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The effect of pre-planting thermal treatment of seed tubers on the yield and quality of potato

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Abstract. Field trials with the potato cultivars 'Ants' (medium late) and 'Laura' (medium early) were carried out on the experimental fields of the Department of Field Crops and Grassland Husbandry located at Eerika (58°22′ N, 26°40′ E), Estonian University of Life Sciences in 2010 and 2011. The yield of tubers and starch, marketable yield of potato, number of tubers per plant and tuber weight were studied. We used the following treatments: untreated control (T_o): seed tubers were planted directly from storage house (storage temperature 4°C); thermal shock (T_S): seed tubers were kept before planting 5 days in a room with temperature of 30°C and 2 days with temperature of 12°C; pre-sprouting (P_S): before planting the seed tubers were kept 26 days in a room with temperature of 15°C and 10 days with temperature of 12°C. The results are presented as the averages of studied years.

According to the average results of two experimental years, the pre-planting treatment with thermal shock increased the number of tubers per plant of cultivar 'Ants' by 30.6%, compared to control treatment. None of the treatments had any effect on the number of tubers of cultivar 'Laura'. The thermal treatment increased the average weight of tubers of cultivar 'Laura' compared to the control treatment (thermal shock by 14.7%, pre-sprouting by 20.7%), but for cultivar 'Ants' the weight of tubers was decreased by 16.7% (thermal shock treatment). The thermal shock treatment increased the tuber yield of cultivar 'Ants' by 10.7% and the pre-sprouting increased the total tuber yield of cultivar 'Laura' by 9.9%. The thermal shock increased significantly the starch content of cultivar 'Ants' and decreased that of cultivar 'Laura'.

Key words: number of tubers per plant, tuber weight, tuber yield, starch yield, starch content.

INTRODUCTION

One of the main components for stable, economically sustainable potato yield is healthy, biologically active high-yielding seed tubers that are being pre-treated according to the end of use (Struik, 2006). In Estonia the growing area and total yield of potato has steadily decreased while the yield has increased (Statistics Estonia Database, 2013). In order to maintain the high yield potential of potato it is important to apply all the necessary measures for it.

Potato cultivars, which are able to provide high quality yields as early as possible in order to be market competitive are vital. Accumulated temperature, precipitation and radiation during the vegetation period favour the growth of early cultivars rather than late cultivars. One such measure is the pre-sprouting of seed tubers. The pre-sprouting of seed tubers of early as well as late potato cultivars is, among the yield-increasing pre-planting measures, widely used in the Netherlands (Struik & Wiersema, 1999). Late cultivars are beneficial because of their higher yield potential and also their ability to maintain nutritional quality during storage (Struik, 2006). Another technique also used for obtaining earlier yield, besides pre-sprouting, is thermal treatment (otherwise known as thermal shock), which increases the physiological age of seed tubers and shortens the chronological time needed for the formation of harvestable tubers (Struik & Wiersema, 1999; Struik, 2007).

Increase the physiological age of seed tubers is a suitable alternative option for increasing the yield, stimulating earlier formation of tubers and enhancing their quality (Möller & Reents, 2007). The physiological age of seed tubers is defined as the physiological status of tubers that will have an impact on its productivity. A physiologically young seed tuber has preconditions to develop better and stronger roots as well as all above-ground parts of the plant, and the largest assimilation surface possible, leading to formation of a high tuber yield (Eremeev et al., 2008a; b; Hagman, 2012a; b). The drawback is that the late sprouting and canopy closure decreases the ability of potato plants to compete with weeds. The delayed development of the assimilation surface puts much of the assimilation potential past the time of maximum photosynthetically active radiation (Boyd et al., 2002), thus the maturation of tubers is delayed.

The seed tubers may be treated before planting in various ways. There are methods where tubers are heated for a short period but at higher temperatures like when using thermal shock and also where heating period is longer but the temperatures used are lower like when using pre-sprouting. Temperatures higher than 30–35°C are rarely used in thermal shock, even for a short time, as the albumins curdle at 40°C (Kulaeva, 1997). While thermal shock is recognized as a good alternative to pre-sprouting there is scant in-depth information regarding the treatment in the literature (Essah & Honeycutt, 2004).

Relatively few studies have addressed the complex research on the effects of different methods of pre-planting treatments on some aspects of the development of different parts of potato plant and finally on the tuber yield.

Previous pre-planting treatment methods need some modifications to prevent the mechanical damaging of sprouts. The effectiveness of different pre-sprouting methods is depending also on the particular climate conditions.

