ISSN 1392-3196
Žemdirbystė=Agriculture, vol. 98, No. 2 (2011), p. 131–138
UDK 633.491:581.144.4.036:581.43

The influence of different temperatures and exposition time on potato tuber sprouting and development of plants

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Abstract

Research on the influence of different temperatures and exposition time on potato tuber sprouting was carried out at the Laboratory of Food Raw Materials, Agronomic and Zootechnical Research, Faculty of Agronomy, Lithuanian University of Agriculture, in the year 2009. Chemical analyses of potato tubers were carried out at the Laboratory of Chemical Research, Lithuanian Institute of Agriculture. Field tests on potato development were carried out at the Experimental Station of the Lithuanian University of Agriculture. The biometric parameters of potato plants were determined at the Laboratory of Plant Physiology, Lithuanian Institute of Horticulture.

Different temperatures −10°C–+50°C influenced the tuber sprouting. The highest number of sprouts, compared to the primary number of eyes, was established in the tubers of potato cv. 'Goda' exposed to −10°C for 60 min (192.6%) and to +50°C for 90 min (194.7%); and in the tubers of potato cv. 'Solara' exposed to −10°C for 60 min (126.1%) and to +30°C for 60 min (167.8%). The tubers, exposed to +30–+50°C temperatures at all exposition times, were established to have the strongest significant influence on the formation of haulms. This increased the number of stems per haulm by 1.5–1.8 times, and leaf area by 77–80% in comparison with the control plants. The plants, whose tubers had been exposed to −10°C, were shorter than the control plants. Analysis of the influence of different temperatures and exposition time showed that protein percent in tubers of cv. 'Goda' significantly increased having exposed them to +30°C for 30 and 60 min, and to +50°C for 60 min ~13%, in tubers of 'Solara' having exposed them to −10°C for 30 min up to 20% and to +40°C for 30 min up to 23%, in comparison to the control plants.

Key words: tubers, thermal influence, exposition time, sprouting, stem number, leaf area.

Introduction

Potato tuber sprouting has been known for a long time. Sprouted potatoes develop more rapidly, produce higher and earlier yield. A few sprouting methods are available; however, inhibition of apical domination of potato tubers in order to stimulate a greater number of stems and leaves per plant has not been investigated. The objective of the present study is to induce stress in tubers, which will result in more active sprouting process as well and to assess its influence on further development of plants.

Potato (*Solanum tuberosum* L.) plants exhibit a unique growth pattern. They may be propagated by tubers, parts, shoots, draws and seeds. Potatoes are commonly propagated by tubers. A potato tuber is a modified stem exhibiting the same structure as an over-ground stem. Eyes are arranged around the tuber in a spiral shape, whereas the greatest number is concentrated in the upper part of a tuber (Шпаар и др., 2004). Naturally, each eye contains some three shoots, and germination of the most developed one occurs first of all.

Sprouting of shoots from tuber eyes starts at the end of the dormancy period. First of all, an eye of the upper part sprouts. Sprouting of other shoots

contained in a tuber eye is blocked. This is called the apical domination effect. If tubers are planted within the apical domination period, the potato plant will probably grow just one stem overall resulting in low yield (Van der Zaag, Van Loon, 1987; Grigoriadou, Leventakis, 1999).

To produce mature potato yield as early as possible, different tuber sprouting methods are applied including the method of temperature influence (Allen et al., 1992). This method stimulates enzymic activity in a tuber, encourages more rapid germination of eyes, shortens the sprouting period and accelerates development of a plant. With increasing temperature, however, respiration intensity grows, therefore, energy resources of a plant are lost (Kirnak et al., 2001; Yamaguchi-Shinozaki et al., 2002). Other authors (Шпаар и др., 2004) maintain that removal of a dominating shoot (e.g. shoot breaking-off) leads to more active sprouting of other shoots contained in an eye, however, such stimulation of tuber sprouting has a negative influence on the tuber as the latter loses energy, moisture and withers. Quantitative phenological observations of over-ground and underground plant parts considering environment factors (Ojala et al., 1990) and distinguishing features of cultivars constitute a very important step in order to achieve comprehensive understanding of potato germination and development (Eremeev et al., 2007).

Low or high temperatures cause abiotic stress. Depending on the intensity and duration of stress, effects on plants may be twofold: positive – elimination of apical dominance and promotion of sprouting, and negative – lesions on plants or even death (Alexeieva et al., 2003).

