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Influence of Temperature and Day-length on Dormancy in Seed Potato cv. 'Asterix'

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ABSTRACT

Dormancy in a potato tuber prevents sprout growth even under optimal sprouting conditions and is the first stage in the physiological ageing process. The intensity and duration of this phase differs between genotypes (cultivars) and may also be affected by environmental conditions both during tuber bulking and early storage. The current study aimed at finding how simulated high latitude growth conditions influence dormancy and the physiological age of tubers to be used as seed potatoes. In a controlled climate at natural light conditions, tubers grown at a low temperature (9°C) had 2-3 weeks shorter dormancy than tubers grown at higher temperatures (15 and 21°C). In tubers grown at artificial light conditions, day-lengths (12, 18 or 24 h) did not affect dormancy significantly. A post-harvest treatment with a low temperature (one month at 4°C and subsequently 18°C) reduced dormancy by 2-3 weeks in tubers from the highest growth temperatures (15 and 21°C) in comparison with constant 18°C post-harvest. After the lowest growth temperature (9°C) the duration of dormancy was not affected by post-harvest temperature treatments. Physiological age was determined by sprouting characteristics after winter storage. At this stage the sprouting capacity was highest in tubers originating from the lowest and the highest growth temperatures. Further, the number of sprouts per tuber was higher in tubers grown at 9°C than at 15 or 21°C. These results were not correlated with duration of dormancy after the various treatments, suggesting that temperatures may affect dormancy and physiological ageing independently. The present results show that dormancy may be shortened by low grow temperatures, and similarly by low post-harvest temperatures at higher growth temperatures.

Keywords: physiological age, post-harvest, pre-harvest, pre-storing, sprouting capacity
Abbreviations: d°>5, day-degrees > 5°C; **DAH**, days after harvest; **DAP**, days after planting; **PAR**, photosynthetic active radiation

INTRODUCTION

During physiological ageing, a potato tuber goes through various stages of development beginning with dormancy, which suppresses sprout growth. Ageing continues with characteristic sprouting phases and ends with senility (Struik and Wiersema 1999). After termination of dormancy, the growth vigour of a tuber (its potential to produce sprouts and plants) gradually increases, levels out and finally declines until the tuber is unable to produce new plants (van der Zaag and van Loon 1987). This process differs between cultivars and is influenced by environmental conditions during production and storage. Although controlled experiments are scarce, there may be preliminary evidence indicating that dormancy is shortest after warm growth conditions (Krijthe 1962; Burton 1989; Susnoschi 1981). However, others have suggested that no such general relation between growth temperature and dormancy exists (Allen *et al*. 1992; van Ittersum and Scholte 1992a). For some cultivars, high growth temperatures may even prolong dormancy as do strong diurnal temperature variations (van Ittersum and Scholte 1992a).

After haulm killing, seed tubers may be exposed to different temperatures, depending upon soil temperatures and pre-storing conditions. Manipulation of pre-storing temperatures may influence the rate of physiological development more than temperatures during the growth period (van Ittersum and Scholte 1992b). Both short periods (weeks) of low temperatures (< 5°C) (Emilsson 1949; Allen *et al*. 1978; Hutchinson 1978; Harkett 1981; van Loon 1983; van Ittersum and Scholte 1992b) and high temperatures (28°C) (van Ittersum and Scholte 1992b) are known to have a clear shortening effect in many cultivars relative to intermediate temperatures.

Irradiation and photoperiod during the growth period may also influence dormancy. It has been assumed that dormancy is shorter in tubers produced at lower latitudes compared to higher latitudes, although supporting data are hard to find (van Ittersum 1992c). Yet, conflicting data have been presented by Susnoschi (1981), who reported that tubers produced in autumn and winter in low northern latitudes had longer dormancy than those produced in spring when days are longer and temperatures are higher. Specific effects of temperature, light intensity and day-length are unclear, and few controlled studies exist. Tsukamoto *et al*. (ref. in van Ittersum 1992b) found shorter dormancy in tubers grown at a short day-length compared to long days. Emilsson (1949), however, found no clear difference between short and long day-lengths. In both of these studies, the different day-lengths included differences in photosynthetic active radiation (PAR), making clear conclusions difficult. van Ittersum (1992c), who studied both the effect of light intensity by shading in field trials, and the effect of day-lengths at the same level of PAR in indoor experiments, found only small and inconsistent effects on dormancy.

