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Green-Sprouting of Potato Seed Tubers (*Solanum tuberosum* L.)—Influence of Daily Light Exposure

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Abstract Pre-sprouting of potato seed tubers (*Solanum tuberosum* L.) in light (green-sprouting) is an established practice in short growing seasons to speed up plant development. Light exposure secures short and robust sprouts for mechanical planting. In 2014–2015, different pre-sprouting treatments were investigated, including different daily durations of light exposure during 6 to 12 weeks at 10 °C in controlled environments. The effects on sprout growth, early growth vigour and field performance in four cultivars were assessed in the greenhouse and in the field. Results indicated that the light treatments involving 8, 16 and 24 h light exposure per day all strongly inhibited sprout growth, with only minor differences between treatments. Compared to untreated tubers, within all cultivars, emergence and early plant growth was clearly and similarly accelerated by all light treatments. At harvest, cultivars were differently affected by the pre-sprouting treatments with regard to haulm senescence (greenness), tuber DM and total yield, and the latest cultivars seemed to benefit more from green-sprouting than the earliest. Different daily durations of light exposure during green-sprouting had a largely similar impact on seed tuber performance in all cultivars. Dark-sprouted tubers (de-sprouted before planting) performed largely similar to control tubers from 4 °C storage. Results demonstrate a potential for shorter daily light exposure during green-sprouting with less energy use and heating problems.

Keywords Chitting · Growth vigour · Irradiation · Physiological age · Pre-spouting · *Solanum tuberosum* L.

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Introduction

Pre-sprouting of seed potato tubers in natural or artificial light (green-sprouting, chitting) is a powerful tool to speed up plant development (McKeown 1994; Struik and Wiersema 1999). It is an established practice in cool and short growing seasons to achieve an advanced plant growth and higher yields early in the season (Furunes 1990; Essah and Honeycutt 2004; Eremeev et al. 2008). It may also secure earlier yields in organic production systems, where late blight disease (*Phytophthora infestans*) may require early harvest (Karalus and Rauber 1997; Hagman 2012). Although crops from physiologically older seed tubers (e.g. pre-sprouted) may be more susceptible to late blight (Hospers-Brands et al. 2008), up to 24% higher yields have been achieved at such early harvests compared to untreated tubers, mainly due to higher proportions of larger tubers (Hagman 2012).

The practice of pre-sprouting normally includes elevated temperature (8–12 °C) during a 4–8-week period, aiming at giving about 150–300 degree days above 4 °C (Johansen and Molteberg 2012). The use of light secures robust and short sprouts for mechanical planting, while sprouts developed in darkness become long and weak with the risk of falling off at handling. However, large-scale green-sprouting is laborious and may involve use of costly energy. The normal practice is to keep lamps burning 24 h per day, which in many cases produces heat with a need of ventilation to keep optimal conditions. It is therefore important to find ways of reducing the use of energy, without reducing sprout quality and seed tuber performance.

The inhibiting effect of light on potato sprout growth has been known for a long time (Dinkel 1963), while knowledge of the underlying physiology and optimal light treatment methods for practical use is rather limited. Earlier studies mainly related to tropical conditions and long-term on-farm storage of seed potatoes in natural indirect light (Potts 1983). McGee et al. (1987) studied how long-term (180 days) light exposure at increasing durations from 30 min to 12 h per day affected sprout growth and found large reductions in growth rate with increasing daily exposure time. In another experiment, these authors showed that light exposure with high intensity for 1 h, or with low intensity for 10 h, with the same total amount of energy, had approximately the same effect.

These previous studies suggest that total light energy is the most important factor for sprout growth inhibition in potato seed tubers. They also show that very low irradiances (0.01 W m^{-2}) can inhibit sprout growth and that high irradiances do not stop growth but reduce it by up to 95% compared to sprout growth in darkness (McGee et al. 1988a). However, scientifically based recommendations of daily light exposure during the currently practised green-sprouting seem lacking. Also the responses of physiological ageing and green-sprouting in commonly used cultivars of different maturity classes need to be investigated, as emergence, stem and tuber numbers and timing of maximum haulm biomass and yield may vary (Moll 1985).