In Lithuania, it is recommended to begin sprouting of seed potato tubers in March already under conditions of natural light, 35–45 days prior to planting, maintaining constant temperature (+12–+15°C), but not higher than +17°C (Lazauskas, Ražukas, 2001).

The aim of the present research is to determine the influence of temperatures (down to −10°C) and temperatures (up to +50°C) and of different exposition time on apical dominance elimination, sprouting and development.

Material and methods

Laboratory studies were carried out at the Laboratory of Food Raw Materials, Agronomic and Zootechnical Research, Faculty of Agronomy, Lithuanian University of Agriculture, in the year 2009. The study involved potato (*Solanum tuberosum* L.) cultivars 'Goda' and 'Solara'. The test containing 16 treatments was carried out in three replications according to the following design:

Treatment	Temperature	Exposure time
1. Control	+18°C	24 h
2.	−10°C	30 min
3.	−10°C	60 min
4.	−10°C	90 min
5.	+5°C	30 min
6.	+5°C	60 min
7.	+5°C	90 min
8.	+30°C	30 min
9.	+30°C	60 min
10.	+30°C	90 min
11.	+40°C	30 min
12.	+40°C	60 min
13.	+40°C	90 min
14.	+50°C	30 min
15.	+50°C	60 min
16.	+50°C	90 min

Potato tuber sprouting was assessed visually 21 days after exposure. The following was established: number of shoots in the upper, middle and bottom parts of a tuber (number and %); mass, by the weight method (in grams and %).

Shortly after exposure, chemical analyses of potato tubers were carried out at the Laboratory of Chemical Research, Lithuanian Institute of Agriculture. The following was established: protein content by Kjeldahl method; dry matter content by the weight method.

Sprouted potatoes were planted in a field at the Experimental Station of the Lithuanian University of Agriculture. The plots were arranged randomly, in replication blocks, by three replications of each treatment. Potatoes were grown in compliance with the growing technologies recommended by the Lithuanian Institute of Agriculture. During vegetation, the following biometric parameters of potato plants were determined: number of stems per plant, stem height, cm; number of leaves; leaf area, cm^2, by leaf area meter CI-202, (CID Inc., JAV) at the Laboratory of Plant Physiology, Lithuanian Institute of Horticulture.

Statistical data processing. A standard deviation for research data average was computed by *MS Excel* software. Research data were processed by ANOVA (Tarakanovas, Raudonius, 2003). The following symbols were applied in the paper: R_{05} – the least significant difference at the probability level of 95%. $S\bar{x}$ – standard error of the mean. Sprouting was computed from the initial number of eyes and expressed in percent.

Test cultivars. 'Goda' is an early ware potato cultivar intended for nutritional use developed at the Vokė Branch of the Lithuanian Institute of Agri-

culture. Analysis of agronomic value of this cultivar was carried out at Kaunas, Rietavas, Utena and Vilnius Plant Variety Testing Stations (PVTS) during 1998–2000. Over the research period, the average yield of marketable potatoes amounted to 29.1 t ha^{-1}. Analysis of 'Goda' potatoes grown in separate experimental years at different PVTS demonstrated that they contained 10.7–16.5% of starch and 22.2–23.2% of dry matter. The tubers of cv. 'Goda' were big, oval, with smooth yellowish peel and a small number of medium-deep eyes.

'Solara' is a medium-early ware potato cultivar intended for nutritional use developed at the potato breeding and seed production company "Europlant Pflanzenzucht" (Germany). Analysis of agronomic value of this cultivar was carried out at Kaunas, Rietavas, Utena and Vilnius PVTS in 2005–2006. During the experimental period, the average yield of marketable potatoes amounted to 29.6 t ha^{-1}, whereas in the experimental farm set up at Kaunas PVTS in 2005 the yield was 40.2 t ha^{-1}. Analysis of 'Solara' potatoes grown in separate experimental years demonstrated that they contain 10.5–15.3% of starch and 16.7–22.1% of dry matter. The tubers of 'Solara' were of the same medium size, oval, with smooth yellow peel, shallow or medium-deep eyes.

Basic seed potato tubers were obtained from the Kaunas PVTS in Muniškės.

