

Screening potato (*Solanum* spp) for cold-induced sweetening

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ABSTRACT

During storage at low temperature reducing sugars in potatoes (*Solanum* species) increase rapidly, as a result tubers become sweet and are not preferred for table as well as processing purposes. For developing potato varieties suitable for cold chipping, 16 wild and two semi-cultivated species were screened for reducing sugars content at harvest and after three months storage at 4°C. Tubers of 105 clones of 47 accessions of the 18 species harvested from summer crops (for two years) raised in glasshouse at Shimla were used for these evaluations. Significant differences were observed between as well as within species, accessions and clones of an accession for reducing sugars content both before and after storage. At harvest, the reducing sugars content ranged between 4.52 mg/100 g fresh weight in *S. berthaultii* ('SS 1785-06') to 1 122.97 mg/100 g fresh weight in *S. cardiophyllum* ('SS 1825-12'). After storage, it ranged between 80.56 and 3229.49 mg/100 g fresh weight in clones 'SS 1920-01' and 'SS 1920' respectively of *S. microdontum*. Clones with low reducing sugars at harvest were not necessarily having low reducing sugars after cold storage also, indicating that per cent increase in reducing sugars content varied with the genotype. Six promising clones with reducing sugars <100 mg/100 g fresh weight at harvest and <200 mg/100 g fresh weight after storage were: 'SS 1764-01' (*S. alandiae*), 'SS 1763-23' (*S. albicans*), 'SS 1825-10' (*S. cardiophyllum*), 'SS 1735-01' (*S. demissum*), 'SS 1920-01' (*S. microdontum*) and 'SS 1724-06' (*S. sparsipilum*).

Key words: Cold-induced sweetening, Potato, Reducing sugars, *Solanum* species

In potato (*Solanum tuberosum* L.), during storage at low temperature (2–4°C), starch converts into the reducing sugars due to the high activities of invertase or low level of invertase inhibitors. The excessive accumulation of reducing sugars imparts sweetening known as 'cold-induced sweetening' and the sweet tubers are not preferred for table as well as processing purposes (Dale *et al.* 2003). For processing potatoes into products like chips and French fries, tubers should have high dry matter (>20%) and low reducing sugars (<100 mg/100 g fresh tuber weight) (Marwaha *et al.* 2008). High reducing sugars result in dark coloured chips and French fries, which are not preferred by the consumers. Fresh potatoes are suitable for processing but due to non-availability of fresh potatoes throughout the year the processing industries are using cold stored potatoes during off-season (Pandey *et al.* 2004). Thus there is need to develop varieties suitable for low accumulation of reducing sugars during cold storage. In the cultivated potato, *S. tuberosum* there is little variability for reducing sugar content after cold storage and very few germplasm accessions suitable for cold chipping have been

identified (Dale *et al.* 2003, Luthra *et al.* 2009). To search for the alternate genetic sources for this character, in the present study 18 wild or semi-cultivated *Solanum* species were screened for reducing sugars content before and after cold storage.

MATERIALS AND METHODS

The accessions used in the study were imported from Potato Introduction Station, Sturgeon Bay, USA in 2000 in true potato seed (TPS) form for evaluation and utilization under Indian conditions. The TPS belonging to different accessions were sown in plastic trays and later transplanted in the pots for converting into tuber form. The tubers obtained from each seedling represent a different clone and these clones were used in the present study.

A total of 150 clones of 47 accessions belonging to 16 wild and two semi-cultivated species, viz *S. tuberosum* ssp *andigena* and *S. phureja* were grown in polyhouse during September 2005 and 2006 at CPRI, Shimla (32° N, 77° E and 2500 m amsl). Harvesting in both the years was done in February and randomly drawn five fresh tubers were cut longitudinally, diced and mixed thoroughly, and 50 g of diced tubers were used for determining reducing sugar content following Arsenomolybdate method of Nelson (Nelson

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1944). The same set of harvested tubers were also kept in polyethylene bags (5 tubers/clone) having small holes for aeration and stored in a walking chamber for three months at 4°C and 95–100% relative humidity were analyzed for reducing sugar contents. In all these accessions the reducing sugars were estimated in three replications. Data were analyzed using computer software MSTAT-C.

RESULTS AND DISCUSSIONS

The analysis of variance showed highly significant ($P < 0.05$) differences between as well as within species, accessions and clones of an accession for reducing sugars content both before and after storage (Table 1). Mean reducing sugars also varied with year, which may be expected due the different environmental conditions, time and stage of harvest. The variation between species, accessions within species and clones within accessions was expected as each clone is a different genotype. An accession being in heterozygous condition results in clones with different genetic constitutions due to shuffling of genes upon selfing/sib-mating which is used for maintenance of an accession.