Therefore, the aim of this study is to establish the effects of pre-sprouting (dark- and green-sprouting) of potato seed tubers as compared to untreated tubers of four cultivars with different origins and earliness. The objectives include (a) investigating the effects of various durations of daily light exposure on sprout growth inhibition, (b) investigating the effects of pre-sprouting treatments on early growth vigour in greenhouse, (c) investigating the effects of pre-sprouting treatments on growth and crop yields in field trials and (d) providing recommendations for daily duration of light exposure during green-sprouting.

Material and Methods

General

Experiments were carried out in 2014–2015 at the phytotron of The Arctic University of Norway (UiT), and in greenhouse and field facilities at the Norwegian Institute of Bioeconomy Research (NIBIO), both located in Tromsø (69.7 °N, 18.9 °E). Treatments were performed in controlled growth chambers (10 ± 0.5 °C) at 80–90% relative humidity (RH). The chambers were equipped with fluorescent lamps (Osram DULUX® EL Longlife 20W/41-827, made in Germany), giving an irradiance rate of about 6 μmol m^{-2} s^{-1} or 1.1–1.2 W m^{-2}.

Growth vigour studies in the greenhouse were performed at ambient temperatures (18–25 °C). Field studies of growth and yield were carried out at average air temperatures of 11.8 and 10.7 °C in 2014 and 2015, respectively. Long days (up to 24 h) during the experimental period partly compensate for the low growth temperatures in the field and secure satisfactory yield development at this northern site.

The cultivars tested were Folva (medium early, consumption and processing), Asterix (medium late, consumption and processing), Gullauge (medium late, consumption) and Mandel (late, consumption), where Gullauge and Mandel are land races with unknown origin. Seed material was obtained from Overhalla Klonavlssenter AS, Overhalla, Norway, except for Gullauge, in 2014 (local origin). Seed tubers were harvested in mid-September of 2013 and 2014, respectively, and shipped to Tromsø where they were stored at 3.5–4.0 °C at about 80–90% RH. In spring (March), 400 tubers (40–60 g) of each cultivar were selected and randomly distributed into five standard pre-sprouting cages (80 in each, one layer). The following treatments were carried out during pre-sprouting:

- 4 °C, darkness (control)
- 10 °C, darkness
- 10 °C, 8 h light exposure
- 10 °C, 16 h light exposure
- 10 °C, 24 h light exposure

Sprouts (mainly apical) that developed in darkness at 10 °C were removed before planting.

Sprout Development

After 8 weeks treatment in 2015, the longest sprout on each of the 10 random tubers from each cultivar and light period (8 h, 16 h and 24 h) was measured. Before planting in the field, after 12 weeks treatment, tubers with typical sprout development from all treatments and cultivars were photographed.

Early Growth Vigour—Greenhouse Trials

In both years, after 6 weeks treatment, 10 tubers (40–50 g) from each treatment and cultivar were planted in a 3:1 (*v*/*v*) fertilized peat/perlite mixture in 1.5-l pots. The trials were arranged in a randomized factorial split-plot set-up in a greenhouse in both years, with the four cultivars as main plots and the five treatments (including 10 pots each) randomly distributed within each cultivar. Plants were supplied with a standard nutrient solution on demand (Junttila 1980) from about 20 cm plant height. For each pot, the date of emergence was registered. At 44 and 47 days after planting (2014 and 2015, respectively), plant height (highest upper leaf base) was measured and number of above-ground stems, above-ground biomass, number of tubers (incl. stolon tip swellings above approx. 10 mm) and total tuber weight were registered.

Growth and Yield—Field Trials

After 11 and 12 weeks treatment in 2014 and 2015, respectively, 60 tubers (50–60 g) from each treatment were planted in field trials in a randomized factorial split-plot design. Four cultivars were distributed on large plots within each of the three replicates (blocks), and the five treatments with 20 tubers each, on small plots within each cultivar. Tubers were hand-planted 30 cm apart within one row (6 m), and the rows were spaced 72 cm apart. Guard plants were established at the ends of each row and guard rows on both sides of the field experiment. A standard fertilizer (Fullgjødsel®, NPK 12-4-18, Yara International) was broadcasted and incorporated into the soil before planting, aimed at giving 80 kg N ha^{-1}. At emergence, a visual assessment of plant status was done (grading 1–9, 1 = no visible plants, 9 = plant height about 15 cm). At the time the crops started to flower within the field (August), plant height (highest upper leaf base) was measured on five successive plants in each plot (only in 2015). At harvest, a visual estimation of percent green haulm on each small plot was performed as indication of haulm maturity (senescence) before plants were pulled and tubers were dug by hand. Total tuber weight for each plot was registered, and tuber DM concentration was calculated from the specific gravity of a 2-kg sample. In the 2015 season, one of the replicates (blocks) was excluded from the experiment due to uneven growth conditions.

