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Full Length Research Paper

The evaluation of biological viability of potato seed tubers grown at different altitudes

Dobrivoj POŠTIĆ[1]*, Nebojša MOMIROVIĆ[2], Zoran BROĆIĆ[2], Željko DOLIJANOVIĆ[2] and Goran ALEKSIĆ[1]

[1]Institute for Plant Protection and Environment, T. Drajzera 9, 11040 Belgrade, Serbia.
[2]Faculty of Agriculture, Nemanjina 6, 11080 Belgrade, University of Belgrade, Serbia.

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Considering the fact that altitude could significantly affect the quality of potato (*Solanum tuberosum* L.) seeds, biological viability of seed tubers and cultivar Desiree originating from three sites in Serbia, Kotraža (700 m a.s.l.), Sjenica (1300 m a.s.l.) and Golija (1600 m a.s.l.), were evaluated at two different temperatures in the light phase of sprouting - commonly at 12℃ and raised 18℃, continously during five weeks, in the two-year period to establish efficient and confident sprouting method. Examined seed tubers had the highest number (8.37) of sprouts and developed the longest (21.24 mm) sprouts, because of heat accumulation at higher sprouting temperature of 18℃. High sprout vigor score (4.54) also was observed at 18℃, while at 12℃ the lowest (2.27) score was calculated. Sprouting capacity increased with the increased altitude and it was highest at the 1600 m a.s.l. (0.30 to 0.85%), while the lowest one was obtained at 700 m a.s.l. (0.17 to 0.64%). Sprouting capacity of tubers was greater at lower sprouting temperature (0.33 to 0.74%).

Key words: Biological viability, potato, tubers, sprouting.

INTRODUCTION

Biological viability of potato seed tubers represents tuber viability to establish new vegetative shoots and new plants after the storage period (Poštić et al., 2009). It is evaluated on the basis of a sprout growth. The term biological viability is used to describe the physiological properties of seed that control it's ability to germinate rapidly in the soil (Milošević et al., 2010). Biological viability of potato tubers determined by properties of seed tubers, are as follows: physiological age, level of sprout development, tuber weight and health.

Physiological age refers to viability of tubers to be used for seed (Pavlista, 2004). This physiological age is widely defined as "the developmental stage of potato seed tubers" (Struik, 2007) or "...physiological status of the tuber as it affects productivity" (Bohl et al., 2003). In general, there is an "optimum" tuber age in which the vigor growth is maximal, which follows a tuber emergence from dormancy and then vigor decreases as tubers advance in age and eventually lose viability. The physiological age depends on the: variety, growing conditions during the seed tuber formation, maturity at harvesting, storage conditions, damage degree and health conditions (Morrenhof, 1998; Struik, 2007). Warm weather, light (sandy) soil, low soil moisture (Karafillidis et al. 1997) and low soil (N) fertility (Lamont, 2002) are production conditions of potato crop during the growing season that can reduce biological viability of tubers, or increase a physiological age of tubers. Storage conditions between harvesting and planting include the temperature (Pavlista, 2004) that plays an important role and directly determines the rate of physiological aging (Bohl et al., 2003; Delanoy et al., 2004) and in the combination with the storage time (days) they are quickly expressed over the heat accumulation sum. During storage, sprouting capacity of tubers gradually increases to a maximum and then decreases (Hartmans and van Loon, 1987; De Weerd et al., 1995). The sprout development rate at planting time determines biological viability of tubers and may have a strong impact on the speed and uniformity of appearance of shoot and on the

*Corresponding author. E-mail: pdobrivoj@yahoo.com.

Table 1. The average meteorological conditions of different Serbian locations.