Results and discussion

Laboratory experiment. The studies on the influence of different temperatures and exposition time on potato tubers suggested that combinations with the different impact exerted influence on sprouting of potato tubers. The significant effects of the combinations were established. The greatest positive result of the thermal treatment influence on tuber sprouting was demonstrated by the cv. 'Goda' cooled to −10°C for 60 min (192.6%) and heated in a thermostat at +50°C for 90 min (number of shoots sprouted to 194.7% of the number of the eyes contained in a tuber). For medium-early potato cv. 'Solara', the highest percentage of sprouting, i.e. 126.1%, was shown by the tubers cooled to −10°C for 60 min and heated at + 30°C for 60 min (167.8%) (Fig. 1).

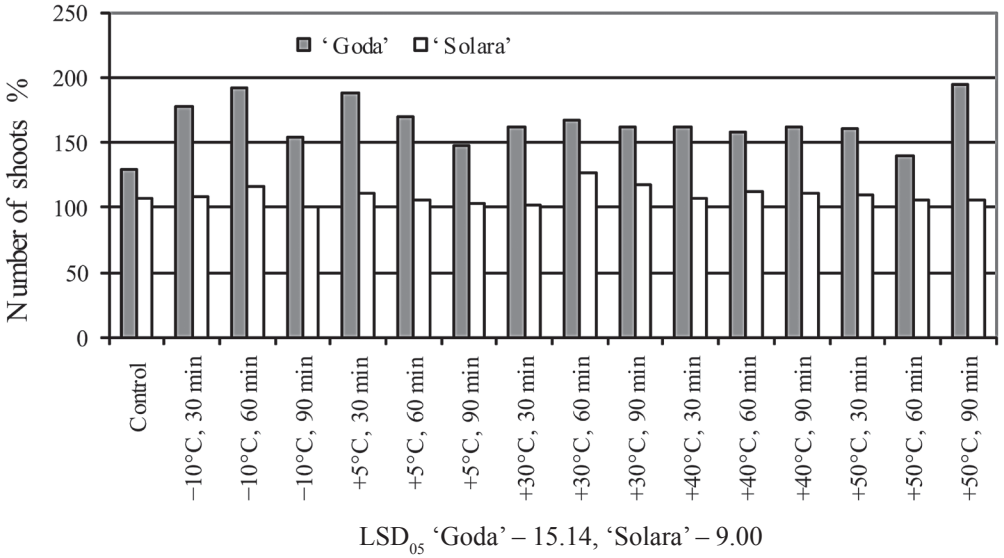


Figure 1. The effect of different temperatures and exposition time on tuber sprouting of cvs. 'Goda' and 'Solara', 2009

During research, the number of eyes germinated in different parts of tubers was assessed. The obtained results demonstrated that the influence of different temperatures and exposition time decreased apical domination of potato tubers and stimulated sprouting of the shoots developed from side eyes (Juknevičienė et al., 2010).

The lowest number of the shoots sprouted in the upper part of tubers was observed for the treatments (2, 5, 8, 11 and 14) where the influence of temperature lasted for 30 minutes ('Goda'). The distribution of eyes sprouted in the upper, middle, and bottom parts of tubers was as follows: some 30–35%, 30–55%, from 20% to 45% of the total eyes of the tuber, respectively. At an exposition time of 90 min at +30°C, +50°C, the number of the sprouted eyes demonstrated by the upper and middle parts of a tuber was 52–58% and 48–42%, respectively. The bottom part of a tuber showed no sprouting of eyes as apical domination was displayed by tubers.

Distribution of the shoots sprouted in the upper, middle and bottom parts of 'Solara' tubers

was as follows: 42%, 25%, 30% (treatment 2) of the total eyes of the tuber, respectively. Tubers stored at +30°C for 90 min demonstrated the following: some 40%, 30%, 30% of the total eyes in the upper, middle and bottom parts of tubers respectively (Juknevičienė et al., 2010).

Temperature that is close to unfavourable one activates inner plant response and this may increase plant resistance and stimulate acclimation. Plant response to temperature changes (frost or heat shock) is the result of gene expression (Thomashow, 1999). Frost activates genes and increases frost resistance; synthesis of more proteins dehydrin replacing membrane conductivity is observed (Borovskii et al., 2002; Anisimovienė et al., 2006). Usually, plant injuries caused by low positive temperature manifest themselves in temporary metabolism disorders, whereas negative temperatures may even lead to irreversible changes. The influence of negative temperatures −10°C exposition time 60 and 90 min of 'Goda'; and exposition time 30, 60, 90 min of 'Solara' violated the cell structure of tubers. 21 days after the influence of different temperature and exposition time, injuries in potato tubers were displayed.