The objective of our experiment was to study the effect of pre-planting thermal treatments (thermal shock and pre-sprouting) on the tuber total and marketable yields, and on the starch content and yield of cultivars 'Ants' and 'Laura'. The longer thermal shock period (5 days at 30°C) is a novel approach that has not been studied before.

MATERIALS AND METHODS

Field trials were carried out on the experimental fields of the Department of Field Crops and Grassland Husbandry located at Eerika (58°22′ N, 26°40′ E), Estonian University of Life Sciences in 2010 and 2011. In the field trials potato cultivars 'Ants' (medium late) and 'Laura' (medium early) were used. A randomized complete block in 4 replications was used (Hills & Little, 1972). The area of a plot was 16.8 m^2, the distance between rows was 70 cm and between seed tubers planted 27 cm. Seed tubers with a diameter of 35–55 mm were used in the experiment. Potato was planted at the beginning of May and harvested in August-September. The total and marketable yield was determined right before the harvest by collecting tubers from 15 consecutive plants. The soil of the experimental field – *Stagnic Luvisol* (*LVj*) according to the World Reference Base classification (FAO, 2006), and the texture of the soil is sandy loam with a humus layer of 20–30 cm (Reintam & Köster, 2006). The agrotechnical measures used were specific to potato cultivation.

We used the following treatments: 1) T_o – untreated (control): 2 days before planting the seed tubers were brought from storage house (storage temperature of 4°C) in order to raise their temperature to the level of soil temperature; 2) T_S – thermal shock: the seed tubers were kept before planting 5 days at 30°C and were left to cool to soil temperature for 2 days; 3) P_S – pre-sprouting: before planting the seed tubers were kept 26 days at 15°C and 10 days at 12°C. After that the tubers were left to cool in order to reach the temperature similar to soil conditions. The light and moisture conditions of the treatment rooms were in accordance to the physiological needs of the seed tubers.

The pre-crop was wheat. Composted manure (40 t ha^{-1}) before autumn ploughing was used as organic fertilizer. On average, the composted cattle manure contained 9.7 g kg^{-1} total N, 4.6 g kg^{-1} total P, 8.6 g kg^{-1} total K, 138 g kg^{-1} total C and 44.8% dry matter. Mineral fertilizers were applied locally at the same time with planting of potatoes in spring. The mineral fertilizer was applied in spring during planting at a rate of 275 kg ha^{-1} (Yara 11-11-21). The potato was planted on the 13th of May each year.

In present article, the yield results of 2010 (samples collected on the 26th of August, 106 days after planting) and 2011 (samples collected on the 30th of August, 110 days after planting) are used. According article authors the cultivars are at different vegetation period: potato cultivars 'Ants' (medium late) and 'Laura' (medium early) Do both cultivars where harvested at the same time and than tubers where analyzed?

From each plot 15 consecutive plants were collected for structural analysis. The marketable yield was determined as the round tubers with diameter of 35 mm and higher for cultivar 'Ants' and oval tubers with diameter of 30 mm and higher for cultivar 'Laura'. After the potato was harvested, tubers were taken from each replication to measure starch concentrations. Tuber starch concentrations were found through tuber specific gravity for what Parov's weight was used (Viileberg, 1986). The starch yield was calculated based on the starch content and tuber yield.

The weather during the experiment period was monitored with a Metos Compact (Pessl Instruments) electronic weather station, which automatically calculates the average daily temperatures and the sum of precipitation. To obtain the decade average of daily average temperatures at the weather station, the daily temperatures were averaged over each decade. The precipitation in 2010 and 2011 differed considerably from the long-term average (1969–2011) as follows: 2011 was arid with 74.5 mm less rainfall than the long-term average; and 2010 was unusually wet with 461.2 mm of rainfall. Average temperatures showed the expected progression from low in May to high in August with a decrease in September. For the month of May the temperatures were lowest in 2011 and highest in 2010. Over the entire season, 2010 was generally the warmest (Tein et al., 2014).

The results were analyzed with Statistica 11, using ANOVA and Fisher LSD test. Statistically significant differences ($p < 0.05$) between variants are denoted with letters. The strength of correlative relationship (coefficient *R*): if the correlation coefficient is denoted as ***, the relationship is significant with the probability of 99.9%. Note '**' means the probability of 99% and '*' the probability of 95%. The results are presented as averages of two years (2010–2011).