Some authors have previously argued an overriding positive effect of cool growth temperatures on vigour and yield in seed potatoes (Wurr 1979; Wiersema and Booth 1985; Wahab 1993). Previous studies in northern Norway have also shown that seed tubers produced at average temperatures below 15°C (immature at harvest) may reach a similar physiological age and perform equally well at planting than tubers produced at warmer conditions (Johansen *et al*. 2002; Johansen and Nilsen 2004; Johansen *et al*. 2008). However, these results are not necessarily in agreement with the underlying concepts of physiological ageing (Struik

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and Wiersema 1999). It has also been questioned if the rate of dormancy development after such low growth temperatures might play a role in physiological ageing and possibly explain the results (Johansen and Nilsen 2004). According to van Ittersum and Scholte (1992a), tubers grown at different temperature regimes may age differently, although dormancy is minimally affected. The current body of literature is lacking data describing the effects of low growth temperatures (< 15°C) and long days on dormancy and physiological ageing in potato, as most previous studies have focused on other growth conditions than those represented in northernmost regions for agriculture. In buds of northern three species, however, it has been demonstrated that high autumn temperatures increased the dormancy period compared to lower temperatures (Heide 2003; Junttila *et al*. 2003).

Recent reviews by Suttle (2004) and Benkeblia *et al*. (2008) underline that the genetically and physiologically regulation of dormancy are complex and that the fundamental mechanisms are still largely unknown. However, several plant hormones are thought to be involved. Current evidence shows that ABA (abscisic acid) and ethylene are required for initiation of dormancy, while only ABA is needed to maintain dormancy. Expression of genes involved in regulating ABA content during dormancy development has recently been identified (Destefano-Beltrán *et al*. 2006a, 2006b; Campbell *et al*. 2008).

Cytokinins appear to be heavily involved in the progress towards the loss of dormancy while endogenous IAA (auxins) and GA (gibberellins) are probably only involved in the regulation of sprout growth after dormancy (Suttle 2004; Benkeblia *et al*. 2008). Contrastingly, Sorce *et al*. (2009) state that IAA might shorten dormancy by enhancing early developmental processes in the buds. Dormancy may also be manipulated and prematurely broken exogenously by chemical treatments, either for research purposes or for stimulation of sprout growth of micro-, mini- or seed tubers. Such agents are GAs (Alexopoulos *et al*. 2007, 2008), bromoethane (Akoumianakis *et al*. 2008; Alexopoulos *et al*. 2009; Suttle 2009), ethanol (Claassens *et al*. 2005) and cytokinins (Suttle 2008).

The current study aims at demonstrating the effects of temperatures and day-lengths during the tuber bulking period on the intensity of dormancy, as expressed by sprout development. The interaction between growth temperatures and short term post-harvest treatments were also studied because conditions between the time for haulm killing and permanent storage may differ strongly in practice. Finally, the relationship between duration of dormancy and physiological age was tested, based on sprouting characteristics.

MATERIALS AND METHODS

The experiments were conducted in climate chambers at The University of Tromsø under both natural daylight and artificial light conditions. The chambers were controlled for temperature (± 0.5°C) and water vapour pressure deficit (0.5 kPa ± 3%). The photoperiod at this latitude (69° 40′ N) was 24 h during most of the experimental period. Depending on meteorological conditions, irradiance during daytime varied between 200 and 1400 µmol m^{-2} s^{-1} with about 75% of light transmitted through the glass in the daylight chambers. For artificial light, Philips TLD 840 fluorescent lamps were used. In this case the irradiance at plant canopy was about 150 µmol m^{-2} s^{-1}. The total PAR per day varied between day-length treatments with the duration of light period.

Plants from pre-sprouted pre-basic seed of cv. 'Asterix' (intermediate to late) were grown individually in a 9:1 (volume) mixture of a standard fertilized peat and sand in 12 l pots. The pots had a bottom layer of one litre Leca pellets and drainage holes 5 cm above bottom. When plants had reached 20 cm in height they were watered and fertilized with a standard nutrient solution (for composition, see Junttila 1980). Pots were placed on trolleys and density of plants within the chambers was approximately 6-7 per m². Position within the growth chambers was changed regularly in a random manner. At harvest, the haulm maturity (% fresh haulm) was visually assessed, and the number of tubers and tuber yield per plant were registered (**Table 1**).

Table 1 Details on tuber growth at different growth conditions during tuber bulking.

