Potato Research (2010) 53:383–392
DOI 10.1007/s11540-010-9179-5

Evaluation of Potato Cultivars for Resistance Against Water Deficit Stress Under In Vivo Conditions

Davoud Hassanpanah

Received: 11 August 2010 / Accepted: 6 November 2010 /
Published online: 24 December 2010

Abstract Water deficit is the most important abiotic stress factor in crop production. Evaluation of the response of different potato cultivars to water deficit stress is necessary to release cultivars for regions with water deficit. A split-plot experiment with three replications was carried out during 2005 and 2006. The main factor consisted of three levels of irrigation (irrigation after 25%, 35% and 50% discharge of the available water, i.e. normal conditions, mild stress and severe stress, respectively), and the split factor included seven potato cultivars (Agria, Savalan, Satina, Caesar, Kennebec, Marfona and Santé). Cultivars Savalan, Caesar and Kennebec had higher total and marketable tuber yield, water use efficiency, and values for stress tolerance indices than the other cultivars, both under mild and severe stress conditions. Cultivars Caesar and Kennebec were selected as tolerant cultivars; cultivars Savalan and Satina were identified as moderately tolerant cultivars whereas cultivars Agria, Marfona and Santé proved to be susceptible to water deficit.

Keywords *Solanum tuberosum* · Stress tolerance · Water deficit · Water use efficiency

Introduction

Potato (*Solanum tuberosum* L.) is grown and eaten in more countries than any other crop (Jackson 1999). The crop is mainly grown in climates with cool temperate with

This paper is based on: Davoud Hassanpanah (2010) Evaluation of potato cultivars against water deficit stress under *in vitro* and *in vivo* conditions. In: Çalīşkan ME and Arslanoğlu F (ed) Potato AgroPhysiology, Proceedings of the International Symposium on Agronomy and Physiology of Potato. 20–24 September 2010, Nevşehīr, Turkey, pp 131–142

D. Hassanpanah (✉)
Agricultural and Natural Resources Research Centre, Ardabil, Iran
e-mail: D_Hassanpanah@yahoo.com

full sunlight, moderate day temperatures and cool nights. Short days generally induce tuber formation in potato, although many modern cultivars can initiate tubers under the long days of northern temperate regions as well (Tarn et al. 1992). Potato is among the most important crops in the world (Fernie and Willmitzer 2001) and in Iran (FAO 2008). In Iran, potato is ranked fourth in annual production after the cereals rice, wheat and barley. Iran is the world's 12th potato producer and the third biggest producer in Asia, after China and India (FAO 2008).

Water stress is a common stress in potato production areas. Water stress leads to yield and tuber quality losses. Potato is susceptible to drought (Foti et al. 1995). Supplying sufficient water is very important to increase potato quality and quantity. It is also very important to study the tolerance of different potato cultivars towards water deficit stress and to assess how much water is consumed by the potato crop.

In the potato growing area of Ardabil, Iran, water deficit is a serious problem. Moreover, the climate in this region has changed recently, resulting in changes in the distribution of precipation over time and changes in river flows and well water availability. Therefore, it is necessary to assess the agronomic characteristics of new potato cultivars in relation to their response to the water availability conditions in Ardabil and to analyse how much water these new cultivars require to obtain a good yield of high quality.

In comparison with other species, potato is very sensitive to water stress because of its shallow root system (Iwama and Yamaguchi 2006). Water deficit strongly decreases the number of leaves, plant water potential (Frensch 1997), leaf area, stem height, ground coverage, canopy radiation interception, number of tubers, growth and yield. In contrast, effects of water stress on radiation use efficiency, harvest index and tuber dry matter concentration (Schittenhelma et al. 2005) and on nitrate reductase (Foyer et al. 1998; Chandra et al. 2004; Das et al. 2005; Kar et al. 2005; Xu and Guang 2006) are relatively small. Water deficit also increases reducing sugar concentration in the tuber, tuber cracking and malformation, surface abrasions, hollow heart, brown centre, internal brown spot, vascular discolouration or bruising, starch degradation in the tuber stem end and total glycoalkaloid concentration (Papathanasiou et al. 1999). Reflectance indices were used to measure biomass and drought stress, changes in leaf water content (Francois and De Proft 2005) and water stress (Bahrun et al. 2003). A set of drought tolerance genes previously found to be up-regulated in tolerant potato under drought (Schafleitner et al. 2007) was assayed for expression changes in potato under drought.