RESULTS AND DISCUSSION

The thermal treatment of seed tubers of cultivar 'Ants'

The number of tuber set by a plant is determined by stem density, spatial arrangement, cultivar and season (Wurr et al., 2001). The best way of manipulating tuber number is by manipulating seed rate, size of the seed tubers and their physiological age. Storage conditions and pre-sprouting treatments strongly influence the number of tubers per plant (Johansen & Nilsen, 2004; Johansen & Molteberg, 2012). Wurr (1979) suggested that tuber number for different genotypes do not result from a difference in number of potential tuber sites, but from some control over tuber initiation. Struik et al. (1990) claimed that tuber set, rather than tuber initiation, determined total tuber number. After the tubers have been set, the growth into various size grades is the result of competition among the tuber settings and growth rate of the individual tubers (Struik et al., 1990; 1991). Our results indicated that the pre-planting thermal shock treatment significantly increased the number of tubers per plant compared to control by 3.7 tubers (30.6%) and to pre-sprouting by 2.6 tubers (19.7%, $p < 0.05$). The average weight of a tuber of cultivar 'Ants' was treated by thermal shock was significantly smaller compared to the other variants (T_o and P_S), 6.8 g (16.9%) and 5.1 g (12.7%, $p < 0.05$) respectively (Table 1).

Table 1. The number of tubers per plant and the average weight of a tuber average results of 2010 and 2011

Cultivar	Variant	Number of tubers per plant	Weight of a tuber, g
Ants			
	Untreated	12.1a ± 0.4*	47.1b ± 1.6
	Thermal shock	15.8b ± 0.4	40.3a ± 1.2
	Pre-sprouting	13.2a ± 0.4	45.4b ± 1.4
Laura			
	Untreated	16.8a ± 0.5	36.7a ± 1.1
	Thermal shock	15.3a ± 0.6	42.1b ± 1.4
	Pre-sprouting	15.5a ± 0.5	44.3b ± 1.4

Note. Within the same column, values with different letters are significantly different (ANOVA, Fisher LSD test); * – ± denote the standard deviation.

Pre-planting thermal shock treatment increased significantly the tuber yield compared to control by 10.7% (3.2 t ha^{-1}, $p < 0.05$) (Table 2). The tuber yield of cultivar 'Ants' had the strongest correlation with the number of tubers in untreated control variant (R = 0.69***) (Fig. 1) and somewhat weaker correlation with thermal treatment – correlation coefficients in case of pre-spouting was R = 0.58** and in case of thermal shock R = 0.43*.

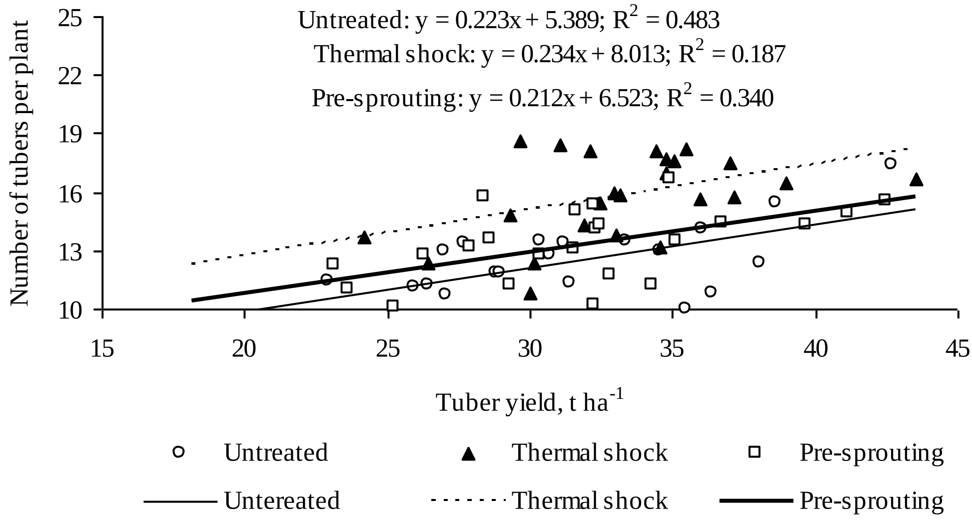

Figure 1. The relationship between the tuber yield and the number of tubers per plant of cultivar 'Ants', due to the effect of pre-planting thermal treatment, average results of 2010 and 2011 (n = 24).

The significant relationship between tuber yield and the weight of tubers of cultivar 'Ants' was observed only in untreated and pre-sprouted treatments (*R* values were 0.62** and 0.55**, respectively) (Fig. 2).