Exp. 1 (2005)[a]	Day/night temperatures (°C)					
	9/9	**12/6**	**15/15**	**18/12**	**21/21**	**24/18**
Fresh haulm (%)	71	78	38	53	68	83
No. of tubers >10 mm	41	43	34	38	37	30
Tuber yield (g)	1420	1579	1528	1623	1700	1430
Tuber DM (%)	20.2	20.8	24.8	25.2	24.3	23.6
Exp. 2 (2006)[b]	**Day/night temperatures (°C)**			**Day-lengths (h)**		
	12/6	**18/12**	**24/18**	**12**	**18**	**24**
Fresh haulm (%)	61	69	54	58	70	57
No. of tubers >10 mm	14	14	17	14	15	16
Tuber yield (g)	831	886	969	779	890	1016

[a] Mean results per plant (N=15)
[b] Results for temperatures averaged over three day-lengths with six plants (N=18). Results for day-lengths averaged over three temperatures with six plants (N=18)

Experiment 1: Effect of pre-and post-harvest temperatures (2005)

Ninety evenly sized (*ca*. 50 g) seed tubers were planted 22 March 2005 and grown at natural daylight (approx. 24 h photoperiod) at 18/12°C (12 h day temperature/12 h night temperature). The plants emerged 13-16 days after planting (DAP) and tuber initiation was observed at 34 DAP (assessed on additional plants).

At 41 DAP, 15 plants were moved to each of six growth temperature regimes at similar daylight conditions as above. Temperatures (12 h day temperature/12 h night temperature) were 9/9, 12/6, 15/15, 18/12, 21/21, 24/18°C. This equals three levels of daily average temperatures (9, 15 and 21°C), each with constant or fluctuating day/night temperature. The nutrient solution was supplied between 28 and 78 DAP and nitrogen (N) per plant varied from 3.5 g at the lowest to 4.3 g at the highest growth temperatures. Haulm and tubers were harvested 114 DAP, equivalent to 702, 1140 and 1578 d° > 5 (day-degrees > 5°C) for 9, 15 and 21°C, respectively. Percent tuber dry matter (DM) was measured from a 2 kg sample from the graded fraction 50-60 mm within each temperature treatment. Tuber yield (30-50 mm) from each growth temperature was divided in three batches and kept at 4, 9 and 18°C for one month (31 days), respectively. Samples for dormancy studies were then collected, and the remaining material from each combination of treatments was placed in cold storage at 4°C until 6 months after harvest.

Experiment 2: Effect of pre-harvest temperatures and day-lengths (2006)

Fifty-four evenly sized (ca. 30 g) seed tubers were planted 3 April 2006 and grown at 15°C and natural daylight. Plants sprouted 13-15 DAP and tuber initiation was observed 37 DAP. The nutrient solution was supplied between 30 and 83 DAP and nitrogen (N) per plant varied from 2.3 g at the lowest to 3.3 g the highest growth temperature. At 49 DAP, six plants were moved to each of nine combinations of growth temperatures and day-lengths at artificial light conditions. Temperatures (12 h day temperature/12 h night temperature) were 12/6, 18/12, 24/18°C and day-lengths were 12, 18 and 24 h. Haulm and tubers were harvested 114 DAP, equivalent to 750, 1140 and 1530 d°>5 for 12/6, 18/12 and 24/18°C, respectively.

Observations

For dormancy assessment, the method described by van Ittersum (1992b) was followed. Thirty evenly sized tubers (3 samples × 10) from the 40-50 mm fraction in Exp. 1 and the 30-50 mm fraction in Exp. 2 (due to limited material) from each combination of treatments were given conditions to sprout in a dark chamber (18°C). The end of dormancy in individual tubers was recorded as the time when the first sprout had reached 5 mm length. However, actual

dormancy had probably ended 3-4 weeks earlier as the time for an apical bud to grow from initial length to a length of about 2 mm at 18°C is about 20 days (van Ittersum *et al.* 1992). The end of dormancy in the sample was defined as the time when 80 percent of the tubers had reached this state (Reust 1986), and duration of dormancy was then expressed as number of days after harvest (DAH). Finally, the spread of dormancy was defined as the time lapse between 10 and 90% sprouting (van Itterssum 1992a). At a fixed date, after end of dormancy for all tubers, the number of sprouts and the length of the longest sprout per tuber were recorded.

For studies of vigour at normal planting time (after cold storage, Exp. 1), 30 evenly sized tubers (30-40 mm) from each combination of treatments were moved to an 18°C dark chamber. Four weeks later, the weight of tuber with sprouts, weight of sprouts, number of sprouts per tuber and the length of the longest sprout were assessed on individual tubers. Sprouting capacity was measured as sprout weight per tuber and results presented as sprout weight in percentage of initial tuber weight due to some variation in tuber size (Hartmans and van Loon 1987).

Statistical analyses

The experiment had a complete 3 × 2 × 3 factorial design to test effects of growth temperature, day/night temperature regime, and post-harvest temperature. Statistical analyses were performed with Minitab 15, ANOVA (GLM procedure). Tukey simultaneous tests were used for pairwise comparisons of treatments, with a setting of $\alpha = 0.05$.