Statistics

Analysis of variance (ANOVA) was used for data analyses (Minitab 16, GLM procedure, Microsoft, State College, PA, USA). For analysing sprout development, results were subjected to one-way ANOVA for cultivar (n = 30), light treatment (n = 40) and light treatment within cultivars (n = 10), respectively. Factors in the data analysis for greenhouse trials (split-plot design) were block (years, random), cultivar (large plots, fixed) and treatment (small plots within large plots, fixed). Factors in the data analysis for field trials (replicated split-plot design in each of the two years) were block (irrespective of years, random), cultivar (large plots, fixed) and treatment (small plots within large plots, fixed). The interaction cultivar × block was used as error for testing the effect of cultivars in both the greenhouse and field trials. Finally, for both trials, results within each cultivar were subjected to a one-way ANOVA with light treatments as a sole factor. In analyses showing significant difference between treatments ($P \leq 0.05$), Tukey's multiple comparison test was used at significance level $\alpha = 0.05$.

Results

Sprout Growth

Sprout length in Folva and Gullauge showed a statistically significant decrease with increasing duration of daily light exposure, while no differences could be found in Asterix and Mandel (Fig. 1). However, these measured differences were too small to detect visually (Fig. 2). On average across all cultivars, the sprout lengths for the various durations of daily light exposure—8 h (15.1 mm), 16 h (13.6 mm) and 24 h (12.8 mm)—did not differ significantly ($P = 0.211$, $n = 40$).

On average across all three light exposure treatments, sprouts were significantly longer in Asterix (19.9 mm) and Folva (18.1 mm) than in Mandel (7.8 mm) and Gullauge (9.6 mm; $P \leq 0.001$, $n = 30$). We did not measure the sprout lengths of dark-sprouted tubers as they were long and weak with a great risk of falling off and would therefore not be used in practice unless de-sprouted (Fig. 2).

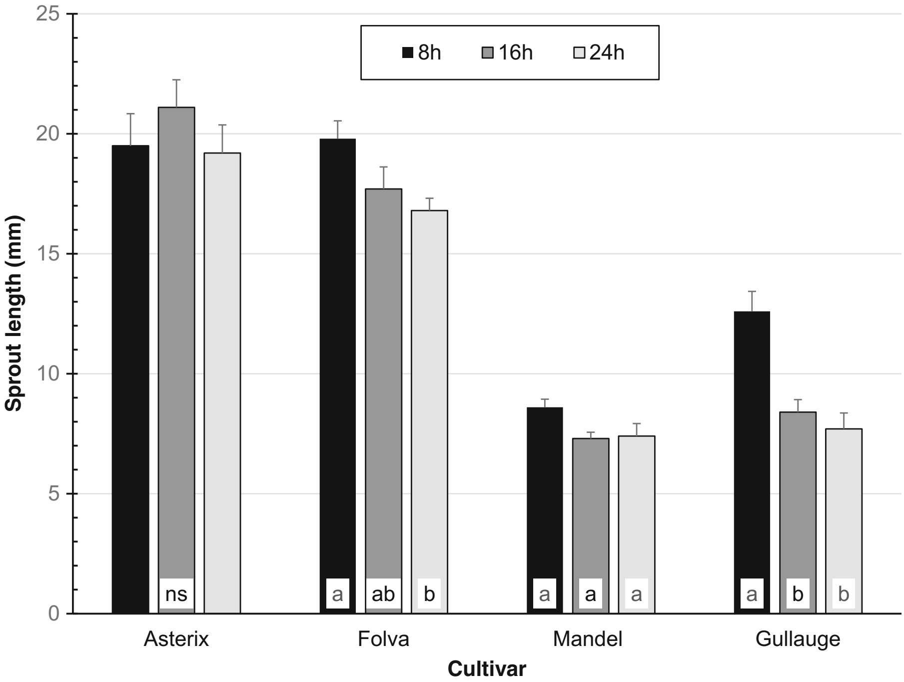

Fig. 1 Average length of the longest sprout (with SE indicated, $n = 10$ tubers) after pre-sprouting of potato seed tubers (*Solanum tuberosum* L.) in 2015 for 6 weeks at 10 °C with various durations of daily light exposure. Pre-sprouting treatments within cultivars not having any lowercase letters in common are significantly different according to Tukey's multiple comparison test ($\alpha = 0.05$)