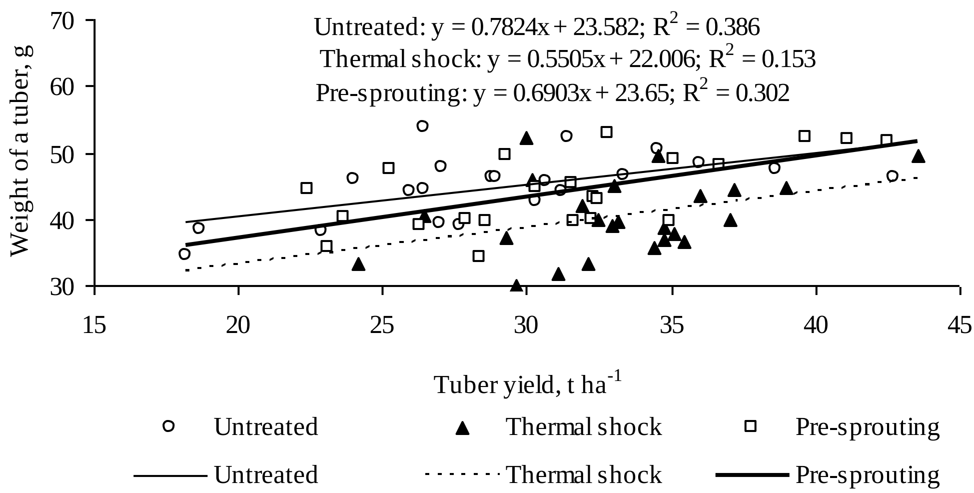

Figure 2. The relationship between the tuber yield and the weight of a tuber of cultivar 'Ants', due to the effect of pre-planting thermal treatment, average results of 2010 and 2011 (n = 24).

In the pre-sprouted treatment the tuber yield did not vary statistically from the control treatment. Also none of the thermal treatments had any effect on the tuber yield (Table 2).

Table 2. The yield of tubers and marketable tubers, due to the effect of pre-planting thermal treatment, average results of 2010 and 2011

Cultivar	Variant	Tuber yield, t ha^{-1}	Marketable yield, t ha^{-1}
Ants			
	Untreated	30.0a ± 1.3*	26.7a ± 1.2
	Thermal shock	33.2b ± 0.8	28.4a ± 0.9
	Pre-sprouting	31.4ab ± 1.1	28.1a ± 1.1
Laura			
	Untreated	32.3a ± 1.0	28.8a ± 1.0
	Thermal shock	33.3ab ± 0.9	30.4ab ± 0.9
	Pre-sprouting	35.5b ± 0.9	32.6b ± 0.8

Note. Within the same column, values with different letters are significantly different (ANOVA, Fisher LSD test); * – ± denote the standard deviation.

Due to the effect of thermal treatment (thermal shock and pre-sprouting) the starch content of cultivar 'Ants' were increased by 1% on average compared to the control ($p < 0.05$) and thermal shock also increased significantly the starch yield by 0.7 t ha^{-1} (16.5%, $p < 0.05$) compared to the control treatment (Table 3), that was directly related to higher total yield (Table 2). The average potato yield in Estonia is 17.5 t ha^{-1} (includes yields from organic farming) and it has been increasing over the past ten years 4.0 t ha^{-1} (Statistics Estonia Database, 2013). The average yield results in this experiment are much higher than Estonian average yields (Table 2). Physiological age is very important for the development of the tuber yield (Struik & Wiersema, 1999). A physiologically older seed accelerates the growth rhythm of potatoes, due to which the yield develops earlier, while the yield formation ability decreases (Caldiz et al., 2001; Johansen et al., 2008). The results also show that the earlier cultivar, the greater the effect of treatment and that the yield develops evenly during the vegetation period in cultivars with longer growth period. Thus, both pre-sprouting and thermal shock increase the physiological age of tubers to some extent.

Table 3. The content and yield of starch, due to the effect of pre-planting thermal treatment, average results of 2010 and 2011

Cultivar	Variant	Starch content, %	Starch yield, t ha^{-1}
Ants			
	Untreated	14.2a ± 0.2*	4.3a ± 0.2
	Thermal shock	15.2b ± 0.1	5.0b ± 0.1
	Pre-sprouting	15.1b ± 0.1	4.7ab ± 0.2
Laura			
	Untreated	14.1b ± 0.1	4.6a ± 0.1
	Thermal shock	13.7a ± 0.1	4.6ab ± 0.1
	Pre-sprouting	14.0ab ± 0.1	5.0b ± 0.1

Note. Within the same column, values with different letters are significantly different (ANOVA, Fisher LSD test); * – ± denote the standard deviation.