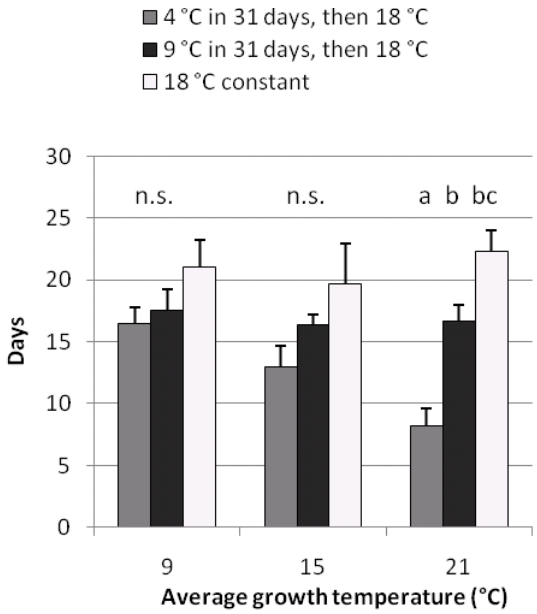

Fig. 2 Spread in dormancy (time between 10 and 90% sprouting) after various combinations of pre- and post-harvest temperature treatments (73 and 31 days, respectively). Results are averaged over two day/night temperature regimes with three replicates each. Values (mean ± SE, N = 6) within each growth temperature accompanied by different letters are significantly different at p = 0.05; ns indicates that differences are not statistically significant.

RESULTS

Exp. 1. Effect of pre- and post-harvest temperatures

1. Dormancy

The duration of dormancy varied strongly between treatments, and there was an interaction between average growth temperatures and both post-harvest temperatures (F=16.82, df=4, p=0.000) and day/night temperature regime (F=4.23, df=2, p=0.022) (**Fig. 1**). In tubers taken directly from growth temperatures to dormancy study conditions (constant 18°C), dormancy was 2-3 weeks shorter in tubers from the lowest temperature (average 9°C) than in those grown at and above 15°C. In tubers grown at 15°C or higher, dormancy was significantly shortened (2-3 weeks) when the tubers were kept at low temperatures (4°C) for a period of one month directly after harvest. For tubers grown at 21°C, also 9°C post-harvest treatment reduced dormancy significantly. At the highest growth temperatures (15 and 21°C), tubers grown at fluctuating rather than at constant day/night temperatures had generally the shortest dormancy, although differences were small. Tubers grown at an average temperature of 9°C were not significantly affected by either day/night fluctuation or varying post-harvest temperatures.

For the spread in dormancy, there was an interaction between average growth temperatures and post-harvest temperatures (F=2.81, df=4, p=0.039) (**Fig. 2**). At treatments with a low post-harvest temperature (4°C), the spread became shorter with increasing growth temperatures. At

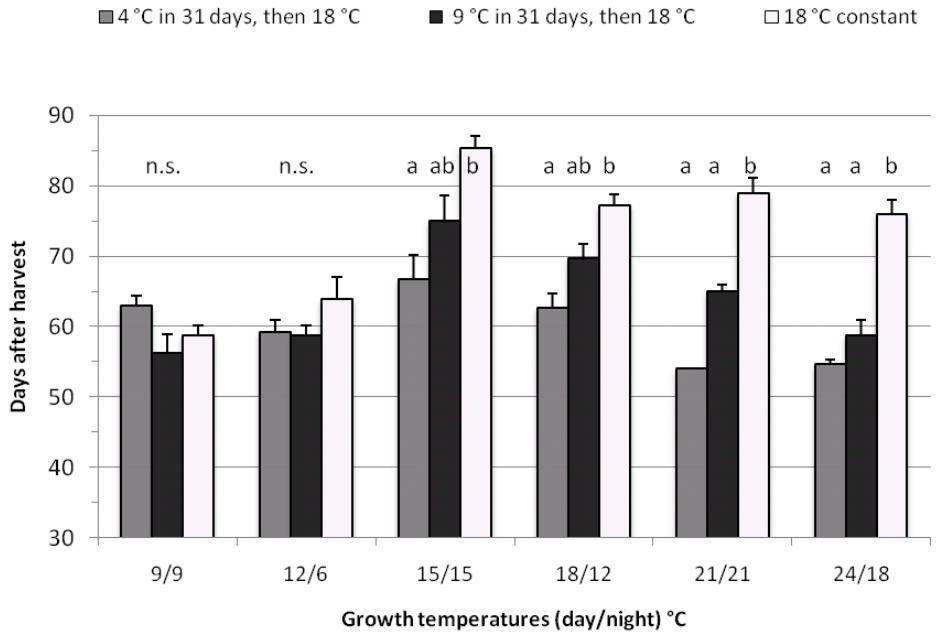

Fig. 1 Duration of dormancy (based on sprouting) after various combinations of pre- and post-harvest temperature treatments (73 and 31 days, respectively). Values (mean ± SE, N = 3) within each growth temperature accompanied by different letters are significantly different at p = 0.05; ns indicates that differences are not statistically significant.