The objective of this study was to evaluate different potato cultivars for their response to water deficit stress under in vivo conditions in order to release cultivars suitable for regions with water deficit in Iran.

Materials and Methods

Experiments were laid out in a split-plot design in three replications. Factor A included three irrigation regimes (normal, mild stress and severe stress, i.e. irrigation after 25%, 35% and 50% discharge of the available water, respectively) and factor B included seven potato cultivars (Agria, Savalan, Satina, Caesar, Kennebec, Marfona and Santé). Experiments were carried out in the growing seasons of 2005 and 2006. Every plot consisted of five rows of 6 m length with a row distance of 0.75 m. Planting arrangement was 75×25 cm. Distances between plots were 1.5 m.

The water amount used was regularly calculated according to the collected evaporation of a Class A Basin using the equation:

$$\mathrm{IW}/\mathrm{CPE} = 0.8$$

where IW=the amount of irrigation water (mm) and CPE=the collected evaporation calculated from evaporation pan (mm).

The amount of irrigation supplied was measured by a water metre. The start of irrigation was on the basis of 30 mm evaporation from a Class A evaporation pan. Amount of precipitation was measured by an udometer and daily evaporation by a Class A evaporation pan.

During crop growth and at harvesting, many characteristics were measured, including the number of main stems, plant height, number of tubers and tuber weight per plant, total and marketable tuber yield, and dry matter concentration. Analysis of variance was carried out, and means were separated using Duncan's range test.

Water use efficiency (WUE; kg m^{-3}) was calculated for potato cultivars under different irrigation regimes, as follows:

$$\mathrm{WUE} = \frac{\mathrm{TY}}{\mathrm{TWU}}$$

where, TY=tuber yield (in kg ha^{-1}) and TWU=total water used (in m^3 ha^{-1}). Indices used for evaluating potato cultivars included Fischer and Maurer stress index (SSI), Fernandez tolerance index (STI), Rosielle and Hamblin tolerance index (TOL), Baron geometric index (GMP) and modified stress tolerance index (MSTI) as indicated below (Fischer and Maurer 1978; Fernandez 1992; Rosielle and Hamblin 1981; Naderi et al. 1999):

1. Stress susceptility index (SSI):

$$\mathrm{SSI} = \left(1 - \frac{Y_{\mathrm{Si}}}{Y_{\mathrm{Pi}}}\right)/\mathrm{SI}$$

where Y_{Si} and Y_{Pi}=yield of cultivar under stress and normal conditions, respectively and

$$\mathrm{SI} = 1 - \frac{Y_{\mathrm{S}}}{Y_{\mathrm{p}}}$$

where Y_{S} and Y_{P}=total yield mean under stress and normal condition, respectively

2. Stress tolerance index (STI)

$$\mathrm{STI} = \frac{Y_{\mathrm{pi}} \times Y_{\mathrm{Si}}}{(\overline{Y}_{\mathrm{p}})^2}$$

3. Tolerance index (TOL)

$$\mathrm{TOL} = Y_{\mathrm{Pi}} - Y_{\mathrm{Si}}$$

4. Geometric mean index (GMP)

$$\mathrm{GMP} = \sqrt{Y_{\mathrm{Pi}} \times Y_{\mathrm{Si}}}$$

5. Mean productivity (MP)

$$\mathrm{MP} = \frac{Y_{\mathrm{Pi}} + Y_{\mathrm{Si}}}{2}$$

6. Modified stress tolerance index (MSTI):

$$\mathrm{MSTI} = K \times \left(\frac{Y_{\mathrm{Pi}} \times Y_{\mathrm{Si}}}{(\overline{Y}_{\mathrm{p}})^2} \right)$$

where $K = Y_{\mathrm{Si}}^2 / Y_{\mathrm{S}}^2$

Analysis of variance and the mean separation using Duncan's range test was carried out using MSTATC software.