Ideally, the clones with mean reducing sugars <100 mg/100 g fresh weight are considered highly suitable for processing into chips (Marwaha *et al.* 2008). However, some authors suggested that this limit of reducing sugars for French fries, canning and dehydrated products can be from 200 mg/100 g fresh weight (Talbert and Smith 1987) to 500 mg/100 g fresh weight (Ezekiel *et al.* 1999).

At harvest, the reducing sugars content in various clones ranged between 4.52 mg/100 g fresh weight in 'SS 1785-06' (*S. berthaultii*) and 1122.97 mg/100 g fresh weight in 'SS 1825-12' (*S. cardiophyllum*). After storage, it ranged between 80.56 and 3229.49 mg/100 g fresh weight in clones, 'SS 1920-01' and 'SS 1920' respectively, of *S. microdontum* (Table 1). At harvest in both the years, 13 clones of *S. alandiae*, viz SS Nos. '1764-17', '1764-01', '1764-14', '1764-08', '1764-07', '1764-19', '1765-07', '1765-17', '1765-23', '1765-20', '1765-18', '1765-16' and '1765-15' and 3 clones of *S. albicans*, viz 'SS 1763-15', '1763-23' and '1763-24' had reducing sugars within the tolerable limit, i.e. less than 100 mg/100 g tuber fresh weight. Such promising clones from other species were: SS No's '1769-03', '1769-06', '1769-09' and '1769-01' of *S. arnezii*, SS No's '1778-05', '1779', '1785-06', '1786-01', '1787-08', '1787-14' and '1787-12' of *S. berthaultii*, SS No's '1735-01', '1838', '1846-06', '1846-05', '1846-03', '1850-05', '1850-03' and '1850' of *S. demissum*, SS No's '1920-01', '1920' and '1921-21' of *S. microdontum*, SS No's '2044-05', '2045-01', '2045-07', '2045-06' and '2055-02' of *S. tuberosum ssp andigena*, 'SS 1794-03' of *S. brevicaulis*, 'SS 1788-01' of *S. bulbocastanum*, 'SS 1825-10' of *S. cardiophyllum*, 'SS 1817-01' of *S. commersonii*, 'SS 1878' of *S. guerreroense*, 'SS 1724-06' of *S. sparsipilum* and 'SS 1725-57' of *S. spegazzinii*.

After storage, there were only two clones, viz 'SS 1764-01' (*S. alandiae*) and 'SS 1920-01' (*S. microdontum*) with reducing sugars <100 mg/100 g fresh weight and another four clones, viz 'SS 1763-23' (*S. albicans*), 'SS 1825-10' (*S. cardiophyllum*), 'SS 1735-01' (*S. demissum*) and 'SS 1724-06' (*S. sparsipilum*) had low reducing sugars <200 mg/100 g fresh weight. These clones also had low reducing sugars (<100 mg/100 g fresh weight) at harvest and thus are of immense value for processing purposes. The range of reducing sugars before and after storage in these six promising clones is presented in Fig 1. These clones had reducing sugar content much lower than that reported in commercial varieties. Uppal and Ezekiel (2002) reported reducing sugar as high as 1753 mg/100 g fresh weight in three months cold stored (4°C) tubers of cultivated potato variety, 'Kufri Badshah'. Even the Indian processing cultivars, viz 'Kufri Chipsona 1', 'Kufri Chipsona 2' and exotic processing cultivars, viz 'Atlantic' and 'Frito Lay 1625' are also not suitable for chipping after cold storage (Pandey *et al.* 2005).

Among the 18 species studied (Table 1), the lowest mean reducing sugars at harvest in both the years was observed in *S. berthaultii* (57.49 and 25.21 mg/100 g fresh wt.) followed by *S. alandiae* (58.56 and 34.81 mg/100 g fresh wt.), *S. guerreroense* (48.69 and 46.79 mg/100 g fresh wt.), *S. commersonii* (22.59 and 104.77 mg/100 g fresh wt.), *S. buessi* (138.05 and 32.94 mg/100 g fresh wt.), *S. brevicaulis* (193.27 and 43.35 mg/100 g fresh wt.) and *S. tuberosum ssp andigena* (172.60 and 66.15 mg/100 g fresh wt.). However, after 3 months of cold storage the minimum mean reducing sugars were observed in *S. spegazzinii* (644.90 mg/100 g fresh wt.) followed by *S. chacoense* (676.06 mg/100 g fresh wt.), *S. microdontum* (733.73 mg/100 g fresh wt.), *S. albicans* (736.92 mg/100 g fresh wt.), *S. alandiae* (766.12 mg/100 g fresh wt.), *S. demissum* (791.21 mg/100 g fresh wt.), but in none of the species the mean reducing sugars after cold storage were within the tolerance limits.