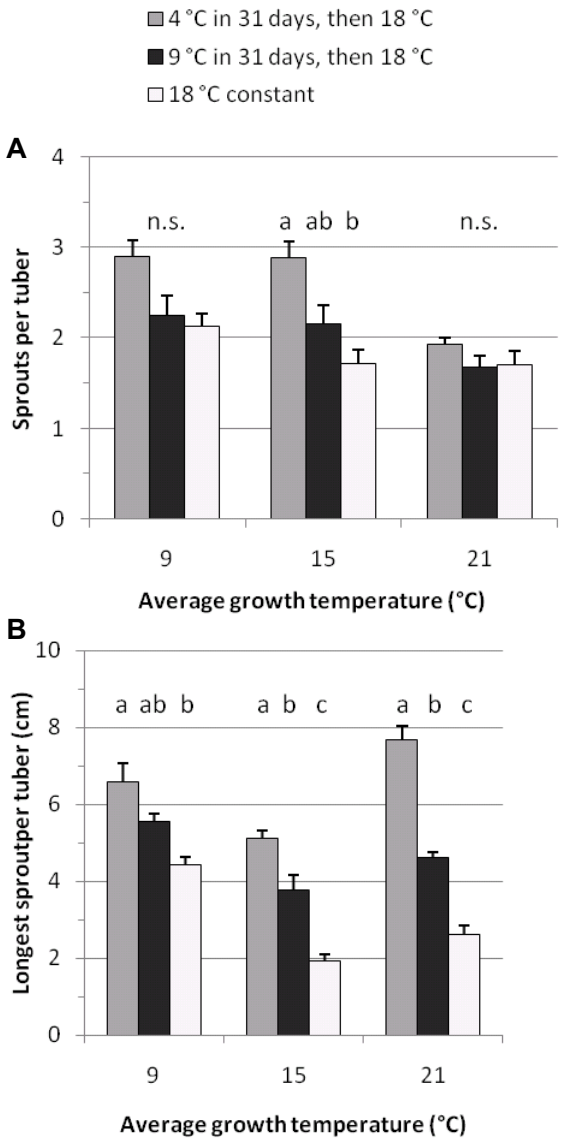

Fig. 3 Apical sprout development after various combinations of pre- and post-harvest temperature treatments (73 and 31 days, respectively). Observations done just after end of dormancy for all tubers (95 DAH). (**A**) No. of sprouts per tuber, (**B**) Length of the longest sprout per tuber. Results are averaged over two day/night temperature regimes with three replicates each (mean of 10 tubers within replicates). Values (mean ± SE, N = 6) within each growth temperature accompanied by different letters are significantly different at p = 0.05; ns indicates that differences are not statistically significant.

21°C the spread was significantly shorter at a low post-harvest temperature than at the other treatments.

2. Apical sprouting after dormancy

When dormancy had ended in all tubers, the appearance of apical sprouts was obviously affected by the variation in time since sprouting started. Nevertheless, there were significantly more sprouts on tubers produced at 9 and 15°C than at 21°C (**Fig. 3A**). Varying day/night temperatures did not affect sprout number or sprout length (data not shown). Likewise, when averaged over the growth temperature, a post-harvest treatment of 4°C resulted in more sprouts per tuber than 9 and 18°C. With respect to sprout length, there was a significant interaction between pre- and post-harvest temperatures (F=7.21, df=4, p=0.000) (**Fig. 3B**). The length of the longest sprout was generally shorter at 15°C than at 9 and 21°C, and increasing post-harvest temperatures reduced the length significantly.

3. Sprouting after cold storage

After cold storage, there was an interaction between growth temperature and post-harvest treatment for sprouting capacity (F=4.95, df=4, p=0.001) (**Fig. 4A**), sprout numbers (F=6.22, df=4, p=0.000) (**Fig. 4B**) and sprout length (longest sprout per tuber) (F=5.21, df=4, p=0.000) (**Fig. 4C**). Day/night temperature fluctuations showed no significant influence on any of the sprouting parameters (data not shown). Sprouting capacity was significantly lower in tubers from 15°C growth temperature than from 9 and 21°C (**Fig. 4A**). Tubers from the lowest growth temperature, with a 9°C post-harvest treatment, had a significantly lower sprouting capacity than those kept at 4 and 18°C.

