Composition of Four Potato Cultivars in Relation to Cold Storage and Reconditioning

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Summary. 'Atlantic', 'BelRus', 'Kennebec', and 'Superior' potatoes (*Solanum tuberosum* L.) were evaluated for ascorbic acid, soluble protein, and sugar content (reducing and nonreducing) at harvest, after 6 weeks of storage at 3C, and after 2 weeks of reconditioning at 25C. At harvest, ascorbic acid and soluble protein contents varied among the cultivars, with 'Superior' containing the highest ascorbic acid (154 mg/100 g dry weight) and soluble protein content (46.4 mg·g⁻¹ dry weight). Cold storage resulted in a drastic reduction ($\pm 50\%$) in ascorbic acid content in all four cultivars. Ascorbic acid also decreased during reconditioning of tubers, but the reduction was less than during cold storage. In contrast, soluble protein contents were not influenced significantly by cold storage or reconditioning, except for 'BelRus' and 'Kennebec', which had less protein after reconditioning. At harvest, glucose, fructose, and sucrose contents were at similar levels in all cultivars, except for fructose in 'Kennebec', which was more than 2-fold higher. 'Kennebec' also had a significantly lower specific gravity than the other cultivars. However, unlike the other cultivars, reconditioning of 'Kennebec' tubers did not affect its specific gravity or total sugar content. Data suggest that 'Kennebec's' poor processing quality may have resulted from a combination of low specific gravity and high total sugar content.

The potato is the most important vegetable in the world, not only for its carbohydrate, but also for its ascorbic acid and protein content (Beukema and Van Der Zaag, 1990). It is estimated that about one-fourth of the daily human requirement of ascorbic acid is supplied by potatoes (Van Der Slice et al., 1990). The potato is also an important source of non-sulfur-containing proteins (Kapoor et al., 1975).

Cold storage is used to extend the shelf life of fresh-market and processed potatoes. During low-temperature storage, sugar content increases significantly in most cultivars (Dogras et al., 1989; Joshi et al., 1990). Sugar content is one of the most important components that influences the processing quality of potatoes. Sucrose, fructose, and glucose are the major sugars found in potato tubers (Beukema and Van Der Zaag, 1990; Van Es and Hartmans, 1987). Potatoes that contain high concentrations of sugars produce dark brown chips and fries as a result of the Maillard reaction between sugars and free amino acids (Ehlenfeldt et al., 1990; Mackay et al., 1990). Sugar accumulation during cold storage usually is reversed before processing by reconditioning the tubers for several days at temperatures above 15C to reduce the sugar content (Iritani and Weller, 1977; Samotus et al., 1974). Processing quality of potatoes also can be evaluated by determining the specific gravity of tubers (Kleinkopf et al., 1987; Santerre et al., 1986). Potato cultivars with high specific gravity are preferred for chips and fries because they accumulate less sugars during cold storage and absorb less oil during processing (Sayre et al., 1975).

Although there have been several studies on the effect of cold storage and reconditioning on sugar content and specific gravity of potatoes, there are no reports on their effect on individual sugars, the relationship between individual sugars and processing quality, and the effect of reconditioning on ascorbic acid and soluble protein contents. The objectives of this study were to determine cultivar differences in ascorbic acid and soluble protein contents and their patterns of change after cold storage and reconditioning. In addition, we evaluated the relationship between individual and total sugars and their impact on specific gravity and chipping quality.

Materials and methods

Plant material. 'Atlantic', 'BelRus', 'Kennebec', and 'Superior' potato tubers were obtained from a research plot in southwestern Virginia. The tubers were harvested at full maturity based on the recommended number of days from planting to harvest for Virginia-grown potatoes (Baldwin et al., 1986). A 6-kg sample of 6.0 ± 0.5 -cm-diameter tubers from each of six replications was washed and cured in the dark at 18C and 90% relative humidity (RH) for 1 week. After curing, the tubers were stored at 3C and 90% RH for 6 weeks and then reconditioned for 2 weeks at 25C and 90% RH.