Fig. 2 Sprout developmental status on potato seed tubers after various pre-sprouting treatments during 12 weeks in 2015. Rows (cultivars) from the top: Mandel, Gullauge, Folva and Asterix. Columns (treatments) from left: control (cold storage at 4 °C), dark-stored at 10 °C, and 8, 16 and 24 h daily light exposure at 10 °C

Early Growth Vigour—Greenhouse Trials

Results from seed tuber treatments, averaged over years and cultivars, clearly showed higher growth vigour in green-sprouted tubers than untreated control ($P \leq 0.05$, 4 d.f., n = 80). For different daily duration of light exposure, however, no significant differences occurred, except for a slightly earlier emergence after the 8 h light exposure than for the 16 and 24 h (7.5 days vs. 8.2 and 8.5 days, respectively). Due to a significant cultivar × treatment interaction ($P \leq 0.05$) for most measured characters, detailed results are presented for each cultivar (Table 1).

In all cultivars, green-sprouting resulted in earlier emergence, faster initial plant growth and higher tuber and haulm biomass at an early growth stage than for the untreated control (Table 1). Stem numbers did not differ, except for a slight decrease for green-sprouted Gullauge.

Dark-sprouted tubers, with sprouts removed before planting, performed largely similarly to cold-stored control tubers, except for Mandel (Table 1). For this cultivar, the vigour of dark-sprouted tubers resembled that of the green-sprouted, with almost as fast emergence, similar early plant growth rate and similar early biomass development for tubers and haulm. For the various durations of light exposure at green-sprouting, however, we found no significant differences in early growth vigour for any of the cultivars, except for Mandel (Table 1). This cultivar emerged slightly earlier at 8 h light exposure than at the longer durations.

Table 1 Early growth vigour in the greenhouse after pre-sprouting of potato seed tubers (*Solanum tuberosum* L.) for 6 weeks at various durations of daily light exposure under controlled conditions (10 °C)

Greenhouse trials	Control 4 °C	0 h[a] 10 °C	8 h 10 °C	16 h 10 °C	24 h 10 °C	*P* value
Cv. Asterix						
Emergence (days)	13.7 a	12.4 b	5.8 c	6.4 c	6.8 c	≤ 0.001
Plant height (cm)	48.5 b	49.4 b	61.2 a	61.3 a	56.8 a	≤ 0.001
No. of stems	3.7	3.4	2.8	2.9	3.1	ns
No. of tubers > 10 mm	2.7 b	2.7 b	3.9 ab	4.5 a	4.0 ab	≤ 0.001
Tuber FW (g)	10.5 b	21.7 b	52.4 a	52.5 a	45.7 a	≤ 0.001
Haulm FW (g)	79.5 bc	72.4 c	98.5 a	101.1 a	90.0 ab	≤ 0.001
Cv. Folva						
Emergence (days)	12.5 a	12.8 a	6.2 b	6.3 b	6.1 b	≤ 0.001
Plant height (cm)	40.7	41.3	39.8	38.9	42.7	ns
No. of stems	3.1	2.9	2.7	2.9	3.1	ns
No. of tubers > 10 mm	5.9	6.6	6.9	5.7	6.5	ns
Tuber FW (g)	62.1 b	63.7 b	94.9 a	86.8 a	91.4 a	≤ 0.001
Haulm FW (g)	58.5 b	55.4 b	63.1 ab	62.2 ab	68.7 a	≤ 0.001
Cv. Mandel						
Emergence (days)	22.1 a	14.9 b	10.4 d	12.2 c	12.9 c	≤ 0.001
Plant height (cm)	25.4 b	41.5 a	37.9 a	41.1 a	40.2 a	≤ 0.001
No. of stems	5.2	5.0	5.1	5.9	5.3	ns
No. of tubers > 10 mm	0.6 c	5.1 b	7.2 a	6.4 ab	7.2 a	≤ 0.001
Tuber FW (g)	0.5 b	19.2 a	22.4 a	18.7 a	16.9 a	≤ 0.001
Haulm FW (g)	41.4 b	63.5 a	64.1 a	69.4 a	67.0 a	≤ 0.001
Cv. Gullauge						
Emergence (days)	14.4 a	11.5 b	7.7 c	8.0 c	8.2 c	≤ 0.001
Plant height (cm)	47.8 b	53.4 b	63.9 a	61.1 a	61.6 a	≤ 0.001
No. of stems	5.7 a	5.0 ab	4.1 b	5.0 ab	5.1 ab	0.032
No. of tubers > 10 mm	6.7	6.8	6.7	7.6	7.7	ns
Tuber FW (g)	42.1 c	57.5 b	77.5 a	77.2 a	82.7 a	≤ 0.001
Haulm FW (g)	84.9 b	86.2 b	103.2 a	105.5 a	111.9 a	≤ 0.001