Potato tubers of individual cultivars differ in chemical composition, physical properties (Ereifej et al., 1997) and response to low storage temperature .

Changes in chemical composition of potatoes established during research are related to the influence of storage temperature (Kaaber et al., 2001), effect of fertilisation and storage conditions (Makaravičiūtė, 2004), and impact of potato treatment with germination inhibitors (Žabaliūnienė, Venskutonienė, 1998). Different temperature and exposition time influenced the changes in the content of proteins and dry matter of potato tubers.

During investigation, we determined the content of proteins and dry matter in different cultivars. Table illustrates the changes in protein and dry matter content as influenced by different temperatures and exposition time. Significant effects of the treatments were established. The total content of proteins in the tubers of cv. 'Goda' significantly increased (13%) after exposure to +50°C for 60 min and to +30°C for 30 and 60 min. The protein content in the tubers of cv. 'Solara' was established to be the highest after exposure to −10°C for 30 min – 20% and after exposure to +40°C for 30 min – 23% temperature influence.

Table. The effect of different temperatures and exposition time on the chemical composition of cvs. 'Goda' and 'Solara', 2009

No.	Effects of combination	Characteristics, % natural materials			
		Proteins		Dry matter	
		'Goda'	'Solara'	'Goda'	'Solara'
1.	+18°C	1.94	2.19	23.3	20.3
2.	−10°C, 30 min	1.72	2.63	24.3	19.9
3.	−10°C, 60 min	1.67	2.19	24.3	19.6
4.	−10°C, 90 min	1.66	2.30	22.0	21.1
5.	+5°C, 30 min	1.81	2.47	23.8	20.7
6.	+5°C, 60 min	1.75	2.38	23.2	20.4
7.	+5°C, 90 min	2.00	2.13	23.8	20.0
8.	+30°C, 30 min	2.19	2.14	25.3	20.0
9.	+30°C, 60 min	2.18	2.48	27.0	19.7
10.	+30°C, 90 min	1.75	2.33	23.7	21.5
11.	+40°C, 30 min	1.94	2.70	24.0	19.1
12.	+40°C, 60 min	1.91	2.44	20.0	20.4
13.	+40°C, 90 min	2.06	2.34	23.4	18.2
14.	+50°C, 30 min	1.99	2.50	24.1	18.9
15.	+50°C, 60 min	2.20	2.48	22.0	21.2
16.	+50°C, 90 min	1.94	2.69	23.6	20.5
	LSD_{05}	0.10	0.10	0.09	0.90
	$S\bar{x}$	0.04	0.04	0.03	0.31

Under the influence of temperatures (−10°C), the greater content of dry matter was observed in tubers of cv. 'Goda' compared to the control treatment, however, the longer influence at −10°C decreased the dry matter content. In other treatments, higher dry matter content was observed compared to the control treatment. Under the influence of different temperatures, slightly lower dry matter content in potato tubers of cv. 'Solara' was observed. The highest dry matter content, i.e. 21.1%

and 21.5%, was exhibited by the tubers exposed to −10°C for 90 min and to +30°C for 90 min, respectively. Increase in the dry matter content is maintained to demonstrate the sprouting start of tubers (Makarevičiūtė, 2004). The tubers stored at higher temperature consume nutrients more actively and show earlier sprouting compared to those stored at lower temperature.

According to literature (Lazauskas, Ražukas, 2001), the best conditions for potato sprouting are at the temperature not higher than +17°C, under light, as shoots in this situation are short and strong; when temperature increases up to +25°C, shoots start lignifying, the tops blacken and sprouting becomes loss making as tubers wither and stop sprouting. Potato tubers are heat sensitive. Sprouting is one of the major factors determining the number of stems that are considered the yield limiting element.

