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The influence of thermal shock and pre-sprouting of seed potatoes on formation of some yield structure elements

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Abstract
For earlier potato yield formation we used pre-sprouting and thermal treatment which both add to the physiological age of potato. At the same time, pre-sprouting is a very time- and energy-consuming procedure. We investigated if thermal treatment could replace pre-sprouting and how it affects the growth and development of potato haulms and tubers. For that purpose an experiment was conducted in 2000–2002 to examine the opportunities for growing potatoes by using different methods of pre-planting treatment of seed tubers.

Early, middle and late maturing potato varieties (two Estonian varieties and one Latvian) were used, each being subdivided into three variant categories: untreated, thermal shock and pre-sprouting.

The experiment indicated that one or the other of thermal shock or pre-sprouting shortened the time to emergence by up to 10 days. With pre-sprouting, the formation of tubers started as soon as 45 days after planting and with thermal shock 50 days after planting, i.e., 5–10 days earlier than in the untreated variant.

Thermal shock of seed tubers had the greatest effect on the number of tubers per plant, while pre-sprouting increased the average weight of tubers.

Both pre-sprouting and thermal shock had a strong effect on the weight of the haulms in varieties with a longer growth period.

Keywords: Haulms, leaf area index, physiological age, potato, tuber weight, tuber yield.

Introduction
In order to ensure the full maturation of varieties with various growing times, especially for late varieties, the sum of active temperatures in Estonia often remains low. At the same time it is vitally important for farmers to market early potatoes as early as possible. With late potato varieties the yield increase is usually negatively affected by wide infestation by diseases before full maturity. Therefore, measures to shorten the growth period of the potato should be implemented, especially for seed potato cultivation.

Different methods are used to achieve an earlier potato yield, including the thermal treatment of seed tubers, which adds physiological age to the tubers and shortens the chronological time that is necessary for the tubers to become harvest-ripe (Allen et al., 1992; Struik & Wiersema, 1999). This method boosts enzyme activity in tubers, stimulates faster development of sprouts from the eyes, reduces the sprouting period and accelerates plant development and tuber formation. The leaf area and tuber yield of potatoes may vary. After the breaking of dormancy, the seed tuber goes through different phases: apical dominance, normal sprouting, production of branched sprouts, senility and incubation (little tuber formation). Crops grown from seed tubers in different phases differ in canopy structure, tuber number, yield, tuber size distribution and quality (Ewing & Struik, 1992; Struik & Wiersema, 1999).

If seed tubers are kept at a higher temperature for some time in spring, then the result is physiologically older tubers. This can be used in the growing of both
early and late potatoes as the maximum weight of the haulms (leaves and stems) and maximum leaf area are achieved faster. An economically optimal tuber yield can also be harvested earlier. However, physiologically younger plants can be more viable and even form a higher tuber yield, although slightly later. The physiological age of the tuber affects the numbers of sprouts and sprout behaviour, but also the growth pattern of the plant that originates from it and thus sometimes the tuber yield of the crop produced (van der Zaag & van Loon, 1987).

In the Estonian University of Life Sciences (EMU) Institute of Agricultural and Environmental Sciences (IAES), at the Department of Field Crop Husbandry we have focused on the effects of seed tubers of different age on the different parts of a potato plant. If the seed tubers are kept for a certain time at higher temperatures before planting, physiologically older tubers are obtained (Eremeev et al., 2003). This is important when growing early or late potato varieties, because maximum weight of the haulms and the leaf area index are attained faster and it is possible to harvest also the economically optimal tuber yield much earlier (Eremeev et al., 2005). Current research analyses the development of potatoes throughout their growth as well as tuber yield, whereas seed tubers are treated by different methods to wake them from the dormancy period. The aims of the present research were: 1) to discover what pre-planting treatment methods (thermal shock and pre-sprouting) are best for our weather conditions to ensure the formation of a large high-quality tuber yield as early as possible; 2) to answer the following questions – can thermal shock replace the long and energy-consuming pre-sprouting period and how can thermal shock affect the growth and development of potato haulms and tubers? 3) to discover correlations between the different parts of a potato plant (leaves, haulms and tubers) depending on the pre-planting treatment of seed tubers.