Control tubers are from cold storage. Average results for 2014 and 2015 ($n = 20$ pots). Final registration 44 and 47 days after planting in 2014 and 2015, respectively

Values within rows not having any lowercase letters in common are significantly different by Tukey's multiple comparisons test ($\alpha = 0.05$)

ns not significant, *FW* fresh weight

[a] De-sprouted before planting

Growth and Yield—Field Trials

Also in the field trials, results averaged over blocks and cultivars showed faster plant growth and higher yields from green-sprouted tubers than for the untreated control ($P \leq 0.05$, 4 d.f., $n = 20$). Between the different durations of daily light exposure, no significant differences occurred. Due to a significant cultivar × treatment interaction for several characters ($P \leq 0.05$), results are presented for each cultivar (Table 1).

Green-sprouted tubers resulted in earlier emergence for all cultivars compared to untreated control (Table 2). There were also a tendency of more mature (less green) haulm at harvest in Asterix and Folva after green-sprouting and a significantly higher tuber DM concentration for Asterix and Mandel. Total yields were clearly greater for Mandel and Gullauge after green-sprouting, while for Asterix and Folva, yields did not differ from control. Tuber numbers and tuber weights were not affected by green-sprouting in Asterix, while for Mandel, green-sprouting resulted in larger tuber numbers and a tendency of reduced average tuber weights. Folva and Gullauge showed tendencies of increased tuber numbers at green-sprouting, but no clear indications of different tuber weights. The field performance of dark-sprouted tubers, with sprouts removed before planting, was largely similar to that of the cold-stored control tubers for all cultivars. Finally, the various durations of light exposure for green-sprouted tubers did not seem to affect field growth characteristics differently for any of the cultivars (Table 2).

The separate study of plant heights in August 2015 showed significant differences between the seed treatments when averaged over blocks and cultivars ($P \leq 0.001$, 4 d.f., $n = 40$). There was, however, a cultivar × treatment interaction and therefore, results are presented for each cultivar (Fig. 3). For all cultivars, plants from green-sprouted seed tubers were clearly shorter than plants from untreated control tubers. For Asterix also, plants from dark-sprouted tubers were shorter, while dark-sprouted Folva, Mandel and Gullauge did not differ significantly from control plants. Daily duration of light exposure at green-sprouting had no effect on plant heights except for some minor differences in Gullauge.

Discussion

The ability of sprout growth differed strongly between cultivars in this study, but pre-sprouting in light (green-sprouting) seemed to inhibit sprout growth of all tested cultivars sufficiently for practical use. For some cultivars, however, results indicated that the inhibiting effect of light increased with increasing daily duration of light exposure. This may be due to a low light intensity in our study, causing a too-low total irradiation per day for the shortest exposure time (McGee et al. 1987, 1988a). In our studies, the light intensity was approx. 6 μmol m^{-2} s^{-1} (1.1–1.2 W m^{-2}), which was only 11–12% of the intensity used by McGee et al. (1987). In their studies, even 1 h light per day strongly inhibited sprout growth for one cultivar during a 180-day treatment period. Total irradiation per day in this case would be comparable to our exposure of 8 h per day. Therefore, our results illustrate a need for more knowledge of total daily irradiation needed for successful green-sprouting of various cultivars and of optimal light intensity at reduced daily durations of light exposure.

Our results show that green-sprouting clearly accelerated emergence and early plant development in potatoes. It may also result in more mature (less green) haulm at the end of the season, a higher tuber DM content, higher total yields, higher tuber numbers per plant and reduced average tuber weights, although with some variations between cultivars in our studies. The results are in agreement with the general understanding of

Table 2 Growth and yield in field trial after pre-sprouting of potato seed tubers (*Solanum tuberosum* L.)