Results and Discussion

Analysis of variance showed significant effects of years for tuber yield, plant height, tuber number and weight per plant, tuber weight less than 35 mm, between 35 and 55 mm and bigger than 55 mm; irrigation treatments had significant effects on total and marketable tuber yield, tuber number and weight per plant, tuber number and weight less than 35 mm and bigger than 55 mm; cultivar effects were significant for total and marketable tuber yield, main stem number, plant height, tuber number and weight per plant, tuber number and weight less than 35 mm, between 35 and 55 mm and bigger than 55 mm; the interactions between irrigation regime and cultivar were significant for total and marketable tuber yield and tuber weight per plant (Tables 1 and 2).

Table 1 Analysis of variance for different tuber traits of potato cultivars grown under different irrigation regimes

Source of variation	D.F.	Total tuber yield	Marketable yield	Main stem number	Plant height	Tuber number per plant	Tuber weight per plant
Year (*Y*)	1	1,529.65[a]	210.88	565.79	2.57[b]	10.858[a]	239,953.94[b]
Error a	4	556.94	354.25	186.17	7.43	15.385	143,354.04
Irrigation regimes (*A*)	2	637.01[a]	542.58[b]	52.44	0.97	11.73[a]	222,939.42[b]
Y×*A*	2	34.54	6.49	2.17	0.167	0.649	7,839.56
Error b	8	92.09	87.99	125.93	0.528	1.279	33,358.03
Cultivar (*B*)	6	256.40[a]	215.86[a]	735.69[a]	7.935[a]	28.897[a]	109,099.04[a]
Y×*B*	6	27.32[b]	33.52[a]	74.38[b]	0.071	0.312	5,956.53
A×*B*	12	19.34[b]	15.99[b]	42.72	1.146	1.752	13,682.12[a]
Y×*A*×*B*	12	11.76	8.35	14.15	0.083	0.209	5,688.79
Error c	72	8.39	7.15	32.89	0.646	1.287	7,747.87
C.V. %	–	11.20	12.80	12.75	17.48	13.85	12.74

[a] Significant at 1% level of probability

[b] Significant at 5% level of probability

Table 2 Analysis of variance for different tuber size distribution traits of potato cultivars grown under different irrigation regimes

Source of variation	D.F.	Tuber number per plant			Tuber weight per plant (g)		
		<35 mm	35–55 mm	>55 mm	<35 mm	35–55 mm	>55 mm
Year (*Y*)	1	3.85[a]	1.14	0.069	714.39[a]	84,275.33[b]	29,867.019[b]
Error a	4	3.09	5.60	0.100	72.83	25,342.71	53,971.89
Irrigation regimes (*A*)	2	1.15[a]	3.55	0.681[a]	797.99[a]	17,156.88	101,736.75[a]
Y×*A*	2	0.055	0.45	0.102	98.02	143,43.74	1,292.55
Error b	8	0.07	1.54	0.055	76.72	16,351.14	5,886.50
Cultivar (*B*)	6	13.84[a]	12.20[a]	0.993[a]	2,179.74[a]	55,349.85[a]	63,260.85[a]
Y×*B*	6	0.05	0.33	0.034	87.01	2,271.17	2,876.80
A×*B*	12	0.56	0.93	0.088	145.88	4,047.08	4,363.88
Y×*A*×*B*	12	0.04	0.14	0.027	32.49	2,104.41	2,120.59
Error c	72	0.29	0.72	0.071	146.63	4,317.54	3,803.65
C.V. %	–						

[a] Significant at 1% level of probability

[b] Significant at 5% and level of probability

The highest total and marketable tuber yield, tuber number and weight per plant were obtained for cultivars Savalan, Caesar and Kennebec in all irrigation regimes (Table 3). Mean comparisons of attributes among cultivars showed that tuber yield of cultivars Savalan, Caesar and Kennebec was higher than yields of other cultivars under stress and non-stress conditions. The yield loss caused by water stress differed among cultivars. In both mild and severe stress conditions, cultivars Savalan, Caesar and Kennebec showed a relatively small decline in tuber yield and could be classified as cultivars tolerant to water stress. These cultivars can produce a relatively high tuber weight per plant in all conditions. Yield decrease in mild and severe water stress conditions compared with normal conditions was 5.6 and 10.9 Mg ha^{-1} in cultivar Savalan, 3.7 and 5.9 Mg ha^{-1} in cultivar Caesar and 1.6 and 6.2 Mg ha^{-1} in cultivar Kennebec, respectively (Table 3). We observed that the most susceptible traits were tuber weight and number in the size classes 35–55 mm and bigger than 55 mm. It can be concluded that water stress decreased total and marketable tuber yield. Marfona had the largest yield loss, both under mild and severe water stress.