Material and methods

The experiment was carried out during the 2000–2002 growing seasons at the Department of Field Crop Husbandry, Plant Biology Experimental Station (58° 23’ N, 26° 44’ E) in EMU IAES. Random block placement in four replications was used (Hills & Little, 1972). The size of a test plot was 21 m². The distance between seed tubers was 25 cm and distance between furrows 70 cm. Seed tubers with a diameter of 35–55 mm were used in the experiment.

Different methods of growing potato were analysed, using various pre-planting treatments. Seed tubers were treated before planting as follows:

1. Untreated variant (0); no thermal treatment was conducted.
2. Thermal shock (TS); a week before planting the seed tubers were kept for two days at 30°C, then 5 days at 12–15°C in a lighted room (Lõhmus et al., 1999).
3. Pre-sprouting (PS); the tubers were kept for 35–38 days before planting in a sufficiently humid (85–90% RH) and lighted room at 12–15°C. Seed tubers were pre-sprouted in wooden boxes (in one or two layers).

The late variety ‘Ants’ and the mid-maturing variety ‘Piret’, both bred at the Jõgeva Plant Breeding Institute in Estonia, and the early variety ‘Agrie Dzeltenie’, bred at the Latvian Priekuli State Plant Breeding Station, were used in the experiments.

The soil of the experimental field was Stagnic Luvisol according to WRB classification (Deckers et al., 1998) with a texture of sandy loam and a humus layer of 20–30 cm. Soil analyses were carried out at the laboratories of the Department of Soil Science and Agrochemistry, EMU. Air-dried soil samples were sieved through a 2-mm sieve. The following characteristics were determined: pH (in 1 M KCl and in 0.01 M CaCl₂: 2.5; organic carbon by Tjurin, Ca and Mg in NH₄OAc at pH 7; K, 164 mg kg⁻¹; Mg, 101 mg kg⁻¹; P, 183 mg kg⁻¹; K, 164 mg kg⁻¹; N, 0.11%; 56% sand; 35% silt and 9% clay.

The Estonian climate is a transitional climate from maritime to continental. It is mainly influenced by the Baltic Sea and the north-eastern part of the Atlantic Ocean. Year-round intensive cyclonic activity causes moist and continuously changing weather conditions. Summer is relatively short and cool, autumn is long, and winter mild. The vegetation period (average diurnal temperature continuously above 5°C) begins usually in the second half of April, lasts 170–180 days and ends in September or October. The period of active plant growth (average diurnal temperature continuously above 10°C) ranges usually from 115 to 135 days (Tarand, 2003). The experimental area belongs to the south Estonia upland agroclimatic region, where the sum of active air temperatures of the year is on average 1750–1800°C and total precipitation is 550–650 mm.
Table I. Average monthly temperatures (°C) and precipitation (mm) average during the vegetation period in 2000–2002 (according to the Erika meteostation) and the average of 1966–1998 in Estonia (Jaagus, 1999).

<table>
<thead>
<tr>
<th>Month</th>
<th>Average of 2000–2002</th>
<th>Average of 1966–1998</th>
<th>Precipitation, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>May</td>
<td>12.0</td>
<td>11.6</td>
<td>42.7</td>
</tr>
<tr>
<td>June</td>
<td>15.2</td>
<td>15.1</td>
<td>75.7</td>
</tr>
<tr>
<td>July</td>
<td>19.8</td>
<td>16.7</td>
<td>101.2</td>
</tr>
<tr>
<td>August</td>
<td>17.1</td>
<td>15.6</td>
<td>75.6</td>
</tr>
<tr>
<td>September</td>
<td>10.8</td>
<td>10.4</td>
<td>22.2</td>
</tr>
</tbody>
</table>

During the trial years, in the vegetation period (from May to September) the amount of precipitation was greater than average in June and July, less than average in May, August and September (Table I). Air temperature remained similar to the average of 32 years (1966–1998); only July was significantly warmer.

Agronomic measures were typical for potato experiments. Composted manure (60 t ha⁻¹) before autumn ploughing was used as organic fertilizer. Mineral fertilizers were applied locally at the same time as planting of potatoes in the spring. In 2000–2002, compound mineral fertilizer (78 kg N, 72 kg P, 117 kg K ha⁻¹) was applied at planting. For plant protection, the insecticide Fastac and fungicides Ridomil Gold, Acrobat Plus and Shirlan were used. All active ingredients for plant protection were used with 400 litres of water per ha.

