vitis* spp. decreased at 14, 13, or 12 h (SD) compared to 15 h (LD) photoperiod (FENNELL and HOOVER 1991). The spring experiment showed that photoperiod had very little effect on growth at low temperature, although at higher temperature SD clearly reduced vegetative growth. Cultivar differences also occurred; in 'Maurin Makea' growth was strongly reduced by SD at 20 °C. The effect was comparable to that of low temperature. SD at high temperature also induced a relatively deep dormancy in cv. 'Maurin Makea'.

Cold hardiness (LT_{50}) of raspberry canes and buds was only affected by treatment temperature. Similarly, in cloudberry cold hardiness was induced by decreasing temperatures and no effect of photoperiod could be observed (KAURIN et al. 1982). In red-osier dogwood (*Cornus solonifera* Michx.) rest induced by short days was a prerequisite for induction of cold hardiness, but short photoperiod alone did not induce acclimation (VAN HUYSTEE et al. 1967). Also in grapevine (*Vitis* spp.) only little cold acclimation in response to short photoperiods (FENNELL and HOOVER 1991), or a lack of photoperiodic effect on acclimation has been observed (WOLPERT and HOWELL 1986).

However, in some species short photoperiod alone may bring along cold acclimation, while in others, the effect of low temperature is enhanced by SD. WELLING et al. (2002) showed that SD and low temperature in-

Table 2. Dormancy status (DD_{50}) of six raspberry cultivars exposed to different temperature and photoperiod (SD = short day, LD = long day) treatments in fall and spring experiments, and the two-way ANOVA table presenting the P-values for the main effects of temperature (T) and photoperiod (P), and their interaction.

Time	Cultivar	DD_{50} (days)							P-values		
		4 °C			20 °C			Cv.			
		SD	LD	Mean	SD	LD	Mean	mean	T	P	T × P
	'Jatsi'	28.3	25.5	26.9	34.3	32.8	33.6	30.2	NS	NS	NS
	'MM'	11.6	13.3	12.5	24.6	15.1	20.8	16.2	0.036	NS	NS
Fall	'Muskoka'	19.4	15.5	17.5	27.3	26.7	27.0	22.2	0.003	NS	NS
	'Ottawa'	26.0	22.6	24.3	34.0	32.9	33.4	28.9	0.008	NS	NS
	'Preussen'	14.8	14.7	14.7	22.8	20.3	21.6	18.1	<0.001	NS	NS
	'Titan'	17.2	15.4	16.3	14.7	16.9	15.8	16.1	NS	NS	NS
	'Jatsi'	16.5	14.1	15.3	19.0	15.1	17.0	16.2	NS	NS	NS
	'MM'	7.1	5.1	6.1	26.2	10.2	18.2	11.0	<0.001	<0.001	0.001
Spring	'Muskoka'	8.8	8.2	8.5	17.2	12.8	15.0	11.7	0.011	NS	NS
	'Ottawa'	9.7	17.4	13.5	28.3	20.6	24.4	19.0	0.002	NS	0.014
	'Preussen'	7.9	14.5	11.2	19.6	11.6	15.0	13.0	0.040	NS	0.003
	'Titan'	5.6	5.9	5.8	9.9	12.0	11.0	8.4	0.014	NS	NS

NS: Non-significant at P<0.05 error level
'MM' = 'Maurin Makea'

duce cold acclimation independently in hybrid aspen (*Populus tremula* × *Populus tremuloides* Michx.). Shortening photoperiod alone triggered growth cessation, cold acclimation, and dormancy development in silver birch (*Betula pendula* Roth.) (LI et al. 2003). However, in Scots pine (*Pinus sylvestris* L.) and Norway spruce [*Picea abies* (L.) Karst.] shortening daylength should precede low temperatures for maximal cold hardiness (BERVAES et al. 1978; CHRISTERSSON 1978). Similarly, short days accelerated dormancy development and hardiness development in white spruce [*Picea glauca* (Moench) Voss], black spruce [*Picea mariana* (Mill.) B.S.P.] and jack pine (*Pinus banksiana* Lamb.) (BIGRAS and D'AOUST 1993; CALMÉ et al. 1993). Short photoperiod during exposure to decreasing temperatures also enhanced cold acclimation of kiwifruit (*Actinidia deliciosa*) vines (LU and RIEGER 1990).

In almost all raspberry cultivars incubation at 20 °C induced deeper dormancy than incubation at 4 °C. At 20 °C SD seemed to induce dormancy, which is in accordance with previous knowledge (WEISER 1970). However, at 4 °C the situation was more complicated; for example in cvs. 'Ottawa' and 'Preussen' deeper dormancy was observed after incubation in LD than in SD during spring experiment. It seemed that at 4 °C dormancy induced by SD had already partially broken. Temperature of 4 °C has a chilling effect and this treatment temperature itself may have released plants from dormancy induced by SD. Endodormancy of raspberry is known to be released by exposure to 5 to 8 weeks of chilling depending on a cultivar (DALE et al. 2003). The other alternative is that plants did not become dormant at 4 °C and SD, but this would be very surprising. However, this finding would warrant more detailed experiments to be cleared out.

Looking at overall cultivar means of dormancy status, deepest dormancy seemed to occur in cvs. 'Ottawa' and 'Jatsi'. 'Ottawa' is considered the most winter hardy cultivar in our field conditions. No long term experience on 'Jatsi' is available, although it is reported to be comparable to 'Ottawa' in hardiness (DALMAN et al. 1997). Most shallow dormancy occurred in cvs. 'Maurin Makea' and 'Titan'. 'Maurin Makea' has been observed to easily lose hardiness in late winter (PALONEN and LINDÉN 1999), and 'Titan' is not winter hardy in our conditions.