There were significant and positive correlations between total tuber yield and marketable tuber yield, tuber weight per plant, tuber number and weight between 35 and 55 mm and bigger than 55 mm; between marketable tuber yield and tuber weight between 35 and 55 mm and bigger than 55 mm, and tuber number bigger than 55 mm; between tuber number per plant and plant height, main stem number, tuber number and weight less than 35 mm and between 35 and 55 mm; between tuber weight per plant and total and marketable tuber yield, tuber number and weight bigger than 55 mm; between main stem number and tuber number per plant, plant height, tuber number and weight less than 35 mm and between 35 and 55 mm; between plant height and tuber number per plant, main stem number, tuber number and weight less than 35 mm, tuber number between 35 and 55 mm and tuber weight bigger than 55 mm (Table 4).

Table 3 Attributes mean in potato different under irrigation regimes

Irrigation regimes	Cultivars	Tuber yield ($Mgha^{-1}$)	Marketable yield ($Mgha^{-1}$)	Tuber weight per plant (g)
Normal[a]	Satina	43.0 bc	35.7 bc	780 bcde
	Savalan	48.5 a	41.3 a	903 a
	Agria	40.7 bcde	33.6 cde	682 efghi
	Caesar	44.5 ab	39.1 ab	825 ab
	Marfona	34.1 ghijk	28.8 efg	578 jk
	Kennebec	43.2 bc	37.8 abc	820 abc
	Santé	42.2 bcd	36.2 bc	723 cdefg
Mild stress[b]	Satina	39.8 bcdef	33.3 cde	713 defg
	Savalan	42.9 bc	35.5 bcd	785 bcd
	Agria	35.3 fghij	30.8 def	704 defgh
	Caesar	40.8 bcde	34.8 bcd	771 bcde
	Marfona	32.9 hijk	27.4 fgh	600 ijk
	Kennebec	41.6 bcde	36.0 bc	733 bcdef
	Santé	32.5 ijk	27.2 fgh	595 ijk
Severe stress[c]	Satina	33.5 hijk	29.9 ef	680 efghi
	Savalan	37.6 defgh	30.7 def	610 hijk
	Agria	34.6 ghij	28.5 fgh	634 fghij
	Caesar	38.6 cdefg	33.3 cde	707 defgh
	Marfona	29.3 k	24.0 h	521 k
	Kennebec	37.0 efghi	30.8 def	631 ghij
	Santé	31.2 jk	25.1 gh	512 k

Means with the same letters in each column are not significantly different at the 5% level of probability according to Duncan's test

[a] Normal, irrigation after 25% discharge of available water

[b] Mild stress, irrigation after 35% discharge of available water

[c] Severe stress, irrigation after 50% discharge of available water

Percent water stress intensity was calculated to be 10% (SI=0.10) under mild stress conditions and 18% (SI=0.18) under severe stress conditions. This showed that tuber yield under mild and severe stress decreased considerably. Percent tuber yield loss under the conditions of this experiment would be 10% and 18% (Table 5). MP, GMP, STI and MSTI indices indicated that Savalan, Caesar and Kennebec were the better cultivars; the SSI indicated that cultivars Marfona, Kennebec and Satina were best whereas TOL indicated that cultivar Satina was the best cultivar under mild and severe water stress conditions. Phenological investigations of cultivars Savalan and Caesar during susceptible periods can lead to designing strategic approaches in agronomy and breeding. Results for GMP, STI and MSTI were very consistent; Savalan, Caesar and Kennebec had the highest yields compared with other cultivars under mild and severe water stress and under normal conditions. So, these genotypes are tolerant to water stress and suitable for the Ardabil region (Table 5). Analysis of tolerance and sensitivity indices for environmental stress conditions showed that