Ascorbic acid, specific gravity, and protein determination. Duplicate freeze-dried and ground subsamples (0.5 g) from each of the six replicates were weighed and placed in 50-ml Erlenmeyer flasks containing 10 ml metaphosphoric acid solution (30 g metaphosphoric acid, 80 ml glacial acetic acid, and 400 ml distilled water). The samples were stirred intermittently for 20 min at room temperature, then filtered through Whatman no. 1 filter paper. The filtrate was brought to 10 ml with metaphosphoric acid solution prepared as above. Ascorbic acid concentrations were determined by titrating a 5-ml sample of the extract against a standardized 2,6-dichloro-indophenol solution, as described in the Association of Official Analytical Chemists (AOAC) procedure (AOAC, 1984).

Soluble protein was determined by extracting 1 g of freeze-dried tissue in 5 ml of 0.2 M potassium phosphate buffer (pH 7.2). The extract was centrifuged at $27,000 \times g$ for 20 min, and the protein concentration was determined according to Bradford (1976). Specific gravity was determined according to the U.S. Dept. of Agriculture (USDA) standards for processing potato (USDA, 1983).

Sugar analysis. A sample of freeze-dried tissue (2 g) from each replicate was Soxhlet-extracted with 25 ml of 80% (v/v) boiling ethanol for 2 h. After filtration, the ethanol extract was vacuum-dried and the residue was dissolved in 10 ml distilled water. The mixture was deionized with 1 g mixture of resin AG 1X 8(OH-) and AG50(H+) (1:1), centrifuged at $8,000 \times g$ for 2 min, and then filtered through a 0.2- μ m nylon filter. A 150- μ l aliquot

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of the filtrate was injected into a high-performance liquid chromatography system (Beckman Instruments, Fullerton, Calif.) equipped with a refractive index detector and a carbohydrate column (Phenomenex, Torrance, Calif.), using glass-distilled water as a mobile phase at a flow rate of 0.6 ml·min⁻¹ and 80°C column temperature. Data were subjected to analysis of variance and Duncan's multiple range test.

A 10-kg sample of each of freshly harvested tubers and tubers stored for 6 weeks at 3°C and reconditioned for 2 weeks at 25°C from each of the four cultivars was given to a local processor to be tested for chipping quality (chip color) according to commercial standards.

Results

Genotype had a significant effect on the ascorbic acid content of tubers at harvest (Table 1). 'Superior' tubers had the highest ascorbic acid content (140 mg·g⁻¹ dry weight) and 'Atlantic' had the lowest (82 mg·g⁻¹ dry weight). During cold storage, the ascorbic acid content dropped nearly 2-fold in all cultivars. Ascorbic acid levels declined after reconditioning the tubers at 25°C for 2 weeks. The decline in ascorbic acid content in reconditioned tubers ranged from 27% to 42% (w/w) compared to the level of cold-stored tubers.

Soluble protein content was higher in 'Superior' and 'BelRus' (Table 2). Soluble protein levels did not change after cold storage. However, reconditioning caused a significant reduction in soluble protein in 'Superior' and 'BelRus' but not in 'Atlantic' or 'Kennebec'.

Tubers of 'Atlantic', 'BelRus', and 'Superior' had significantly higher specific gravities than tubers of 'Kennebec' (Table 3). After cold storage, specific gravity was highest in 'Atlantic' and lowest in 'Kennebec'. When tubers were reconditioned, an increase in specific gravity was found in 'BelRus' and 'Superior' but not in 'Atlantic' or 'Kennebec'.

At harvest, there were no significant differences among cultivars in glucose, sucrose, and total sugars (Table 4). Tubers of 'Kennebec' had the highest content of fructose, while the other cultivars did not differ significantly.

Reducing, nonreducing, and total sugars increased significantly during cold storage; however, the rate of

increase varied among cultivars (Table 4). Glucose content increased by 7.3-fold in 'Atlantic' and by more than 14-fold in 'Superior'. Similarly, the fructose content increased in cold-stored tubers of all cultivars except 'Kennebec', in which it remained unchanged. After cold storage, the sucrose content increased by 3-fold in 'Superior' and more than 2-fold in 'Atlantic' and 'BelRus'; however, in 'Kennebec', the sucrose content did not change significantly.

During cold storage, total sugars increased in all cultivars 2- to 4-fold. 'Superior' accumulated the largest quantity of total sugars in cold storage, followed by 'BelRus', 'Atlantic', and 'Kennebec'.