Field experiment. The number of shoots in potato tubers at planting determined the number of stems per plant. The research demonstrated that the lowest number of stems per plant (2–2,3 on average) was grown by the tubers frozen at −10°C. After treatment, tubers were damaged, start of rotting was observed resulting in low number of stems per plant (Fig. 2); this fact also had an influence on the number of leaves per plant (Fig. 3 b). The influence of +30°C, +50°C temperatures on potato tuber sprouting and further development was positive, the number of stems formed by potato plants was up to 1.5 times higher (treatment 12 for cv. 'Solara') and 1.8 times higher (treatments 14, 15 for cv. 'Goda').

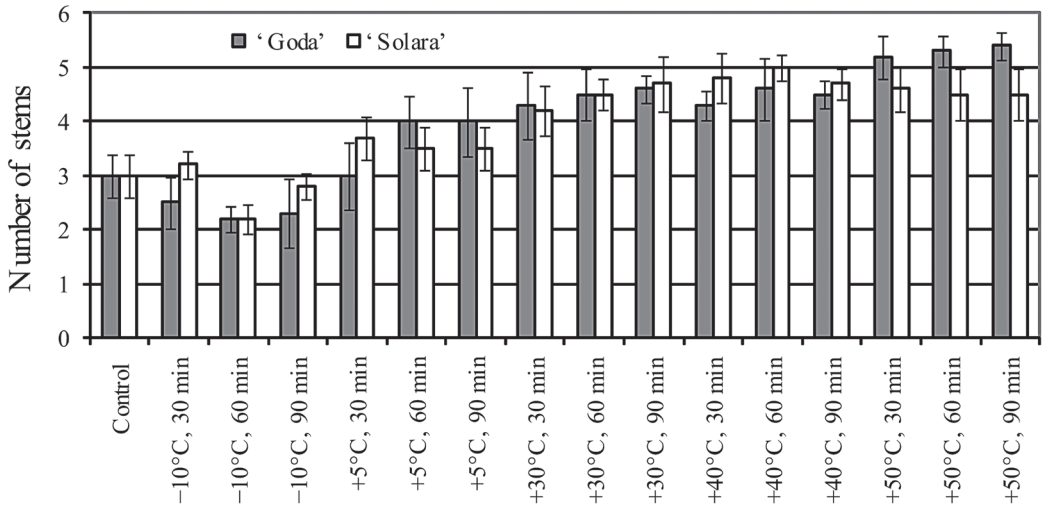
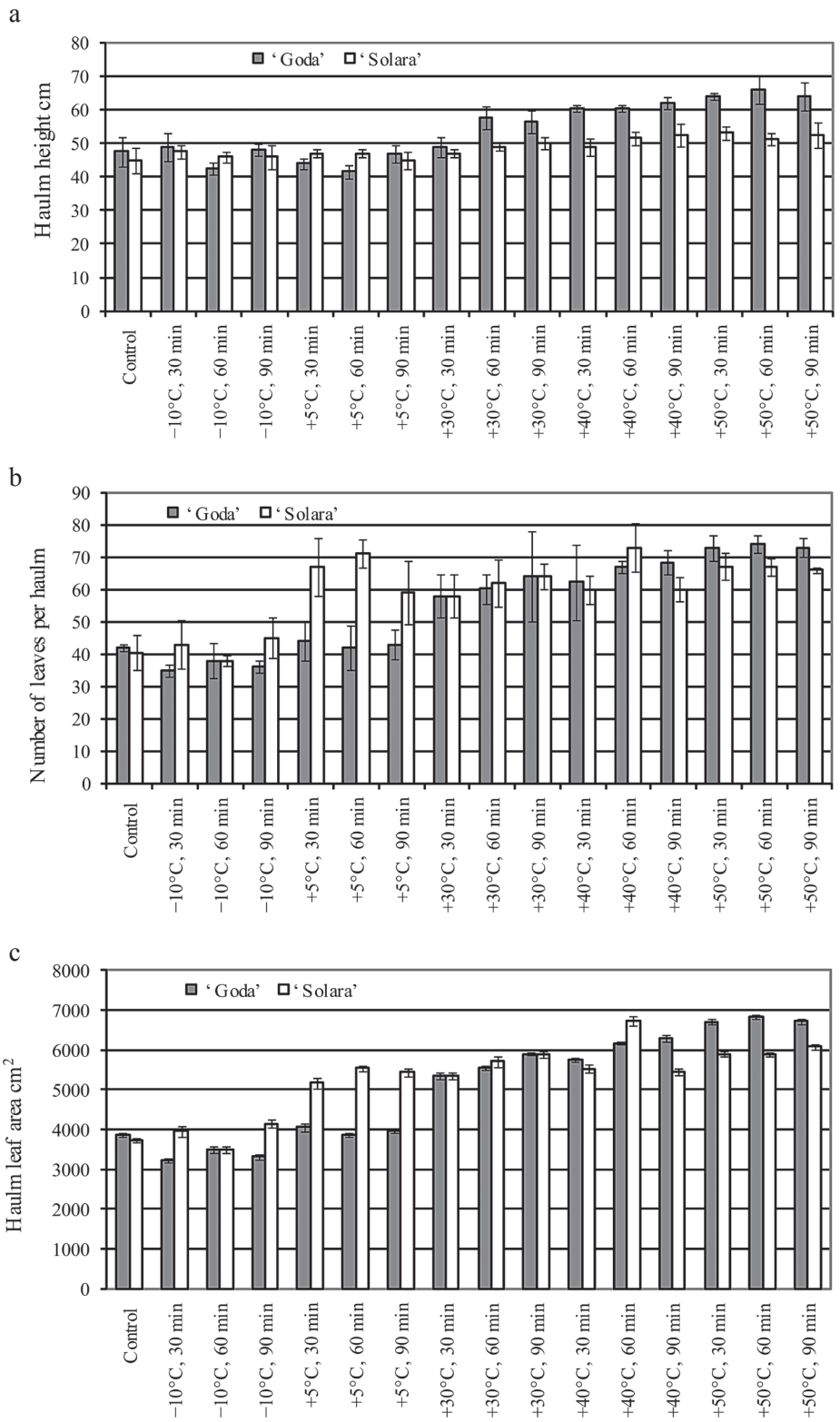