Location	Latitude	Longitude	Altitude (m)	Rainfall[a] (mm)		Temperature[b] (℃)	
				2000	2001	2000	2001
Kotraža	43°42' N	20°13' E	700	334.6	812.3	18.7	17 .7
Sjenica	43°21' N	19°79' E	1300	254.4	341.0	15.1	1 4.3
Golija	43°20' N	20°17' E	1600	199.2	361.4	14.1	13 .7

[a]Total rainfall for the May-September period, [b]Average temperature for May-September period.

finale yield (Mckeown, 1994). The tuber weight and size affect biological viability and determine the increase and the finale plant yield (Rykbost and Locke, 1999). The significance of a tuber size as an important factor of seed quality is reflected by the number of sprouts and vigour, but it is limited and associated with the physiological age of tubers. The altitude affects the development of potato crops. At higher altitudes the intensity of light is higher (van der Zaag, 1992), the utilisation of solar radiation is greater (Pereira et al., 2008), the different spectral composition of light is changed, the daily air temperature is lower and soil maturity is delayed, while the vegetation is prolonged, which favours obtaining seeds of good biological viability. At lower altitudes the intensity of light is lower (van der Zaag, 1992), the effect of utilisation of solar radiation is lower, due to higher air and soil temperatures (He et al., 1998), maturity is accelerated, while the vegetation of potato crops is shortened. A low light intensity favours the stem elongation, reduces the leaf thickness (Burton, 1989) and alltogether with higher temperatures (Reust, 1982) shortening the duration of dormancy (van Ittersum, 1992), because it influence plants to synthetise large amounts of growth hormones giberelic acids and cytokinins (van der Plas, 1987; Ewing and Struik, 1992).

The aim of the present study was to evaluate the impacts of different altitudes on the quality of potato seeds. In order to establish efficient and assured method of sprouting, the different heat accumulation was teseted in the light phase and its effects on biological viability of the potato seed tubers cultivar Desiree.

MATERIALS AND METHODS

The potato variety Desiree was planted in mid-May during two years in three locations Kotraža (700 m a.s.l.), Sjenica (1300 m a.s.l.) and Golija (1600 m a.s.l.). The production of potato crops was performed during years 2000 and 2001 by the application of standard cropping practices without irrigation. During the vegetation season, average daily temperature of air and precipitation sum were recorded (Table 1).

After harvest in mid-October, tubers were sorted out and healty tubers of 35 to 55 mm in diameter were selected and stored in the dark at 2 to 4℃ (95% RH) until the end of December. In the beginning of January, samples were transferred to a growth chamber where they were exposed to thermal induction for 7-10 days under conditions (18℃, 95% RH, dark) in order to break dormancy. The appearance of apical sprouts is a certain sign of breaking tuber's dormancy. Then, apical sprouts were removed from all tubers in order to provide a formation of a greater number of uniform sprouts per tubers. In mid-January 80 tubers samples were exposed for 2 weeks at 18℃ (95% RH, dark). In the beginning of February samples (80 tubers) were divided and half (40 tubers) were exposed for 3 weeks at 12℃ (75% RH, 9h flu to rescent tubes 40 to 65 W / 4 to 5 m^2). The second half of samples (40 tubers) were exposed for 3 weeks at 18℃ (75% RH, 9 h fluorescent tubes 40 to 65 W / 4 to 5 m^2). Biological viability of potato seed tubers was estimated once a week from the beginning of sprouting and the following indicators were recorded: number of sprouted tubers (%), number of sprouts per tuber, sprout length (mm), sprout vigour and sprouting capacity (%).

Data collection

Tuber's sprouting was calculated as a percentage of sprouted tubers in the sample. A tuber was considered sprouted when it had at least one visible sprout of at least 3 mm in length (Wiersema, 1985). All 40 tubers from samples were used to determine the average number of sprouts per tuber. The sprout length was determined by measuring the length of the longest sprout of the potato seed tubers to the nearest 1 mm using a caliper. The sprout vigor score was evaluated on the basis of the thickness on basal part of the sprout. The evaluation was based on the 1:5 scale (Gachango et al., 2008). Sprouting capacity (%) was determined at the end of sprouting by the method of Hartmans and van Loon (1987).