Field trials	Control 4 °C	0 h[a] 10 °C	8 h 10 °C	16 h 10 °C	24 h 10 °C	*P* value
Cv. Asterix						
Emergence score (1–9, 9 best)	2.4 b	2.6 b	8.0 a	8.0 a	7.6 a	≤ 0.001
Green haulm at harvest (%)	86 a	85 a	76 a	74 a	76 a	0.033
Tuber yield (Mg ha^{-1})	42.3 ab	39.7 b	45.5 ab	49. 6 a	47.8 a	0.007
DM (%)	20.5 b	20.3 b	21.5 a	21.4 a	21.6 a	≤ 0.001
No. of tubers per plant	9.2	9.5	9.6	9.5	10.6	ns
Average tuber weight (g)	100.7	90.8	103.4	115.2	97.2	ns
Cv. Folva						
Emergence score (1–9, 9 best)	2.4 b	2.4 b	8.0 a	7.6 a	7.6 a	≤ 0.001
Green haulm at harvest (%)	86 a	83 ab	74 ab	73 ab	72 b	0.018
Tuber yield (Mg ha^{-1})	46.6 ab	39.1 b	50.1 a	48.5 a	50.3 a	0.005
DM (%)	19.5	19.5	19.8	19.8	20.1	ns
No. of tubers per plant	13.4 b	9.7 c	15.8 ab	16.8 ab	17.4 a	≤ 0.001
Average tuber weight (g)	77.8 ab	92.3 a	70.1 b	64.3 b	65.4 b	0.003
Cv. Mandel						
Emergence score (1–9, 9 best)	1.0 b	1.8 b	5.2 a	4.4 a	4.8 a	≤ 0.001
Green haulm at harvest (%)	78	68	70	70	72	ns
Tuber yield (Mg ha^{-1})	27.7 b	30.2 ab	35.2 a	34.5 a	34.7 a	0.001
DM (%)	24.5 c	25.1 bc	26.1 a	26.1 a	25.8 ab	≤ 0.001
No. of tubers per plant	12.9 b	13.2 b	18.7 a	16.7 a	17.9 a	≤ 0.001
Average tuber weight (g)	46.6 ab	50.7 a	41.5 b	44.7 ab	42.3 b	0.016
Cv. Gullauge						
Emergence score (1–9, 9 best)	1.8 b	2.2 b	7.6 a	7.0 a	7.4 a	≤ 0.001
Green haulm at harvest (%)	68	69	67	66	61	ns
Tuber yield (Mg ha^{-1})	31.7 b	29.4 b	42.3 a	40.8 a	41.2 a	≤ 0.001
DM (%)	23.1	23.2	23.5	23.8	24.9	ns
No. of tubers per plant	12.8 bc	11.0 c	15.4 ab	14.6 ab	16.9 a	0.001
Average tuber weight (g)	53.6	58.8	59.7	60.7	52.7	ns

Average results ($n = 5$) for 2014 and 2015 after 11–12 weeks treatment with various durations of daily light exposure in controlled climate (10 °C). Control tubers are from cold storage. Plants harvested 106–107 days after planting

Values within rows not having any lowercase letters in common are significantly different by Tukey's multiple comparison test ($\alpha = 0.05$)

ns not significant

[a] De-sprouted before planting

physiological ageing of seed tubers (van der Zaag and van Loon 1987); increased physiological age, as compared to cold-stored tubers, promotes a shorter growth cycle (faster emergence, lower plants and earlier growth cessation) with a higher yield potential in short seasons. On the other hand, in our studies, the relatively fresh haulm and greater plants of the untreated tubers at harvest demonstrate the higher yield