Figure 2. The effect of different temperatures and exposition time on the number of stems per plant of cvs. 'Goda' and 'Solara', 2009

Potato tubers were planted in the soil 21 days after treatment (1 May, 2009). Sprouting of potato crop was recorded as soon as 75% of shoots emerged on the surface of the soil. The first potato shoots (on 14 May) emerged in treatments 9, 12, 13, 14, 15, 16 ('Goda') and treatments 10, 12, 13, 14, 15, 16 ('Solara'). In control plots, sprouting occurred 5–6 days later.

The most intensive growth occurs in potatoes prior to the onset of flowering (organogenesis stage IX) (Куперман и др., 1982). Later, plants stop growing at all, whereas the leaf area at this stage is the greatest throughout the vegetation period (Šlapakauskas, Duchovskis, 2008). The research showed that the highest haulm weight (Fig. 3 a) and greatest leaf area (Fig. 3 c) were formed by the potato plants having grown from the tubers treated with +30°C, +50°C temperatures.

The effects caused by stress factors are determined by treatment intensity and duration (Alexieva et al., 2003). Plant response to temperature changes depends on a cultivar, physiological age and development level (Hekneby, 2004; Abdul Jaleel et al., 2007). The potato tubers stored at higher temperature get old physiologically, however, the tubers stored at low temperatures both get old and experience a stress. A few potato cultivars featuring greater resistance to low temperatures are also available. Low temperatures retard the natural ageing processes; however, the injuries caused by a stress to less resistant potato cultivars accelerate the ageing processes (O'Donoghue et al., 1995). Our findings also illustrated that the response of the potatoes under investigation to the stress caused by temperatures depended partially on a cultivar.



Note. Biometric characteristics: a – haulm height, cm, b – number of leaves per haulm, c – leaf area, cm^2.

Figure 3. The effect of different temperatures and exposition time on potato cvs. 'Goda' and 'Solara', 2009

According to literature, the best way to overcome apical domination and to stimulate sprouting of side eyes is to extend storage duration of tubers beyond the apical domination period. Potato tubers shall be stored at (+4°C) until the end of apical domination period; then the temperature shall be increased up to (+15°C), which should stimulate germination of side eyes. For physiologically old potato tubers, however, such a sprouting method may be harmful, since tubers may dehydrate and

stop sprouting (Dongyu et al., 2004). Eremeev et al. (2003) maintain that the longer storage period of seed tubers at high temperature accelerates physiological senescence.