The thermal treatment of tubers of cultivar 'Laura'

The average weight of the tubers of a plant depends mostly on the cultivar (Eremeev et al., 2008c). The higher the number of tubers per plant, the lower the average weight of tubers (Eremeev et al., 2008b; Margus et al., 2014). In our experiment the thermal treatment increased the average weight of the tubers of cultivar 'Laura' by 5.4 g (14.7%) in case of thermal shock and by 7.6 g (20.7%) in case of pre-sprouting compared to the control treatment ($p < 0.05$) (Table 1). The number of tubers per plant was not significantly affected by thermal treatments (T_S, P_S). The pre-sprouting increased significantly the total tuber yield by 3.2 t ha^{-1} (9.9%) and the yield of marketable tubers by 3.8 t ha^{-1} (13.2%) ($p < 0.05$) compared to the control (Table 2). As for the cultivar 'Ants' the tuber yield of cultivar 'Laura' depended also on the number of tubers per plant (Fig. 3). Although the relationship was not affected by the thermal treatments used – the correlation between the yield and the number of tubers was strong ($R = 0.52^{**}$– 0.54^{**}). The starch content and the quality of tubers is influenced by several factors: properties of the cultivar, agroecological and climatic conditions, agrotechnical measures, fertilization and storage conditions of tubers (Ierna, 2010). Due to the thermal shock the starch content of the tubers was significantly reduced by 0.4% (6.8% increase compared to the control treatment), but the pre-sprouting increased the starch content by 0.41 t ha^{-1} (20.7%, $p < 0.05$) (Table 3). The use of pre-sprouted tubers provides good basis for higher yield that has also been related to the increase in starch content.

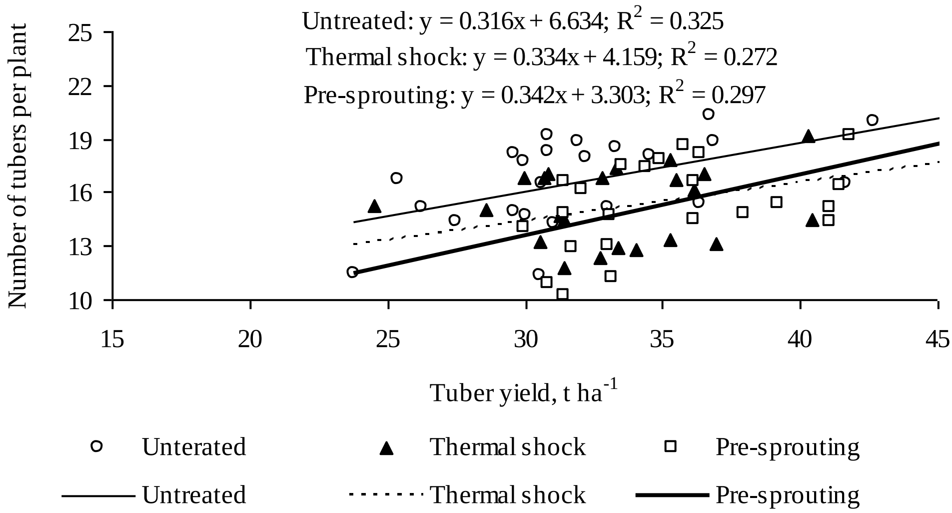

Figure 3. The relationship between the tuber yield and the number of tubers per plant of cultivar 'Laura', due to the effect of pre-planting thermal treatment, average results of 2010 and 2011 (n = 24).

The thermal treatment of tubers did not have any significant impact on the nitrate content of the cultivars studied (71.2–78.2 mg kg^{-1} for cultivar 'Ants' and 21.2–28.9 mg kg^{-1} for cultivar 'Laura'). The values measured were dependent on the properties of the cultivars.

CONCLUSIONS

1. The pre-planting thermal shock treatment of tubers of cultivar 'Ants' increased the number of tubers per plant compared to the control treatment by 30.6%, but no changes were observed in the pre-sprouted treatment.

2. In case of cultivar 'Laura', the pre-planting thermal treatment of tubers did not have any significant effect on the number of tubers per plant, but increased the average weight of tubers compared to the control variant (by 14.7% with thermal shock and by 20.7% with pre-sprouting).

3. The weight of the tubers of cultivar 'Ants' was reduced (by 16.9%) with the use of thermal shock treatment compared to the control treatment.

4. The treatment with thermal shock increased significantly the tuber yield of cultivar 'Ants', by 10.7% compared to the control and pre-sprouting increased the total tuber yield of cultivar 'Laura' by 9.9%.

5. Due to the thermal shock the starch content of cultivar 'Ants' was increased and that of cultivar 'Laura' was decreased.

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