The dynamics of tuber yield, the weight of the haulms, leaf area, the number of tubers per plant and the average weight of each tuber were determined with an interval of 3–5 days and each sample consisted of four plants from the test plot.

Statistical data analysis by regression methods was performed (Mead et al., 1993; Lauk, 1995, 1996; Lauk et al., 2002). The following formula was used:

\[ y = a + bx + cx^2, \]

where \( y \) is the argument function, the index that is calculated on the basis of the equation: tuber yield, the weight of the haulms, leaf area index (LAI), the number of tubers per plant and the average weight of a tuber, \( a \) is the constant term of the equation, \( b \) and \( c \) the regression coefficients, \( x \) the argument, number of days after planting (DAP).

For every variant, separate regression formulas were found, and based on their differentials it was possible to calculate the average formulas for multiple years. Standard errors (SE) and confidence limits (CL₀.05 – level of statistical significance \( p = 0.05 \)) were calculated by using the relevant methodology (Lauk & Lauk, 2000). The calculation of confidence limits was based on the Student’s theoretical criterion (Mead et al., 1993).

All the data in the figures were calculated according to the formulas of regression analysis. To assess the probability of differences between test variants the least significant differences (LSD₀.05) were calculated according to the corresponding methodology (Lauk et al., 2004).

Correlation analysis was used to study the correlation between different parts of the potato plants and pre-planting treatment of seed tubers. Linear correlation coefficients between variables were calculated, the significance of coefficients being \( p < 0.001 \), \( p < 0.01 \), \( p < 0.05 \), NS = non-significant (\( p > 0.05 \)).

In this paper all the experimental data are presented on the average of 2000–2002 years.

Results and discussion

Weight of the haulms

Physiological ageing advanced sprout growth, crop emergence, crop establishment and usually improved tuber yield (Burke & O’Donovan, 1998). Transition of developmental stages and their duration is often quite different. It depends on the biological characteristics of a variety, quality of seed potato, climatic and soil conditions and also agronomic measures used (Christiansen et al., 2006).

Earlier studies at the Department of Field Crop Husbandry indicated that PS and TS increased the physiological age of seed tubers and initiated earlier emergence (Löhmus et al., 1999; Eremeev et al., 2001). Plants from seed tubers treated before planting emerged 1–4 days (late varieties) and 1–7 days (early varieties) earlier (Löhmus et al., 1999; Eremeev et al., 2001). In present study, the pre-planting treatment of seed tubers ensured earlier field sprouting in the TS variant by 4, and in the PS variant by 10, days earlier than in variant 0, as a three-year average. The faster growth of the haulms of the plants that developed from thermally treated seed tubers provided furrow coverage nearly a week earlier, as a result of which the last inter-row tillage could be omitted at just the critical time.
when there were very favourable conditions for the growth of weeds.

The pre-planting treatment of seed tubers (PS and TS) accelerated the development of the haulms, and the weight of the latter was higher than in variant 0 up to 50 DAP (Figure 1). The weight of the haulms reached its maximum in variant PS by 76 DAP, and in 0 by 81 DAP (Figure 1). The later the maximum weight of the haulms was achieved, the higher it was because the visible signs of ageing appeared earlier in physiologically older plants. Thus, the maximum weight of the haulms in variant 0 was 31.9 t ha⁻¹, exceeding PS and TS, respectively, by 4.2 and 2.9 t ha⁻¹ (Figure 1). Therefore, the weight of the haulms in plants formed faster and was lower.

Both PS and TS had a stronger effect on the development of the weight of the haulms in varieties with a longer growth period. 'Aants' achieved the maximum weight of the haulms in thermally treated variants (PS and TS) 7–8 days earlier than in variant 0. It occurred in 'Piret' five days earlier and practically at the same time as 'Agrie Dzeltenie' in all variants.

Thus, the weight of the plant haulms developed from physiologically older seed tubers, formed more quickly and remained lower. Pre-planting treatment of seed tubers (i.e., increasing the physiological age) gave earlier field emergence. The later the potato plants attained the maximum weight of the haulms, the higher it was. In physiologically older plants obvious signs of senescence started to appear earlier (partial wilting and yellowing of the lower leaves). According to Putz (1986), after the death of the haulms, growth of tubers ceases, the skin hardens and starts to suberize.