Conclusions

1. Different temperatures −10–+50 influenced tubers sprouting. The highest number of sprouts, in comparison to the initial number of eyes, was established in the tubers of potato cv. 'Goda' exposed to −10°C for 60 min (192.6%) and to +50°C for 90 min (194.7%); and in the tubers of potato cv. 'Solara' – correspondingly exposed to −10°C for 60 min (126.1%) and to +30°C for 60 min (167.8%).

2. Treatment with +30–+50°C at all exposition times was established to have the strongest significant influence on the formation of haulms. This increased the number of stems per haulm by 1.5–1.8 times, and leaf area by 77–80% compared with the control plants. The plants, whose tubers had been treated with −10°C, were shorter than the control plants.

3. Analysis of the influence of different temperatures and exposition times showed that the percentage of proteins in the tubers of cv. 'Goda' significantly increased ~13%, having treated them with +30°C for 30 and 60 min, and with +50°C for 60 min. The tubers of cv. 'Solara' treated with −10°C for 30 min up to 20% and with +40°C for 30 min up to 23%, compared with the control plants.

Received 16 11 2010
Accepted 07 04 2011

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ISSN 1392-3196
Žemdirbystė=Agriculture, vol. 98, No. 2 (2011), p. 131–138
UDK 633.491:581.144.4.036:581.43

Skirtingos temperatūros ir ekspozicijos laiko poveikis bulvių stiebagumbių dygimui bei augalų vystymuisi

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Santrauka

Tyrimų tikslas – nustatyti −10–+50 °C temperatūros ir skirtingo ekspozicijos laiko poveikį bulvių stiebagumbių dygimui bei augalų tolesniam vystymuisi.

Skirtingos temperatūros ir ekspozicijos laiko poveikio bulvių stiebagumbių dygimui laboratoriniai tyrimai atlikti 2009 m. Lietuvos žemės ūkio universiteto Agronomijos fakulteto Maisto žaliavų, agronominių ir zootechninių tyrimų laboratorijoje. Siekiant įvertinti skirtingos temperatūros ir ekspozicijos laiko poveikį bulvių stiebagumbių dygimui, kiekiniu metodu nustatyta stiebagumbių masė (g ir %) ir sudygusių daigelių skaičius (vnt. ir %) stiebagumbių viršutinėje, vidurinėje bei apatinėje dalyse. Po poveikio bulvių stiebagumbių cheminė analizė atlikta Lietuvos žemdirbystės instituto Cheminių tyrimų laboratorijoje. Bulvių augalų vystymosi analizės lauko bandymai atlikti Lietuvos žemės ūkio universiteto Bandymų stotyje. Vegetacijos metu nustatyti bulvių augalų biometriniai rodikliai: stiebų skaičius kere (vnt.), stiebų aukštis (cm), lapų skaičius, lapų plotas (cm^2) lapų ploto matuokliu (CID Inc., JAV) Lietuvos sodininkystės ir daržininkystės instituto Augalų fiziologijos laboratorijoje.

Skirtinga temperatūra (−10–+50 °C) turėjo įtakos sausųjų medžiagų kiekiui stiebagumbiuose ir skatino jų dygimą. Didžiausias stiebagumbių daigelių skaičius veislės ‘Goda’ bulvių nustatytas esant −10 °C 60 min. (192,6 %) ir + 50 °C 90 min. (194,7 %), o veislės ‘Solara’ bulvių – esant atitinkamai −10 °C 60 min. (126,1 %) ir +30 °C 60 min. (167,8 %) nuo pirminio akelių skaičiaus. Didžiausia teigiama reikšminga įtaka kerų formavimuisi nustatyta +30–+50 °C temperatūra paveiktų stiebagumbių esant visam ekspozicijos laikui. Stiebų skaičius kere nustatytas 1,5–1,8 karto, o lapų plotas – net 77–80 % didesnis nei kontrolinio varianto augalų. Mažesni nei kontroliniai augalai buvo tie, kurių stiebagumbiai paveikti −10 °C temperatūra. Baltymų procentas veislės ‘Goda’ bulvių stiebagumbiuose juos paveikus +50 °C esmingai padidėjo ~13 %, o ‘Solara’ – 22 %, palyginti su kontroliniais stiebagumbiais.

Reikšminiai žodžiai: stiebagumbiai, temperatūros poveikis, ekspozicijos laikas, dygimas, stiebų skaičius, lapų plotas.