Reconditioning significantly reduced glucose content by nearly 50% in 'BelRus' and 'Superior' compared to cold-stored tubers. However, reconditioning had no significant effect on glucose concentration in

'Kennebec' and 'Atlantic', whereas fructose content declined only in 'Superior' after reconditioning. Reconditioning also reduced total sugars and sucrose in all cultivars except 'Kennebec'.

A local processor rated the chipping quality of the four cultivars based on chip color from good to poor as follows: 'BelRus', 'Atlantic', 'Superior', and 'Kennebec'.

Discussion

Recent labeling regulations by the U.S. Food and Drug Administration requires that all food products, including horticultural crops, be labelled for nutritional quality, health claims, and waxing material applied to these commodities. The present study examined potato tubers for total and individual sugars, ascorbic acid, and soluble protein content at harvest, after cold storage, and after reconditioning. Cold storage resulted in a significant reduc-

Table 1. Ascorbic acid content of potato tubers at harvest, after cold storage, and after reconditioning.

Cultivar	Harvest	Cold storage	Reconditioned
	(mg/100 g dry wt)		
Atlantic	82.0 c A	44.9 c B	32.7 b C
BelRus	108.4 b A	54.5 b B	31.6 b C
Kennebec	112.3 b A	53.4 b B	35.5 b C
Superior	140.3 a A	70.0 a B	44.1 a C

Potatoes were stored at 3°C for 6 weeks and reconditioned at 25°C for 2 weeks.

Mean separation within columns (lower case letters) and within rows (upper case letters) by Duncan's multiple range test at $P = 0.05$.

Table 2. Soluble protein content of potato tubers at harvest, after cold storage, and after reconditioning.

Cultivar	Harvest	Cold storage	Reconditioned
	(mg·g ⁻¹ dry wt)		
Atlantic	41.5 c A	45.3 ab A	40.4 ab A
BelRus	45.4 ab A	49.3 ab A	40.3 ab B
Kennebec	42.2 bc A	43.0 ab A	42.9 a A
Superior	46.0 a A	49.4 a A	37.7 b B

Potatoes were stored at 3°C for 6 weeks and reconditioned at 25°C for 2 weeks.

Mean separation within columns (lower case letters), and within rows (upper case letters) by Duncan's multiple range test at $P = 0.05$.

Table 3. Specific gravity of potato tubers at harvest, after cold storage, and after reconditioning.

Cultivar	Specific gravity		
	Harvest	Cold storage	Reconditioned
Atlantic	1.097 a B	1.099 a A	1.099 a A
BelRus	1.096 a B	1.097 a B	1.100 a A
Kennebec	1.083 c A	1.092 b A	1.092 c A
Superior	1.091 b C	1.093 b B	1.097 b A

Potatoes were stored at 3°C for 6 weeks and reconditioned at 25°C for 2 weeks.

Mean separation within columns (lower case letters) and within rows (upper case letters) by Duncan's multiple range test at $P = 0.05$.

Table 4. Concentrations of sugars (mg·g⁻¹ dry weight) in potato tubed at harvest, after cold storage, and after reconditioning.

Cultivar	Harvest	Cold storage	Reconditioned
<i>Glucose</i>			
Atlantic	0.4 a B	2.9 c A	3.0 a A
BelRus	0.5 a C	5.6 b A	3.5 a B
Kennebec	0.5 a B	5.3 b A	5.3 a A
Superior	0.7 a C	10.1 a A	5.0 a B
<i>Fructose</i>			
Atlantic	1.3 b B	3.3 b A	2.0 a A
BelRus	0.6 b B	4.2 abA	3.1 a A
Kennebec	3.5 a A	3.3 b A	3.9 a A
Superior	1.5 b B	6.3 a A	3.5 a B
<i>Sucrose</i>			
Atlantic	1.7 a c	3.7 a A	2.5 a B
BelRus	2.6 a B	4.7 a A	2.4 a B
Kennebec	2.6 a A	3.7 a A	3.1 a A
Superior	2.0 a B	5.9 a A	3.1 a B
<i>Total sugars</i>			
Atlantic	3.4 a C	9.9 b A	7.5 b B
BelRus	3.7 a C	13.5 b A	9.0 b B
Kennebec	6.6 a A	12.3 b A	12.3 a A
Superior	4.2 a C	22.3 a A	11.6 a B

^aPotatoes were stored at 3C for 6 weeks and reconditioned at 25C for 2 weeks.