A rapid increase in the reducing sugars was observed during cold storage and it ranged from 2.33 to 29.42 folds in

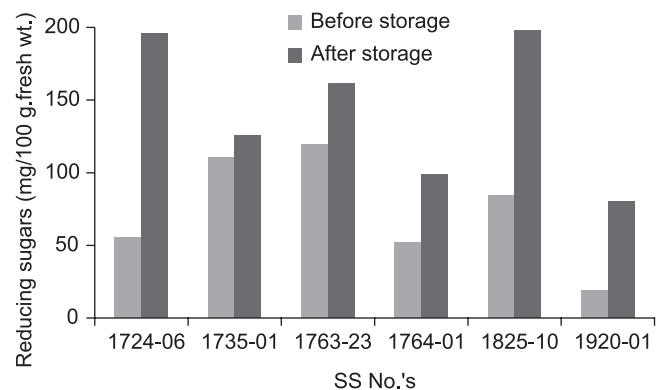


Fig 1 Reducing sugars in some promising clones before and after cold storage

Table 1 Mean reducing sugars before and after 3 months of cold storage in some species of potato

Species	Accessions (PI no.)	No. of clones	Mean reducing sugars (mg/100 g fresh weight)						Promising clones (SS no's)
			At harvest				After three months storage		
			Year 1		Year 2		Range	Mean	
		Range	Mean	Range	Mean				
<i>S. alandiae</i> (24,2)	498089	6	6.02–69.92	22.21	9.17–81.67	34.58	82.08–1133.92	563.18	1764–01
	568913	10	28.00–155.00	80.37	8.33–81.67	39.34	188.48–1471.36	887.88	
	<i>Mean</i>		6.02–155.0	58.56	8.33–81.67	34.81	82.08–1471.0	766.12	
<i>S. albicans</i> (72,4)	365310	6	153.61–525.59	318.67	229.17–637.50	418.98	462.34–1751.04	954.48	1763–23
	498201	17	30.12–926.19	243.38	65.83–611.66	219.71	155.04–1687.20	660.13	
	<i>Mean</i>		30.12–926.19	263.02	65.83–637.50	271.69	155.04–1751.04	736.92	
<i>S. arnezii</i> (24,2)	545880	8	12.00–452.00	156.77	4.17–93.33	47.08	522.88–1638.56	1063.87	
	545958	2	162.65–410.40	301.05	137.50–325.83	229.58	424.69–646.00	538.35	
	<i>Mean</i>		12.00–452.00	185.63	4.17–325.83	83.58	424.69–1638.56	958.77	
<i>S. berthaultii</i> (24,2)	218215	1	45.00–65.00	55.33	11.87–13.42	12.56	1123.28–1200.80	1160.77	
	265857	1	7.53–18.07	12.55	12.39–17.55	14.79	1383.20–1489.60	1423.73	
	473339	1	1.51–7.53	4.52	2.32–7.74	5.42	828.40–927.20	886.67	
	473340	1	69.28–144.60	108.43	9.81–11.61	10.92	1079.20–1132.40	1099.47	
	498104	3	4.52–70.78	40.83	7.48–22.97	12.91	828.40–1106.56	995.60	
	595507	1	144.56–165.66	156.62	112.61–124.99	119.25	684.00–758.48	732.64	
	<i>Mean</i>		1.51–165.66	57.49	2.32–124.99	25.21	684.00–1489.60	1036.26	
<i>S. brevicaulis</i> (24,2)	473378	2	43.67–353.91	193.27	7.23–92.90	43.35	542.64–1703.92	1126.83	
<i>S. buessi</i> (24,2)	568922	1	132.53–146.08	138.05	28.90–38.71	32.94	1550.40–1586.88	1565.60	
<i>S. bulbocastanum</i> (24,1)	BGRC 8009	1	418.67–429.21	423.19	31.07–33.01	32.01	1109.60–1191.68	1156.72	
	243505	1	21.08–225.90	90.36	88.00–94.19	90.32	1026.00–1060.96	1046.27	
	<i>Mean</i>		21.08–429.21	256.77	31.07–94.19	61.18	1026.00–1191.68	1101.49	