Tubers from the lowest growth temperature had more sprouts than tubers from the higher growth temperatures (**Fig. 4B**). Post-harvest treatments showed significant differences on tubers from the lowest and highest growth temperatures, but the differences were small and unsystematic.

Sprout length was shortest on tubers grown at 15°C and longest on tubers grown at 21°C (**Fig. 4C**). Differences between post-harvest treatments were only significant in tubers from 9 and 21°C. Post-harvest treatment of 4°C resulted in shorter sprouts than at higher temperatures.

Exp. 2. Effect of pre-harvest temperatures and day-lengths

Growth temperatures affected dormancy significantly (F=41.15, df=2, p=0.000), while day-lengths did not (**Fig. 5**). There were no interactions between factors. The duration of dormancy was shortest in tubers after the lowest growth temperature, and increased with increasing growth temperatures. The spread in dormancy was also only affected significantly by growth temperatures (F=5.24, df=2. P=0.016) and no interaction was observed (**Fig. 6**). The spread was highest in tubers from the highest growth temperature.

DISCUSSION

For the first time in a controlled climate, this study demonstrates the effect of sub-arctic temperature and light conditions on dormancy in potato tubers. It became evident that low growth temperatures, in this study well below 15°C, had a specific shortening effect on dormancy in cv. 'Asterix' while photoperiod had no influence. At higher growth temperatures, a similar shortening effect was induced by low temperature post-harvest treatments. The growth temperatures seemed to affect dormancy and physiological age independently. However, as cultivars may react differently on environmental conditions, the results should not be generalized.

It is difficult to demonstrate end of dormancy without letting the tubers sprout. The time from end of dormancy until sprouting and the definition of sprouting are then crucial factors when results are to be compared (see van Ittersum *et al.* 1992). Some of the complexity also arises from a probable difference in optimum temperatures for dormancy and sprout development, and a possible difference between early and late phases of dormancy. New studies are needed to clarify these aspects. However, although we are not measuring the exact duration of dormancy, differences between treatments on the basis of sprouting records are expected to be valid.

The current experiments with cv. 'Asterix', strengthens the view that there is no linear shortening effect on dormancy of increasing growth temperatures in general. Most previous studies have focused on growth temperatures higher than 15°C while this study shows that there is a deviating effect of lower temperatures. In tubers taken directly from growth to dormancy studies at 18°C, dormancy was quite long and stable when growth temperatures were 15°C or higher. Lower growth temperatures, however, reduced dormancy significantly, similar to some previously reported