Statistical analysis

The obtained experimental data were processed by mathematical-statistical procedure using statistical package STATISTICA 8.0 for Windows (Analytical software, Faculty of Agriculture, Novi Sad, Serbia). The differences between the treatments were determined by the analysis of variance (ANOVA) and by the least significant difference test (LSD), which was used for individual comparisons.

RESULTS AND DISCUSSION

Number of sprouted tubers (%)

The number of sprouted tubers in the first two weeks of sprouting can be conditionally accepted as a sprouting rate, because all tubers in treatments were full sprouted by the third week (Table 2). Seed tubers produced at lower altitudes (700 and 1300 m) sprouted faster in the first two weeks than tubers originating from a high altitude (1600 m). The longer sprouting has the higher number of

Table 2. Effects of different altitudes on percentage of average number of sprouted seed tubers during the first two weeks of sprouting.

Sprouting week	Year	Altitude (m)		
		700	1300	1600
I	2000	57	68	45
	2001	76	75	52
II	2000	85	95	79
	2001	96	97	95
	Average	78.50	83.75	67.75

Table 3. Effects of different temperatures on average number of sprouts per potato seed tubers during 5 weeks of sprouting.

Sprouting duration (weeks)	Year					
	2000			2001		
	Temperature (°C)					
	12°C	18°C	Average	12°C	18°C	Average
III	6.90[bc]	7.28[c]	7.09	5.82[c]	6.06[c]	5.94
IV	7.16[ab]	7.78[b]	7.47	6.11[ab]	6.57[b]	6.34
V	7.41[a]	8.37[a]	7.89	6.32[a]	7.00[a]	6.66
$LSD_{0.05}$	0.31			0.27		

Values of means followed by the same letter are not significant at 0.05.

Table 4. Effects of different altitude and various temperatures on average number of sprouts per potato seed tuber after 5 weeks of sprouting.

Altitude (m)	Year					
	2000			2001		
	Temperature (°C)					
	12°C	18°C	Average	12°C	18°C	Average
700	6.18[c]	6.62[c]	6.40	5.82[a]	6.16[a]	5.99
1300	6.61[b]	7.19[b]	6.95	5.23[c]	5.71[c]	5.47
1600	6.89[a]	7.47[a]	7.18	5.77[ab]	6.03[ab]	5.90
$LSD_{0.05}$	0.24			0.21		

Values of means followed by the same letter are not significant at 0.05.

sprouted tubers over all observed altitudes, which was in accordance with the results obtained by Gachango et al. (2008) and Poštić et al. (2009). A higher seasonal stimulation of physiological age due to higher air and soil temperatures have caused the faster sprouting of tubers at lower altitudes.

Number of sprouts and length of sprouts per tuber

The cultivar Desiree have formed a large number of sprouts per tuber in the first year of study. The achieved values have increased with the duration and the temperature of sprouting and significantly differed in both years of examination, Table 3. Similar results obtained under higher temperatures were recorded by Wurr et al. (2001). Physiological age determines the behaviour of each bud on the seed tuber and thus affects the number of sprout per eye (Moll, 1994; Struik, 2007; Poštić et al., 2009;). Recent findings shows that the exposure of seed tubers to lower temperatures during dormancy causes an increase in the number of sprouts per tuber after dormancy breaking (Struik, 2007).

The number of sprouts per tuber have increased with

Table 5. Effects of different temperatures on length of longest sprout (mm) of seed potato tubers during 5 weeks of sprouting.

Sprouting duration (weeks)	Year					
	2000			2001		
	Temperature (°C)					
	12°C	18°C	Average	12°C	18°C	Average
III	8.53[c]	10.27[c]	9.40	13.83[c]	17.89[c]	15.86
IV	9.89[b]	12.48[b]	11.19	15.18[b]	19.71[b]	17.45
V	11.02[a]	13.93[a]	12.48	17.96[a]	21.24[a]	19.60
$LSD_{0.05}$	0.90			1.08		

Values of means followed by the same letter are not significant at 0.05.