Table 4 Linear correlation coefficients between different traits in potato cultivars grown at different irrigation regimes

Correlation coefficients		Tuber yield	Marketable yield	Tuber number per plant	Tuber weight per plant	Main stem number	Plant height	Tuber number per plant			Tuber weight per plant		
								<35 mm	35–55 mm	>55 mm	<35 mm	35–55 mm	>55 mm
Marketable yield		0.98[a]	–										
Tuber number per plant		0.37	0.33	–									
Tuber weight per plant		0.93[a]	0.95[a]	0.29	–								
Main stem number		0.07	0.07	0.62[a]	0.17	–							
Plant height		−0.10	0.03	0.47[b]	0.03	0.62[a]	–						
Tuber number per plant	<35 mm	−0.08	−0.11	0.78[a]	−0.17	0.78[a]	0.49[b]	–					
	35–55 mm	0.47[b]	0.41	0.85[a]	0.41	0.85[a]	0.50[b]	0.38	–				
	>55 mm	0.60[a]	0.66[a]	−0.31	0.72[a]	−0.32	−0.08	−0.57[a]	−0.22	–			
Tuber weight per plant	<35 mm	0.14	0.09	0.85[a]	0.03	0.85[a]	0.46[b]	0.93[a]	0.52[b]	−0.46[b]	–		
	35–55 mm	0.73[a]	0.69[a]	0.64[a]	0.75[a]	0.64[a]	−0.18	0.06	0.85[a]	0.23	0.23	–	
	>55 mm	0.71[a]	0.77[a]	−0.23	0.79[a]	−0.23	0.43[b]	−0.04	−0.19	0.90[a]	−0.30	0.22	–

[a] Significant at 1% level of probability

[b] Significant at 5% level of probability

Table 5 Estimates of water stress indices for potato cultivars under mild and severe stress

Cultivars	Mild stress						Severe stress					
	SSI	GMP	MP	TOL	STI	MSTI	SSI	GMP	MP	TOL	STI	MSTI
Satina	0.72	41.4	41.4	3.2	0.96	1.05	1.20	37.9	38.2	9.5	0.80	0.76
Savalan	1.13	45.6	45.7	91.3	1.16	1.48	1.22	42.7	43.0	86.1	1.02	1.20
Agria	1.29	37.9	38.0	76.1	0.80	0.70	0.82	37.5	37.7	75.3	0.79	0.79
Caesar	0.81	42.6	42.7	85.3	1.01	1.17	0.72	41.5	41.6	83.1	0.96	1.20
Marfona	0.35	33.5	33.5	67.1	0.63	0.47	0.77	31.6	31.7	63.4	0.56	0.40
Kennebec	0.37	42.4	42.4	84.8	1.00	1.20	0.78	40.0	40.1	80.2	0.89	1.02
Santé	2.23	37.0	37.4	74.7	0.77	0.56	1.41	36.3	36.7	73.4	0.74	0.60

For different stress indices, see "Materials and Methods"

Mild stress, SI=0.10; severe stress, SI=0.18

efficiency of these indices depends on the variation between genotypes in yield and on the assessment aimed for. The Fischer and Maurer index classifies genotypes as tolerant or sensitive, regardless of their yield level and therefore is efficient in finding genotypes with resistance genes. TOL's efficiency is conditional, but after classifying genotypes based on similar TOL values, we can select resistant genotypes with MP. Finding equal TOL in different groups is very hard. With regard to the roles of TOL and MP, genotypes with high MP might not be present in the groups with the least TOL and selecting superior genotypes might be difficult. The Fernandez index (STI) uses yield under stress and non-stress conditions and geometric means but the geometric equation is problematic as it combines data that have different natural background.

In all provinces of Iran, environmental changes are visible. The MSTI index includes the calculation of the KSTI for suitable and unsuitable conditions and is useful for selecting superior genotypes for each region. MSTI results are very notable.

Cultivars Savalan, Caesar and Kennebec had the highest WUE under normal conditions with values of 7.80, 7.17 and 6.96 kgm^{-3}, respectively; under mild stress conditions, values were 7.92, 7.54 and 7.68 kgm^{-3}, and under severe stress conditions values, were 8.88, 9.12 and 8.74 kgm^{-3}, respectively (Table 6).