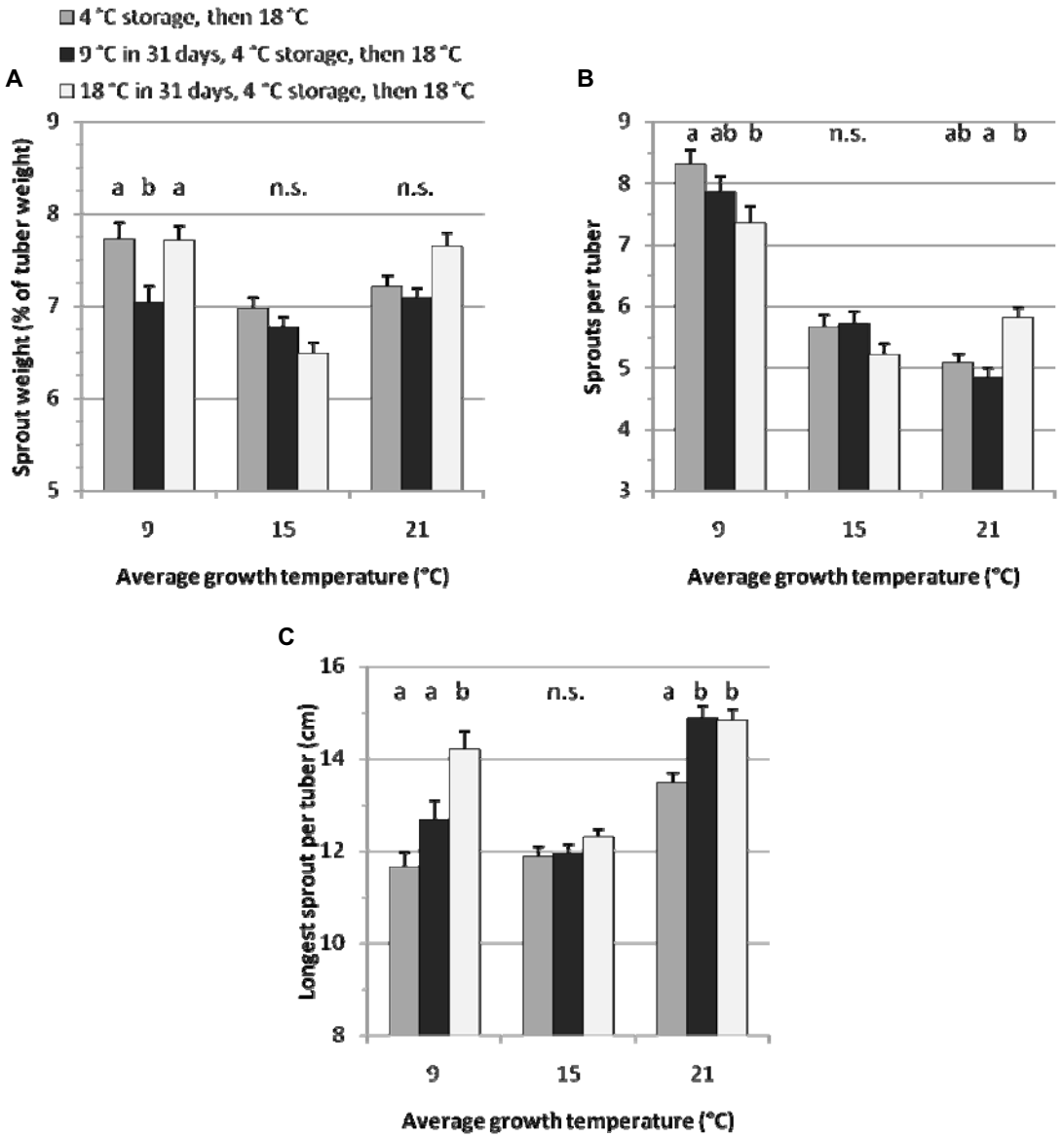

Fig. 4 Sprouting characteristics after winter storage (six months after harvest) in tubers from various combinations of pre- and post-harvest temperature treatments (73 and 31 days, respectively). (**A**) Sprouting capacity, (**B**) No. of sprouts per tuber, (**C**) Length of the longest sprout per tuber. Results are averaged over two day/night temperature regimes with 30 replicates (tubers) each. Values (mean ± SE, N = 60) within each growth temperature accompanied by different letters are significantly different at p = 0.05; ns indicates that differences are not statistically significant.

effects of high temperatures (van Ittersum and Scholte 1992a; Krijthe 1962; Burton 1989; Susnoschi 1981). So, both very low and very high growth temperatures may speed up dormancy development. Day-length did not seem to affect dormancy in these studies. Although PAR varied with different day-lengths, the results support the conclusions by van Ittersum (1992c) about small and inconsistent effects on dormancy of photoperiods after tuber initiation.

It has been argued that growth conditions have limited effect on dormancy as long as tubers are attached to the green foliage (van Ittersum 1992b, 1992c; van Ittersum and Scholte 1992a). In the current studies, plants from all treatments showed maturity symptoms. All tubers were harvested on the same day, and the percentage of remaining green haulm varied from 38 to 83% between treatments (see **Table 1** for DM content also). Thus, tubers may have been affected differently by ambient temperatures during a short period just before harvest, as the controlling influence by the green foliage was reduced. However, the differences in duration of dormancy were too pronounced and systematic between growth temperatures to be attributed to these unsystematic differences in maturity. Thus, the results presented here contradict conclusions by van Ittersum and Scholte (1992a) about limited effects of growth temperatures on dormancy in tubers harvested immature. The lowest growth temperature clearly shortened dormancy.

The duration of dormancy in cv. 'Asterix' also seemed to be strongly affected by a period with low post-harvest temperatures. In tubers from the highest average growth temperature (21°C), a cold treatment (4°C) in one month, reduced dormancy with 20-25 days, compared to constant 18°C. Other authors have demonstrated similar results, and have found that the effects of such cold treatments are most significant in cultivars with long dormancy (Allen *et al.* 1978; van Loon 1983; van Ittersum and Scholte 1992b). Optimum duration of low temperature treatment also seems to be longest in cultivars with long dormancy (van Loon 1983; van Ittersum and Scholte 1992b). More than 30-40 days seldom have any reducing effect, and may even prolong dormancy (Hutchinson 1978).