Table 6. Effects of different altitude and various temperatures on length of longest sprout (mm) of potato seed tubers after 5 weeks of sprouting.

Altitude (m)	Year					
	2000			2001		
	Temperature (°C)					
	12°C	18°C	Average	12°C	18°C	Average
700	7.13b[c]	8.89[c]	8.01	12.30[c]	15.28[c]	13.79
1300	7.85[ab]	10.57[ab]	9.21	15.34[a]	16.24[ab]	15.79
1600	8.30[a]	10.86[a]	9.58	13.31[b]	16.57[a]	14.44
$LSD_{0.05}$	0.69			0.84		

Values of means followed by the same letter are not significant at 0.05.

the higher altitude and sprouting temperature and with a superior heat accumulation, Table 4, which is in accordance with results achieved by Wurr et al., 2001. The lowest average of 5.47 sprouts per tuber was obtained in the second year of study at the altitude of 1300 m, while the largest number of 7.18 of sprouts per tuber was obtained at the altitude of 1600 m in 2000 year. A larger number of sprouts per tuber and lower values for other indicators of biological viability in 2000 year, compared to the second year resulted from higher seasonal stimulation of physiological age (Pavlista, 2004), due to somewhat higher air temperatures and sustained drought stress, which is confirmed by earlier findings (Karafyllidis et al., 1991).

The cultivar Desiree have formed a greater length of sprouts per tuber in the year 2001. The obtained values increased with the increased duration and the temperature of sprouting and significantly differed in both years of examination (Table 5).

The increase of the heat accumulation with the duration and higher temperatures of sprouting, have caused the formation of longer sprouts in both years, which match with the results obtained by Poštić et al. (2009) and Rykaczewska (2010).

The lowest average of 8.01 mm in the sprout length per tuber was formed in 2000 year of study at the altitude of 700 m, while the maximum sprout length per tuber (15.79 mm) was formed in the second year at the altitude of 1300 m (Table 6).

The effect of all individual factors: altitude (A), sprouting duration (B) and sprouting temperature (C) on the number and length of sprouts per tuber and as well first order interactions (A × C) and (B × C) were established for both years of investigation by the analysis of variance (Table 7). The impact of the second order interaction (A × B × C) was not statistically established. The number and length of sprouts per tubers increased at all observed altitudes with sprouting duration. The same results were obtained by Gachango et al. (2008). In comparison with lower temperatures, the higher temperature by the third week of sprouting significantly affected a greater formation of the number of sprouts of a greater length at all investigated altitudes. These results had confirmed previously gained results that the number of sprouts per tuber (Poštić et al., 2009) and the length of sprouts per tuber (Moll, 1994; Poštić et al., 2010) were increasing with the increase of physiological age of seed tubers.

Sprout vigor

Sprout vigor increased with the sprouting duration at all observed altitudes, which coincides with the results gained by Gachango et al. (2008). Many authors have considered that the sprout vigor was determine higher sprouting temperature and also it was greater at all examined altitudes, then on tubers sprouted at lower

Table 7. F-values of sprout's number and sprout's length for examined factors during two years of investigation.

	Number of sprouts		Sprout length (mm)	
	Year			
	2000	2001	2000	2001
Altitude (m) (A)	21.73**	13.46**	10.92**	11.51**
Sprouting duration (weeks) (B)	75.42**	72.20**	104.40**	146.60**
Sprouting temperature (℃) (C)	5.08**	11.42**	17. 11**	125.77**
(A) x (B)	0.83^{ns}	1.14^{ns}	1.04^{ns}	0.15^{ns}
(A) x (C)	8.99**	0.46^{ns}	7.98**	8.56**
(B) x (C)	5.90**	8.58**	3.30**	16.87**
(A) x (B) x (C)	0.89^{ns}	0.54^{ns}	0.18^{ns}	0.46^{ns}