This study shows that water stress increased WUE. Haverkort et al. (1990) also showed that drought increased WUE. Bodlaender (1986) showed that there was no relation between water usage and produced dry matter but that WUE had a significant negative relation with drought resistance. Slight stomata closure decreased transpiration more than photosynthesis and WUE increased. Severe drought led to full closure of stomata and decreased WUE and then yield (Beukema and Van Der Zaag 1990). Wright and Stark (1990) reported that the WUEs for conditions favouring maximum yields range from approximately 50 to 100 $kgha^{-1}mm^{-1}$. Kiziloglu et al. (2006) and Nagaz et al. (2007) reported that the range of WUE was from 44.1 to 63.4 $kgha^{-1}mm^{-1}$ and from 8 to 14 kgm^{-3}, respectively. Nagaz et al. (2007) concluded that WUE varied around 8–9, 6–8 and 11–14 kgm^{-3} for autumn-, winter- and spring-planted potato, respectively. Nasseri and Baharamloo (2009) showed that the highest increase in WUE was 21.2% relative to control conditions. Based on WUE values, they recommended

Table 6 Average water use efficiency (in kilograms per cubic metre) in potato cultivars under mild and severe stress

Cultivar	Normal[a]	Mild stress[b]	Severe stress[c]
Satina	6.92	7.36	7.92
Savalan	7.80	7.92	8.88
Agria	6.56	6.53	8.17
Caesar	7.17	7.54	9.12
Marfona	5.50	6.08	6.92
Kennebec	6.96	7.68	8.74
Santé	6.79	6.01	7.37

[a] Normal, irrigation after 25% discharge of available water

[b] Mild stress, irrigation after 35% discharge of available water

[c] Severe stress, irrigation after 50% discharge of available water

that potato cultivar Marfona should be irrigated at 59 days after planting to achieve the optimum WUE. Yarnia et al. (2009) indicated that increasing stress intensity decreased WUE in all cultivars. But severe stress had a higher WUE than mild stress. In all stages, increasing stress to a mild level decreased WUE, but beyond that, WUE increased. In all cultivars, irrigation at 50% soil available water increased WUE, and this was associated with a larger decline in tuber yield. Agria cultivar showed the highest WUE.

Conclusion

The cultivars Savalan, Caesar and Kennebec had a higher total and marketable tuber yield, water use efficiency, and more favourable stress indices than the other cultivars, both under mild and severe stress.

Cultivars Caesar and Kennebec were selected as tolerant cultivars; cultivars Savalan and Satina were identified as moderately tolerant cultivars whereas cultivars Agria, Marfona and Santé cultivars were classified as susceptible to water deficit.

Acknowledgements The author acknowledges the support of the Seed and Plant Improvement Institute, Karaj and Agricultural and Natural Resources Research Centre of Ardabil, Iran. The author also would like to thank Mr. Latif Fathi and his colleagues for their assistance.

References

Bahrun A, Mogensen VO, Jensen CR (2003) Water stress detection in field-grown maize by using spectral vegetation index. Commun Soil Sci Plant Anal 34:65–79

Beukema HP, Van der Zaag DE (1990) Introduction to potato production. Wageningen, The Netherlands, p 224

Bodlaender KBA (1986) Effects of drought on water use, photosynthesis and transpiration of potatoes. I. Drought resistance and water use. In: Beekman AGB, Louwes KM, Dellaert LMW, Neele AEE (eds) Potato research of tomorrow. PUDOC, Wageningen, pp 36–43

Chandra A, Pathak PS, Bhatt RK, Dubey A (2004) Variation in drought tolerance of different Stylosanthes accessions. Biol Plant 48:457–460

Das K, Pradhan T, Ghosh S, Mishra BK (2005) Evaluation of drought resistance characteristics of upland rice cultivars. Oryza 42:138–144

FAO (2008) International year of the potato 2008. www.potato2008.org. Accessed 26 Feb 2010

Fernandez GCJ (1992) Effective selection criteria for assessing plant stress tolerance. Crop Sci 28:13–16