<i>S. cardiophyllum</i> (24,1)	GLKS 95	1	270.56–300.96	162.16	27.18–51.21	35.92	298.19–319.20	306.70	
	341233	5	42.17–1207.81	591.88	1.51–170.83	87.13	165.68–1830.08	1008.80	1825–10
	<i>Mean</i>		42.17–1207.81	541.30	1.51–170.83	78.59	165.68–1830.08	891.78	
<i>S. chacoense</i> (24,2)	OKA 4957	1	328.31–436.74	380.52	34.71–42.72	39.88	775.20–874.00	825.87	
	133073	2	25.45–268.07	159.11	131.61–135.48	118.12	434.72–775.20	601.16	
	<i>Mean</i>		25.45–436.74	232.91	34.71–135.48	92.04	434.72–874.00	676.06	
<i>S. commersonii</i> (24,1)	590917	1	13.55–36.14	22.59	29.42–252.89	104.77	1817.92–1963.84	1873.65	
<i>S. demissum</i> (72,4)	GLKS 221	1	238.44–259.03	249.49	64.07–102.18	85.03	533.52–550.24	540.61	1735–01
	GLKS 269	3	57.76–272.59	156.78	51.21–156.78	94.17	118.97–525.92	305.53	
	160220	1	778.24–840.35	809.08	68.13–105.80	91.01	792.16–857.28	823.40	
	160222	1	46.67–52.71	50.54	28.61–48.19	37.15	448.40–541.12	506.67	
	161149	1	234.94–269.57	255.02	80.51–106.32	91.18	1357.36–1456.16	1420.19	
	161169	2	303.92–398.78	350.37	3.01–72.29	37.90	1026.00–1603.89	1286.10	
	161366	8	28.61–325.30	141.00	7.23–85.84	25.01	354.16–1389.28	882.17	
	175423	3	33.13–76.81	54.89	4.64–115.09	41.23	468.16–1007.76	662.38	
<i>Mean</i>		28.61–840.35	191.39	3.01–156.78	49.32	118.97–1603.89	791.21		
<i>S. guerreroense</i> (72,4)	161727	1	45.18–52.71	48.69	39.74–51.87	46.79	1102.00–1194.72	1140.51	
<i>S. microdontum</i> (24,2)	458358	3	4.52–316.26	134.87	15.23–72.29	37.94	59.28–3340.96	1312.77	1920–01
	473170	4	23.00–298.19	175.79	57.80–160.77	96.92	343.37–1051.84	560.82	
	595505	1	355.42–371.98	363.45	60.13–63.48	61.93	519.84–544.16	531.49	
	595509	7	112.95–1126.49	371.40	12.05–83.87	55.21	346.56–1191.25	613.26	
	<i>Mean</i>		4.52–1126.49	271.40	12.05–160.77	63.33	59.28–3340.96	733.73	
<i>S. oplocense</i> (48,4)	OKA 4499	1	768.06–823.78	789.01	20.14–23.30	21.84	810.23–1033.60	943.44	
<i>S. phureja</i> (24,2)	225671	1	524.09–539.15	530.61	11.89–20.87	15.13	1532.16–1710.00	1592.45	
	320379	1	775.20–802.56	792.93	63.48–80.51	69.33	820.77–894.56	862.44	
	<i>Mean</i>		524.09–802.56	661.77	11.89–80.51	42.23	820.77–1710.00	1227.44	
<i>S. sparsipilum</i> (24,2)	DA 019	1	606.92–698.78	648.08	18.07–46.69	33.63	1240.32–1361.92	1319.36	1724–06
	412921	16	51.20–680.96	366.85	2.18–40.77	17.57	105.60–2432.00	808.66	

(contd..)

(concluded...)