No. of sprouts 2000	A	B	C	AB	AC	BC	ABC
$LSD_{0.05}$	0.24	0.31	0.19	0.54	0.34	0.44	0.77
$LSD_{0.01}$	0.42	0.54	0.34	0.93	0.59	0.76	0.93
No. of sprouts 2001	A	B	C	AB	AC	BC	ABC
$LSD_{0.05}$	0.21	0.28	0.17	0.47	0.30	0.39	0.68
$LSD_{0.01}$	0.37	0.47	0.30	0.82	0.52	0.67	1.16
Sprout length 2000	A	B	C	AB	AC	BC	ABC
$LSD_{0.05}$	0.70	0.90	0.57	1.56	0.99	1.27	2.21
$LSD_{0.01}$	1.19	1.54	0.97	2.67	1.69	2.17	3.77
Sprout length 2001	A	B	C	AB	AC	BC	ABC
$LSD_{0.05}$	0.84	1.09	0.19	1.88	1.19	1.54	2.66
$LSD_{0.01}$	1.44	1.86	0.34	3.22	2.04	2.63	4.56

** - significant at 0.01; * - significant at 0.05; ns - not significant.

Table 8. Effects of different temperatures on sprout vigor of seed potato tubers during 5 weeks of sprouting.

Sprouting duration (weeks)	Year					
	2000			2001		
	Temperature (℃)					
	12℃	18℃	Average	12℃	18℃	Average
III	2.27^{c}	2.61^{c}	2.44	3.70^{c}	3.93^{c}	3.82
IV	2.93^{b}	3.19^{b}	3.06	4.05^{b}	4.37^{b}	4.21
V	3.27^{a}	3.77^{a}	3.52	4.27^{a}	4.54^{a}	4.41
$LSD_{0.05}$	0.12			0.10		

Values of means followed by the same letter are not significant at 0.05.

temperatures (Table 8).

At the end of sprouting period in the year 2000, tubers had a good vigor (ranging from 3.27 to 3.77), while in the year 2001, tubers had higher vigor, which ranged from 4.27 to 4.54. Physiological age was closely associated with vigor of seed tubers, which strongly affected sprouting and the initial development of plants (van der Zaag and van Loon, 1987). The highest average value of tuber's sprout vigor was recorded at the altitude of 1300 m during both years, Table 9. Sprout vigor had increased with the duration of sprouting, which is in accordance with the results obtained by Gachango et al. (2008).

All individual factors: altitude (A), length of sprouting (B), temperature of sprouting (C) and interaction factors (A × B), (B × C) very significantly affected sprout vigor during both years of investigation, (Table 10). The effect of interaction of factors (A × C) was not established, while the second order interaction (A × B × C) had a significant

Table 9. Effects of different altitude on sprout vigor of seed potato tubers during 5 weeks of sprouting.

Sprouting duration (weeks)	Year					
	2000			2001		
	Altitude (m)					
	700	1300	1600	700	1300	1600
I	1.36[e]	1.51[e]	1.13[e]	1.93[e]	2.42[e]	1.94[e]
II	1.84[d]	2.34[d]	1.69[d]	3.16[d]	3.43[d]	3.10[d]
III	2.43[c]	2.65[c]	2.28[c]	3.81[c]	3.85[c]	3.75[c]
IV	3.07[b]	3.05[b]	2.98[b]	4.37[b]	4.23[b]	4.01[b]
V	3.49[a]	3.62[a]	3.53[a]	4.52[a]	4.42[a]	4.32[a]
Average	2.44	2.63	2.32	3.56	3.67	3.42
$LSD_{0.05}$	0.09			0.10		

Values of means followed by the same letter are not significant at 0.05.

Table 10. F-values of sprout vigor for examined factors during two years of investigation.