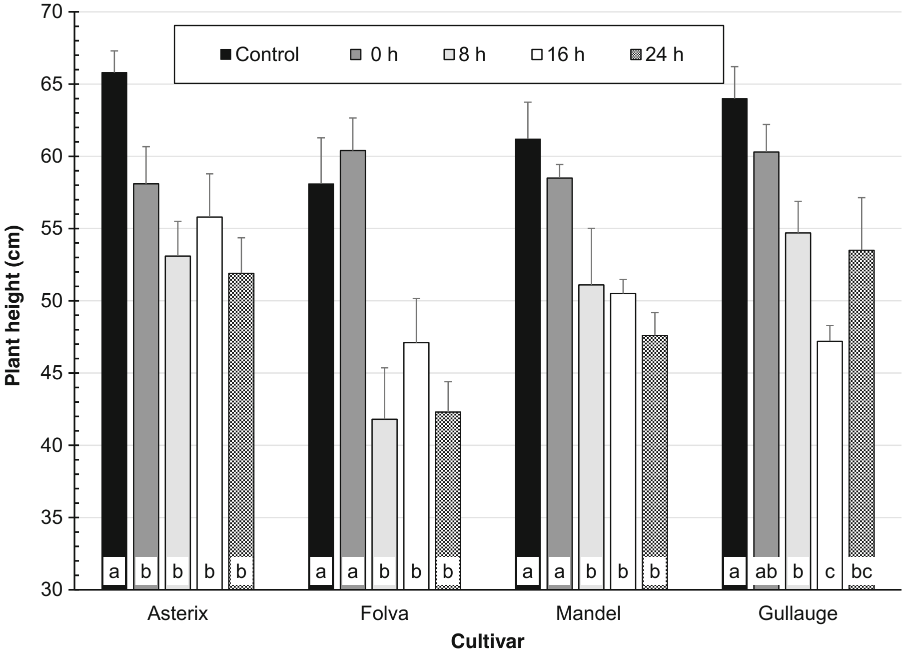

Fig. 3 Average plant heights (with SE indicated, $n = 10$) in the field on 10 August 2015 after pre-sprouting of the potato seed tubers according to different treatments during 12 weeks at 10 °C. Dark-sprouted tubers (0 h) were de-sprouted before planting. Green-sprouted tubers with varying daily light exposure (8, 16, 24 h). Control tubers from cold storage (4 °C). Treatments within cultivars not having any lowercase letters in common are significantly different according to Tukey's multiple comparisons test ($\alpha = 0.05$)

potential if seasons were longer. The yield increase after green-sprouting in the current short season studies, about 7–10 t ha^{-1} for the latest cultivars, seems comparable to previous reports (Furunes 1990; Essah and Honeycutt 2004; Hagman 2012).

The duration of light exposure in general did not seem to affect seed tuber performance. Nevertheless, Mandel tended to emerge earlier after short light exposure than at the longer exposures. An explanation for this may be the differences in sprout length at planting, with somewhat longer sprouts at short light exposure, and thereby a shorter way to go to reach the soil surface. Overall, results for sprout length and emergence, averaged over cultivars, support such an interpretation. Response to treatment photoperiod is another possibility as long photoperiods may decrease growth vigour at storage in light (Scholte 1989; Struik and Wiersema 1999, p. 126). However, this seems unlikely at the current low treatment temperatures.

The late-maturing cultivars Gullauge and Mandel seem to benefit more from green-sprouting than the earliest, Folva and Asterix, regarding total yield at the actual short season conditions. This is probably due to early cultivars reaching the "young = old" yield equilibrium (Struik and Wiersema 1999, p. 84) earlier than late cultivars. Yield equilibrium refers to the point of time when the yield for physiologically old tubers (e.g. green-sprouted) ceases off development and crosses the curve for the continuing yield development from physiologically young tubers.

Dark-sprouted tubers stored at similar temperatures as the green-sprouted tubers perform largely similarly to cold-stored control tubers after de-sprouting. Results are in accordance with Rønsen (1977) and McGee et al. (1988b) who found a consistently delayed emergence and reduced yields after de-sprouting. An exception in our trials was dark-sprouted Mandel, which after de-sprouting performed clearly better than cold-stored tubers for most early vigour characters in the greenhouse experiment. This cultivar is an old land race, classified as "late", with slow sprout development. At the time for early planting in the greenhouse, even dark-sprouted sprouts were very short and some of them may have missed de-sprouting and thereby maintained the effect of ageing at elevated temperatures. After the much longer pre-sprouting period before field planting, de-sprouting was probably more effective, as Mandel performed similarly to the other cultivars.

In conclusion, the study demonstrates that continuous light exposure during green-sprouting is not necessary for either sprout-growth inhibition or for growth vigour, plant development or yield formation. However, before recommendations of a minimum duration of daily light exposure are presented, more knowledge is needed on the combined effect of duration and intensity of light. The results imply options for reduced energy use and costs, better control of temperatures during green-sprouting and thus better sprout quality.

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