Species	Accessions (PI no.)	No. of clones	Mean reducing sugars (mg/100 g fresh weight)						
			At harvest				After 3 months storage		Promising clones (SS no's)
			Year 1		Year 2		Range	Mean	
			Range	Mean	Range	Mean	Range	Mean	
<i>Mean</i>			51.20–698.78	383.39	2.18–46.69	18.52	105.60–2432.00	838.71	
<i>S. spegazzinii</i> (24,2)	CGN 17839	10	73.79–878.56	344.14	0.73–118.44	24.50	170.24–1100.89	650.97	
	442686	1	322.28–341.86	197.12	57.80–63.48	60.90	337.44–951.52	584.19	
<i>Mean</i>			73.79–878.56	343.16	0.73–118.44	27.81	170.24–1100.89	644.90	
<i>S. tuberosum</i> ssp. <i>andigena</i> (48,4)	161716	1	201.80–254.51	224.90	1.70–3.64	2.83	1383.20–1436.40	1403.47	
	225629	1	478.91–493.97	484.93	96.59–112.13	105.25	1079.20–1132.40	1107.07	
	237208	1	15.06–21.08	18.07	10.68–19.90	15.21	624.72–747.84	705.79	
	243361	4	3.01–283.13	57.66	13.11–75.72	50.02	227.41–1928.88	918.51	
	460701	2	57.23–427.70	239.34	10.54–97.89	69.53	439.75–904.40	658.49	
	243449	2	3.01–466.89	230.67	51.45–197.80	132.60	500.08–1360.40	900.60	
<i>Mean</i>			3.01–493.97	172.60	1.70–197.80	66.15	227.41–1928.88	909.87	
	Total		47 accessions	150 clones					

*Italic values are the species means	CD ($P = 0.05$)	After harvest	After storage	
#Values in parentheses are chromosome number and endosperm balance number (EBN) of the specified species		values:	5.78	CD ($P = 0.05$)
	Accession×	Accessions	Clone	112.98
	year	23.58	23.87	72.65
	Species	22.31	Clone × year	48.50
	Species×	31.55	CV (%)	8.43
	year		18.25	

the different species. The 'n' fold increase was minimum (2.33) in *S. oplocense*, followed by *S. albicans* (2.76), *S. cardiophyllum* (2.88), *S. spegazzinii* (3.48), *S. phureja* (3.49) and maximum in *S. commersonii* (29.42). Among accessions also, an increase in reducing sugars was observed and it was minimum 1.83 folds in 'SS 1837' (*S. demissum*), followed by 'SS 1730' (1.89, *S. cardiophyllum*), 'SS 1986' (2.00, *S. phureja*) and 'SS 1770' (2.03, *S. arnezii*). Among clones, the minimum 1.13 fold increase in reducing sugars after cold storage was in 'SS 1763–20' (*S. albicans*), followed by 'SS 1735–01' (1.14, *S. demissum*), 'SS 1763–21' (1.20, *S. albicans*) and 'SS 1763–23' (1.35, *S. albicans*). Though the increase in above mentioned six promising clones ranged from 1.1 to 4.3 folds, yet the reducing sugars in these clones were within the tolerance limits.

The genotypes with low reducing sugars content also had desirable tuber characters. Tubers of all such clones were white, round to oval, with fleet eyes, except of 'SS 1735–01' (*S. demissum*) and 'SS 1825–10' (*S. cardiophyllum*), which had dark-purple and light-purple tubers, respectively. The tuber of 'SS 1763–23' (*S. albicans*, 6x and 4EBN) were of medium size, while the tubers of other clones with low reducing sugars were comparatively smaller. The genotypes identified in the present study, however, cannot be utilized for potato improvement directly as most of these species are

diploid (13) with endosperm balance number (EBN) 1–2 and are thus not readily crossable with cultivated tetraploid potato, *S. tuberosum* ssp. *tuberosum* (Thill and Peloquin 1995). The cold chipping trait from the promising clones of diploid species (2x and 2EBN), viz *S. alandiae* ('SS 1764–01'), *S. microdontum* ('SS 1920–01') and *S. sparsipilum* ('SS 1724–06') can be transferred to cultivated potato, *S. tuberosum* ssp. *tuberosum* by means of unreduced gametes. These species need to be crossed with dihaploids (as recurrent parent) of *S. tuberosum* and after appropriate back crossing and selection the elite interdihaploid genotypes producing 2n gametes can be crossed with tetraploid *S. tuberosum* genotype (Ortiz 2003). The promising clone, SS 1825–10 of *S. cardiophyllum* (2x, 1EBN) can be utilized probably only through somatic hybridization. However, the promising clone, viz SS 1763–23 of *S. albicans* and SS 1735–01 of *S. demissum* are hexaploid (2n=6x) with 4 EBN. These can be directly crossed with cultivated, *S. tuberosum* ssp. *tuberosum*. This trait from these two species can also be transferred into *S. tuberosum* ssp. *tuberosum* through tetraploid hybrid clone of *S. chacoense* along with *S. phureja*, which serves as a bridge between these species and *S. tuberosum* (Carpato et al. 2000).

It is concluded that there was a considerable variation for reducing sugar content among clones, accessions as well as

species of potato. The clones with low reducing sugars and desirable tuber characters can be pre-bred for developing tetraploid parents for use in breeding for cold-chippers.

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