				Year			
				2000		2001	
Altitude (m) (A)				23.13**		21.03**	
Sprouting duration (weeks) (B)				433.15**		707.73**	
Sprouting temperature (°C) (C)				15.66**		23.21**	
(A) × (B)				4.55**		6.52**	
(A) × (C)				1.67[ns]		1.02[ns]	
(B) × (C)				6.67**		4.27**	
(A) × (B) × (C)				2.20**		0.63[ns]	
2000	A	B	C	AB	AC	BC	ABC
$LSD_{0.05}$	0.09	0.12	0.07	0.20	0.13	0.17	0.29
$LSD_{0.01}$	0.16	0.20	0.13	0.35	0.23	0.28	0.49
2001	A	B	C	AB	AC	BC	ABC
$LSD_{0.05}$	0.07	0.19	0.06	0.17	0.11	0.14	0.24
$LSD_{0.01}$	0.13	0.17	0.11	0.29	0.18	0.24	0.41

** - significant at 0.01; * - significant at 0.05; ns- not significant.

impact on sprout vigor only in the first year.

Sprouting capacity (%)

Sprouting capacity or sprout weight per tuber was increased in both years of investigation with the higher altitudes, hence the highest values were achieved at the highest altitude of 1600 m (0.30-0.85%), while the lowest values were achieved at the lowest altitude of 700 m (0.17-0.64%) (Table 11). Seed tubers had a higher sprouting capacity in 2001 year of evaluation than in 2000 year. Sprouting capacity of tubers depends on the metabolism within the tuber, which continues after harvesting and causes changes on which biological viability depends (Morrenhof, 1998).

A higher seasonal stimulation of physiological age at lower altitudes and higher sprouting temperatures resulted in the increased heat accumulation in the tubers and a faster flow of physiological processes (Morrenhof, 1998) within each tuber. On the other hand, greater physiological age and a smaller sprouting capacity resulted in the decreased heat accumulation in tubers and a slower flow of physiological processes at the altitude of 1600 m in both years of evaluation. A high to a very high correlation was established between physiological age and sprouting capacity (van der Zaag and van Loon, 1987).

Conclusion

Based on the results obtained in these studies, the following conclusions can be drawn: The percentage of

Table 11. Effects of different temperatures on average (%) sprouting capacity of seed potato tubers after 5 weeks of sprouting.

Year	Altitude (m)	Average sprouting capacity (%)	
		Temperature (℃)	
		12℃	18℃
2000	700	0.24	0.17
	1300	0.33	0.29
	1600	0.42	0.30
	Average	0.33	0.25
	Index	100	76
2001	700	0.64	0.49
	1300	0.74	0.61
	1600	0.85	0.84
	Average	0.74	0.65
	Index	100	88

sprouted tubers originating from 1600 m a.s.l. after first two weeks of sprouting was by 10.75-16.00% lower, comparing to those tubers originating from lower altitudes (700 and 1300 m a.s.l.).

Sprouting at higher temperature range (18℃) influenced higher number of sprouts per tuber by 0.68-0.96, comparing to those sprouted at lower temperature range (12℃). The length of the longest sprout per tuber after 5 weeks of sprouting at 18℃ was by 2.91 to 3 .30 mm higher, comparing to those tubers sprouted at 12℃.

Sprout vigor of tubers at 12℃ was lower by 0.27 to 0.50 regarding tubers sprouted at 18℃. Oppositely, the higher sprouting capacity by 0.08 to 0.09 was obtained after five weeks of sprouting at 12℃, comparing to those tubers sprouted at 18℃.

Higher sprout number of seed tubers and better sprout vigor (high altitudes, high sprouting temperature) optionally could lead to a formation of a higher number of primary stems per potato plant and toward production of more tubers under regular and favorable conditions. On the other hand, higher sprouting capacity (lower sprouting temperature range) could be useful for short season, and an early potato production with lower number of primary stems, and accordingly faster formation of heavier tubers.

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