Time of a year had an effect on behaviour of raspberry plants. In spring experiment growth was more vigorous than in fall experiment primarily due to longer internodes, and the plants reacted more readily to the changes in photoperiod. During fall experiment plants acquired greater cold hardiness and deeper dormancy was induced in axillary buds than during spring experiment. According to WEISER (1970), hardy woody plants possess cyclic internal factors that affect their growth pattern. During the spring flush of growth plants are not able to cold acclimate fully, although grown under short photoperiod and low temperature. Furthermore, in the fall at the end of the growth cycle, plants acclimate to some extent although grown under non-acclimating conditions. In *Rhododendron* cold hardiness has been observed to change with calendar time, although external environmental conditions remained unchanged (CAMERON and DIXON 2000). Apparently, some internal factors regulated the growth of raspberry plants, although environmental conditions were similar during both experiments.

References

BERVAES, J.C.A.M., D.O. KETCHIE and P.J.C. KUIPER 1978: Cold hardiness of pine needles and apple bark as affected by alteration of day length and temperature. Physiol. Plant. **44**, 365–368.

BIGRAS, F.J. and A.L. D'AOUST 1993: Influence of photoperiod on shoot and root frost tolerance and bud phenology of white spruce seedlings (*Picea glauca*). Can. J. For. Res. **23**, 219–228.

CALMÉ, S., H.A. MARGOLIS and F.J. BIGRAS 1993: Influence of cultural practices on the relationship between frost tolerance and water content of containerized black spruce, white spruce, and jack pine seedlings. Can. J. For. Res. **23**, 503–511.

CAMERON, R.W.F. and G.R. DIXON 2000: The influence of temperature, photoperiod and calendar date on cold tolerance of *Rhododendron*. J. Hortic. Sci. & Biotech. **75**, 481–487.

CAREW, J., P. HADLEY, N. BATTEY and J. DARBY 1999: The effect of temperature on the vegetative growth and reproductive development of the primocane fruiting raspberry 'Autumn Bliss'. Acta Hort. **505**, 185–190.

CAREW, J.G., K. MAHMOOD, J. DARBY, P. HADLEY and N.H. BATTEY 2003: The effect of temperature, photosynthetic photon flux density, and photoperiod on the vegetative growth and flowering of 'Autumn Bliss' raspberry. J. Amer. Soc. Hort. Sci. **128**, 291–296.

CHRISTERSSON, L. 1978: The influence of photoperiod and temperature on the development of frost hardiness in seedlings of *Pinus silvestris* and *Picea abies*. Physiol. Plant. **44**, 288–294.

DALE, A., A. SAMPLE and E. KING 2003: Breaking dormancy in red raspberries for greenhouse production. HortScience **38**, 515–519.

DALMAN, P., H. HIIRSALMI, T. HIETARANTA and M.-M. LINNA 1997: 'Jenkka' and 'Jatsi', two new red raspberry cultivars. Agric. and Food Sci. in Finland **6**, 19–24.

FENNELL, A. and E. HOOVER 1991: Photoperiod influences growth, bud dormancy, and cold acclimation in *Vitis labruscana* and *V. riparia*. J. Amer. Soc. Hort. Sci. **116**, 270–273.

HOOVER, E., J.J. LUBY, D. BEDFORD, M. PRITTS, E. HANSON, A. DALE and H.A. DAUBENY 1989: Temperature influence on harvest date, and cane development in primocane fruiting red raspberries. Acta Hort. **262**, 297–303.

IRVING, R.M. and F.O. LANPHEAR 1967: Environmental control of cold hardiness in woody plants. Plant Physiol. **42**, 1191–1196.

JUNTTILA, O. 1996: Plant adaptation to temperature and photoperiod. Agric. and Food Sci. in Finland **5**, 251–260.

KAURIN, Å., C. STUSHNOFF and O. JUNTTILA 1982: Vegetative growth and frost hardiness of cloudberry (*Rubus chamaemorus*) as affected by temperature and photoperiod. Physiol. Plant **55**, 76–81.

LI, C., O. JUNTTILA, A. ERNSTSEN, P. HEINO and T. PALVA 2003: Photoperiodic control of growth, cold acclimation and dormancy development in silver birch (*Betula pendula*) ecotypes. Physiol. Plant. **117**, 206–212.

LINDÉN, L., H. RITA and T. SUOJALA 1996: Logit models for estimating lethal temperatures in apple. HortScience **31**, 91–93.

LU, S. and M. RIEGER 1990: Cold acclimation of young kiwifruit vines under artificial hardening conditions. HortScience **25**, 1628–1630.

PALONEN, P. and L. LINDÉN 1999: Dormancy, cold hardiness, dehardening, and rehardening in selected red raspberry cultivars. J. Amer. Soc. Hort. Sci. **124**, 341–346.

VAN HUYSTEE, R.B., C.J. WEISER and P.H. LI 1967: Cold acclimation in *Cornus stolonifera* under natural and controlled photoperiod and temperature. Bot. Gaz. **128**, 200–205.

WEISER, C.J. 1970: Cold resistance and acclimation in woody plants. HortScience **5**, 403–410.

WELLING, A., T. MORITZ, E.T. PALVA and O. JUNTTILA 2002: Independent activation of cold acclimation by low temperature and short photoperiod in hybrid aspen. Plant Physiol. **129**, 1633–1641.

WILLIAMS, I.H. 1959: Effects of environment on *Rubus idaeus* L.. III. Growth and dormancy of young shoots. J. Hortic. Sci. **34**, 210–218.

WOLPERT, J.A. and G.S. HOWELL 1986: Effect of night interruption on cold acclimation of potted 'Concord' grapevines. J. Amer. Soc. Hort. Sci. **111**, 16–20.

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