^bMean separation within columns (lower case letters) and within rows (upper case letters) by Duncan's multiple range test at *P* = 0.05.

tion of ascorbic acid content in all cultivars. Temperature and duration of storage influence ascorbic acid loss in storage (Keijbets and Ebbenhorst, 1990; Linneman, et al., 1985). The rate of ascorbic acid loss during cold storage of potatoes invariable. According to some studies, ascorbic acid loss during cold storage occurs more rapidly during the first month than afterwards (Finglas and Faulks, 1984); other studies suggest that losses occur more gradually over the duration of cold storage (Keijbets and Ebbenhorst-Seller, 1990). In contrast, only a few studies examined changes in ascorbic acid during potato reconditioning. Linneman et al. (1985) observed an increase in ascorbic acid content when tubers were stored at 16 and 28C for up to 12 weeks. In this study, ascorbic acid also decreased during cold storage and reconditioning compared to freshly harvested tubers; however, the amount of decline was greater after cold storage than after reconditioning.

Small potato tubers have a higher specific gravity than large ones (Schippers, 1976). Therefore, tubers of similar sizes (about 6.0 cm in diameter) were used in this study to minimize the size effect on specific gravity. Results of this study show that potato cultivars vary in specific gravity at harvest (Table 3). When tuber samples

from this study were tested at a local chipping facility, 'Kennebec' gave the poorest color quality of chips, while 'BelRus' gave the highest quality; chips of 'Atlantic' and 'Superior' were of intermediate quality (data not shown).

Glucose content of tubers at harvest did not correlate with specific gravity. Although there were significant differences among cultivars in specific gravity and chipping quality at harvest, glucose content was not significantly different. Similarly, differences in fructose and sucrose concentrations did not correspond to differences in specific gravity or chipping quality. Neele and Louwes (1989) compared glucose content to chipping quality of 18 potato cultivars using Reflocheck Glucose and Gluko-Test strips (Boehringer, Mannheim, Germany). They found that differences in glucose content did not correspond to differences in chip color.

Glucose and sucrose contents were similar in tubers of 'BelRus' and 'Kennebec' at harvest, yet the chips produced from 'BelRus' were rated by a local processor to have a better color than chips from 'Kennebec' (data not shown). 'BelRus' and 'Atlantic' had the lowest total sugars, the highest specific gravity, and produced better-color-quality chips than the other two cultivars. Data suggest that testing for

an individual sugar, such as glucose or sucrose, may not be a reliable indicator of chipping quality. In this study, we found that specific gravity and total sugars are reliable in predicting the chipping quality of the four cultivars tested.

Sugar accumulation in potato tubers depends on many factors, including duration of the vegetation period and the postharvest temperature treatment (Samotus et al., 1974). The maturity of tubers at harvest is also an important factor influencing sugar accumulation during storage. Physiologically immature tubers accumulate more sugars during cold storage than mature ones (Samotus et al., 1974), which suggests that the accumulated large quantities of glucose and sucrose in tubers of 'Superior' during cold storage could be due to immaturity of the tubers.

Presey and Shaw (1969) reported that 'Kennebec' tubers had only traces of reducing sugars and no fructose at harvest; however, in this study, we found significant quantities of sucrose and fructose in tubers of 'Kennebec' at harvest. The differences could be due to different analytical methods used for sugar determination. During cold storage of 'Kennebec' tubers, the fructose content did not change while the glucose content increased significantly, which suggests that the glucose accumulation in 'Kennebec' could be due to a starch-sugar equilibrium rather than the metabolism of sucrose (Uppal and Verma, 1990). The lack of sucrose metabolism in cold-stored 'Kennebec' might have resulted from the presence of low invertase activity and a large concentration of invertase inhibitors in this cultivar (Pressy and Shaw, 1969).

The results reported here reemphasize the fact that postharvest quality of potato tubers is very responsive to storage temperature. Based on the quality factors that were evaluated, specific gravity and total sugars were better indicators of chipping quality than individual sugars. The four cultivars are ranked in order of best chipping quality as follows: 'BelRus', 'Atlantic', 'Superior', and 'Kennebec'.

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