There were positive correlations between the weight of the haulms and the LAI and the number of stems, both as the average for all experimental variants \( r = 0.95; p < 0.001 \) and \( r = 0.53; p < 0.001 \) and at the level of varieties and the pre-planting treatment of seed tubers. The number of tubers per plant \( (r = 0.79; p < 0.001) \) and the average tuber weight \( (r = 0.45; p < 0.05) \) increased with the development of the weight of the haulms.

**Leaf area index**

Leaf area index indicates the ratio of assimilative area of the leaf and the surface area (Watson, 1947). For optimal photosynthetic rate it is necessary that LAI should be over 4 for as long a period as possible, otherwise the use of photosynthetically active radiation (PAR) and thus the production of organic matter, decreases (Scott & Wilcockson, 1978; Allen & Scott, 1980; Khurana & McLaren, 1982). The pre-planting treatment of seed tubers (TS and PS) accelerated the growth and development of leaves and leaf area from the beginning of sprouting until 60 DAP (statistically significant until 45 DAP).

Later, the increase of the leaf area in different variants became similar. From earlier experiments with late varieties it is known that the LAI reaches a maximum (average 3.7 units) by 72 DAP and then starts to decrease (Eremeev et al., 2001). In the present research (Figure 2) the maximum LAI (3.9 units) was reached 74 DAP and on 50 days after emergence (DAE). According to the 30-years study by the Norwegian scientist Eltun (1996), it took 45 DAE to form maximum LAI. In the present experiment the highest LAI was reached between 68 and 81 DAP. The maximum LAI in variant PS was achieved by 72 DAP (3.7 units), in TS (3.8 units) and 0 (4.1 units), respectively, by 73 and 76 DAP. In varieties with a shorter growth period the leaf area reaches its maximum earlier.

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**Figure 1.** The effect of thermal treatment on the weight of the haulms (average of 2000–2002, t ha⁻¹). \( y = -82.8 + 2.849x - 0.01769x^2, n = 117, R^2 = 0.985, SE = 0.45, Cl_{95} = 1.02 \); TS=Thermal shock: \( y = -72.3 + 2.63x - 0.01715x^2, n = 117, R^2 = 0.946, SE = 0.55, Cl_{95} = 1.24 \); PS=pre-sprouting: \( y = -57.1 + 2.227x - 0.01462x^2, n = 117, R^2 = 0.946, SE = 0.46, Cl_{95} = 1.04 \).

**Figure 2.** The effect of thermal treatment on the leaf area index (the average of 2000–2002). \( 0 = \text{Untreated variant}; y = -13.7 + 0.468x - 0.00307x^2, n = 123, R^2 = 0.953, SE = 0.09, Cl_{95} = 0.20 \); TS=Thermal shock: \( y = -12.5 + 0.446x - 0.00306x^2, n = 123, R^2 = 0.917, SE = 0.11, Cl_{95} = 0.24 \); PS=Pre-sprouting: \( y = -10.3 + 0.389x - 0.00271x^2, n = 123, R^2 = 0.911, SE = 0.10, Cl_{95} = 0.22 \).
Tuber weight

The weight of tubers depends on the weather conditions and the available nutrients during tuber formation (Panelo & Caldiz, 1989). It also depends on the growth and development of leaves and branches, formation of assimilation products and their distribution between different parts of the plant, rate of tuber formation and the time of perishing of haulms (Caldiz et al., 2001).

Pre-sprouting provided a stably reliable (LSD$_{05}$ 4.9) average tuber weight throughout the vegetation period (Figure 3). According to data presented by Burke (1997), the physiological age of the tubers increases the average weight of tubers. In our experiment this effect was seen only in the PS variant, while in the TS variant the increase in the average weight of tubers could be seen until 75 DAP. The 0 and TS variants developed more slowly at the start, resulting in a longer vegetation period and the tubers did not reach their maximum weight by the time of harvest.

Based on the pre-planting treatment of the seed tubers, only the PS variant reached the maximum average tuber weight (77.6 g) by 121 DAP (Figure 3).