Fernie AR, Willmitzer L (2001) Molecular and biochemical triggers of tuber development. Plant Physiol 127:1459–1465

Fischer RA, Maurer R (1978) Drought resistance in spring wheat cultivars. I. Grain yield responses. Aust J Agric Res 29:897–912. doi:10.1071/AR9780897

Foti S, Mauromicale G, Lerna A (1995) Influence of irrigation regimes on growth and yield of potato cultivar Spunta. Potato Res 38:307–318

Foyer CH, Valadier M, Migge A, Becker TW (1998) Drought induced effects on nitrate reductase activity and mRNA and on the coordination of nitrogen and carbon metabolism in maize leaves. Plant Physiol 117:283–292

Francois IM, De Proft M (2005) Reflectance indices indicative for changes in water contents of chicory leaves. Commun Agric Appl Biol Sci 70:135–138

Frensch J (1997) Primary response of root and leaf elongation to water deficits in the atmosphere and soil solution. J Exp Bot 48(310):985–999. doi:10.1071/AR9780897

Haverkort AJ, van de Waart M, Bodlaender KBA (1990) The effect of early drought stress on numbers of tubers and stolons of potato in controlled and field conditions. Potato Res 33(1):89–96

Iwama K, Yamaguchi J (2006) Abiotic stresses. In: Gopal SM, Khurana P (eds) Handbook of potato production, improvement and post harvest management. Food Product, New York, pp 231–278

Jackson SD (1999) Multiple signaling pathways control tuber induction in potato. Plant Physiol 119:1–8

Kar M, Patro BB, Sahoo CR, Hota B (2005) Traits related to drought resistance in cotton hybrids. Indian J Plant Physiol 10:377–380

Kiziloglu FM, Sahin U, Tune T, Diler S (2006) The effect of deficit irrigation on potato evapotranspiration and tuber yield under cool season and semiarid climatic conditions. J Agron 5:284–288

Naderi A, Majidi E, Hashemi A, Rezaie A, Nour Mohamadi G (1999) Efficiency analysis of indices for tolerance to environmental stresses in field crops and introduction of a new index. J Seed Plant 15 (4):390–402

Nagaz K, Masmoudi MM, Mechlia NB (2007) Soil salinity and yield of drip-irrigated potato under different irrigation regimes with saline water in arid conditions of southern Tunisia. J Agron 6:324–330

Nasseri A, Baharamloo R (2009) Potato cultivar Marfona yield and water use efficiency responses to early-season water stress. Int J Agric Biol 11(2)

Papathanasiou F, Mitchell SH, Watson S, Harvey BMR (1999) Effects of environmental stress during tuber development on accumulation of glycoalkoloids in potato (*Solanum tuberosum* L.). J Sci Food Agric 79:1183–1189

Rosielle AA, Hamblin J (1981) Theoretical aspects of selection for yield in stress and non-stress environments. Crop Sci 21:943–946

Schafleitner R, Gutierrez F, Espino R, Gaudin A, Perez J, Martinez M, Dominguez A, Tincopa L, Alvarado C, Numberto G, Bonierbale M (2007) Field screening for variation of drought tolerance in *Solanum tuberosum* L. by agronomical, physiological and genetic analysis. Potato Res 50:71–85

Schittenhelma S, Sourellb H, Lopmeierc F (2005) Drought resistance of potato cultivars with contrasting canopy architecture. Institute of Crop and Grassland Sci. Federal Agric Res Centre, Braunschweig

Tarn RT, Tai GCC, Jong D, Murphy AM, Seabrook JEA (1992) Breeding potatoes for long-day, temperate climates. Plant Breed Rev 9:217–332

Wright JL, Stark JC (1990) Potato. In: Stewart BA, Nielson DR (eds) Irrigation of agricultural crops. Amer Soc Agron, USA, pp 859–889

Xu ZZ, Guang S (2006) Combined effects of water stress and high temperature on photosynthesis, nitrogen metabolism and lipid peroxidation of a perennial grass Leymus chinensis. Planta 224:1080–1090

Yarnia M, Khorshidi MB, Nasseri A, Hassanpanah D (2009) Drought stress effects in different growth stages on potato cultivars. Int Conf Ecol Microbiol Biotech Problems 7:384–354