The current results indicated that a period with low post-harvest temperatures reduced the spread in dormancy in cv. 'Asterix', although only significantly after the highest average growth temperature. Such synchronization is normally explained as late developed individuals catching up with early developed individuals in periods with "barriers" (e.g. threshold temperatures) for the early ones. In this case, such a barrier could be prevention of sprout growth at the

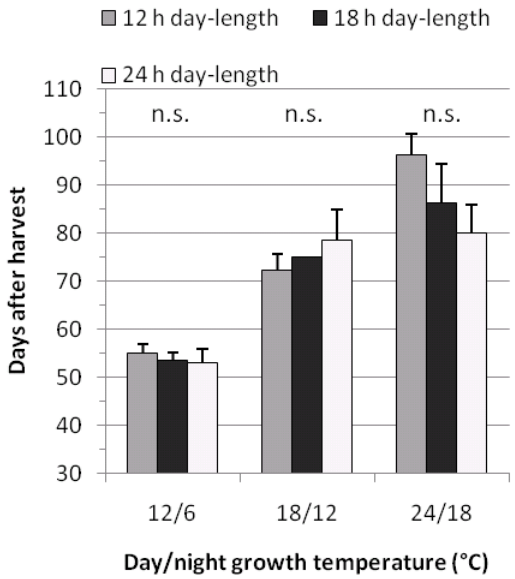

Fig. 5 Duration of dormancy (based on sprouting) after various combinations of temperatures and day-lengths during tuber bulking. Values (mean ± SE, N = 3) within each growth temperature accompanied by different letters are significantly different at p = 0.05; ns indicates that differences are not statistically significant.

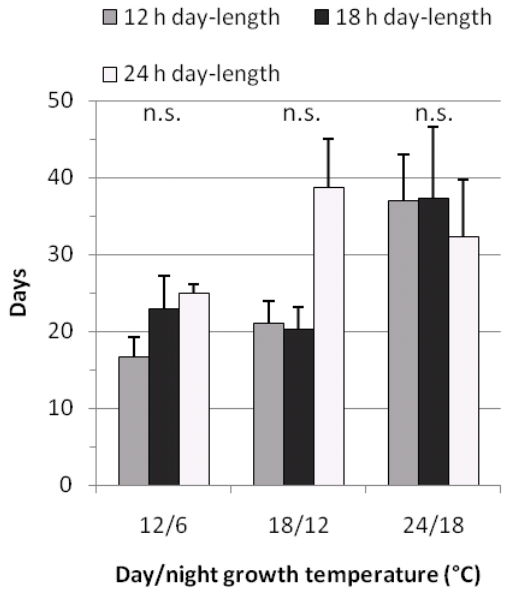

Fig. 6 Spread in dormancy (time between 10 and 90% sprouting) after various combinations of temperatures and day-lengths during tuber bulking. Values (mean ± SE, N = 3) within each growth temperature accompanied by different letters are significantly different at p = 0.05; ns indicates that differences are not statistically significant.

low temperature treatment. However, it is not known exactly how much of the treatment period that interfered with the sprouting phase for the tubers. A treatment with low spread may be used as an example (**Fig. 1**, day/night growth temperature 24/18°C, post-harvest 4°C). Under the assumption that sprouting after dormancy release takes about 25 days until 5 mm sprout length at 18°C (20 days for 2 mm sprouts, see van Ittersum *et al.* 1992), many tubers would have ended dormancy during the 31 days treatment period, and low temperature would be a barrier for sprout growth.

Sprout number and sprout length after dormancy had ended in all tubers was expected to vary between treatments due to variation in time since sprouting started (cf. **Figs. 1** and **3**). Nevertheless, this apical sprouting showed indications of different physiological effects of treatments. In tubers from the highest growth temperatures (average 21°C) the number of sprouts was quite low and similar between post-harvest treatments, indicating a strong apical dominance. Tubers from the lower growth temperatures developed higher sprout number, and also showed some differences between post-harvest treatments, indicating a lower apical dominance. The differences in sprout lengths between treatments seemed to be mainly an effect of the time since dormancy ended.

In the studies of sprout vigour after winter storage, smaller tubers were used due to limited material of the same size as used in the dormancy studies. Although smaller tubers may have deviating dormancy and vigour from larger tubers, it was assumed that the different treatments would have the same impact in both. The current results support the view that dormancy and physiological ageing are affected differently by temperatures during growth of the tubers (van Ittersum and Scholte 1992a). Regarding sprouting characteristics after storage, differences were clear between growth temperatures, but the results did not reflect the patterns of dormancy duration at the same temperatures. In addition, the patterns of dormancy duration resulting from varying post-harvest temperatures, were not reflected at sprouting, also indicating independency between dormancy and physiological ageing.

This study has shown interesting effects of environmental stresses from both low growth temperatures and short post-harvest treatments with low temperatures on both dormancy and physiological ageing. However, there is a need for more research to understand how these factors relate to and affect the metabolism of dormancy regulating hormones.

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