By the time of harvest the average tuber weight reached the maximum in variant PS in ‘Ants’ by 116 DAP (69.6 g), in ‘Piret’ variant TS by 117 DAP and variant 0 by 120 DAP, with, respectively, 67.1 g and 71.1 g, in ‘Agrīe Dzeltenie’ variant TS by 114 DAP and variant PS by 119 DAP (respectively, 66.3 g and 86.3 g).

The number of tubers per plant

PS and TS increased the formation of tubers per plant, particularly at the beginning of tuber formation (until 60 DAP, LSD$_{05}$ 1.3), whereas the maximum number of tubers was formed at 93–94 DAP (12.6 and 14.0 tubers, respectively). In variant 0, the respective value was 13.2 and it formed at 95 DAP. Throughout the entire vegetation period the positive effect of TS treatment on the number of tubers per plant was observed (Figure 4).

Pre-sprouting increased the number of tubers with the variety ‘Piret’ and only at the beginning of tuber initiation. Throughout the entire vegetation period the number of tubers of the variety ‘Ants’ was higher due to the TS treatment than in other variants, in the varieties ‘Piret’ and ‘Agrīe Dzeltenie’, until 50 DAP and 60 DAP, respectively.

The varieties ‘Piret’ and ‘Agrīe Dzeltenie’ started to form tubers early but had a lower average number of tubers per plant compared to ‘Ants’. In ‘Agrīe Dzeltenie’ the maximum number of tubers was formed at 92 DAP (12.8 tubers), in ‘Ants’ (14.6 tubers) and ‘Piret’ (12.1 tubers), respectively, at 93 and 97 DAP.

Tuber yield

The main purpose of PS is obtaining an earlier yield (Straüks & Wieserma, 1999). In order to obtain the yield as early as possible, the PS should also start earlier, and sprouting would still take four or five weeks (Joudu, 2002). If it is too late for PS, the tubers can be stimulated using TS, which makes them develop faster (Eremeev et al., 2003; Eremeev et al., 2005). The pre-planting TS accelerated the beginning of tuber yield formation and ensured its increase during the initial growth period (until 60 DAP) (Figure 5). The positive effect of PS on tuber yield was longer (until 110 DAP). This does not mean that the pre-planting TS of seed tubers had no positive effect at all. The seed tubers that received TS were physiologically older than the variant 0, which enabled the tuber yield to develop faster. As a result, a harvest-ripe tuber yield was formed earlier.
the tuber yield was established. Within one variety there were no significant correlative differences between the yield structure elements and yield formation. However, the negative effect of small tubers (less than 35 mm) on the tuber yield was established in ‘Ants’ and ‘Piret’.

Thermal treatment of the seed tubers before planting had a different effect on varieties with different growing periods. A physiologically young seed tuber is preconditioned to develop better and stronger roots as well as all parts of the plant that are above the ground and the largest assimilation surface possible. These advantages are preconditions for the formation of a high tuber yield. The drawback is that the late sprouting and covering of furrows with leaves decreases the competitiveness of potato plants. The later ‘working time’ of the assimilation surface is the time when the quantity of physiologically active radiation decreases.

Although there is a growing literature on the physiological age of seed tubers, the application for potato management is currently imprecise. In general, advancing seed-potato age affects crop yield, but the actual effect depends not only on the variety (van der Zaag & van Loon, 1987), but also on the field conditions (Knowles & Botar, 1991; Caldiz et al., 1998), cropping systems (Karalus & Rauber, 1997), and managerial skills.

Enhancing physiological ageing of seed potatoes has the potential to substantially affect production, especially for short-season growing areas (Asiedu et al., 2003). Obtaining a relatively early potato yield is important not only for early but also for late potato varieties. Growing of late varieties is necessary due to their higher tuber yield potential and the fact that they can be preserved better.

As a conclusion it must be noted that especially for early potato yield formation pre-sprouting should be used. Photosynthetically active leaf area develops earlier which results in a bigger yield, and also the tubers are larger than in other variants. Thermal shock is an effective tool in seed production, while it increases the number of tubers compared to using the pre-sprouted seed tubers. Also the average weight of the tubers is lower. When grown as maincrop potato it is useful for mid-early yield formation.

**References**


