POTATO COMPOSITION: II. TISSUE SELECTION AND ITS EFFECTS ON TOTAL SUGAR, TOTAL REDUCING SUGAR, GLUCOSE, FRUCTOSE AND SUCROSE CONTENTS

M.L. Weaver, H. Timm,[1] M. Nonaka, R.N. Sayre, R.M. Reeve, R.M. McCready and L.C. Whitehand

Abstract

Total sugar, reducing sugar, glucose, fructose, and sucrose were determined in three parts (bud-end, stem-end, and core) of tubers of White Rose, Red La Soda, Kennebec, Russet Burbank, Norchip and Lenape. Tubers were sampled at harvest, after storage for 2 and 4 mo at 7 C, and after reconditioning for 3 wk at 20 C after each storage period. The quantity of different sugar fractions varied with cultivar and changed with storage treatments. Only sucrose was uniformly distributed among the different parts of the tuber. Except for fructose and sucrose the relationships among different parts of the tuber for distribution of all other sugar fractions varied significantly with cultivar, and these relationships among parts were not significantly changed by temperature, or duration of storage.

Resumen

Azúcares totales, azúcares reductores, glucosa, fructosa y sucrosa se determinaron en tres partes (ápice, base y centro) de tubérculos de White Rose, Red La Soda, Kennebec, Russet Burbank, Norchip y Lenape. Los tubérculos fueron muestreados a la cosecha, después de almacenamiento de 2 y 4 meses a 7° C, y después de re-acondicionar por 3 semanas a 20° C después de cada periodo de almacenamiento. La cantidad de las diferentes fracciones de azúcares variaron con el cultivar y cambiaron con los tratamientos de almacenamiento. Solo la sucrosa estuvo distribuída uniformemente entre las diferentes partes del tubérculo. Con la excepción de fructosa y sucrosa las relaciones de distribución entre las diferentes partes del tubérculo de todas las fracciones de azúcares variaron significativamente con el cultivar y esas relaciones entre partes no fueron cambiadas significativamente con la temperatura o con la duración del almacenamiento.

[1] Department of Vegetable Crops, University of California, Davis, California 95616

Western Regional Research Center, Agricultural Research Service, U.S. Department of Agriculture, Berkeley, California 94710

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Introduction

A uniform light brown finish-fried color is desirable for both French-fried potatoes and potato chips. The late-season, undesirable, dark-brown color in some fried potato products is caused by the charring of free sugars, and/or, more importantly, by a chemical reaction between reducing sugars and certain amino acids (10).

Since the processing season for potatoes spans the entire year, most of the potato crop must be put into cold storage. The low temperature used to maintain the tubers for extended periods of time causes an increase in the sugar content of most cultivars. Consequently, the sugar content may have to be reduced prior to frying. The two methods most often used to reduce sugar content are reconditioning (holding stored tubers at elevated temperatures, usually about 20°C, for several days prior to processing), and leaching (removing surface sugars from cut strips by timed immersion in hot water). Due to differences in varietal responses to reconditioning (3, 8), and the variable response of tissue having certain functional disorders, i.e., sugar-end (20) and translucent-end (13), to leaching in water, neither method is totally effective.

Sucrose, fructose, and glucose are the major sugars in potato tubers, with other sugars present in trace amounts (18). The amount and kind of sugar in a particular cultivar are inherited characteristics (6, 15). Whether this inherited potential for sugar is achieved depends on growing environment, maturity of the tubers at harvest, cultural practices (irrigation, fertilization, etc.), and time and temperature of storage and/or reconditioning (1, 4, 8, 14, 16).

All sugars do not contribute equally to the production of dark-colors during frying. Most research indicates that only the reducing sugar content is related to the final degree of darkening in the finished product (7, 11, 19, 20). However, under certain conditions, sucrose has also been implicated (5). Although it is generally felt that both glucose and fructose contribute to the formation of dark-colored pigments during frying, the extent to which each contributes to the overall problem is still in question. It is not clearly understood whether the concentration of different sugars changes to the same degree in response to external stimuli (fertilization, irrigation, storage and reconditioning), whether the total changes and/or rate of change of sugars in different parts of the tuber are of equal magnitude, and whether the changes are due to genetic control.

The objectives of this study were to investigate: 1) how tissue selection and sampling technique may affect sugar content data and, thus, the interpretation of relationships for sugar content among genetically different tubers; and, 2) how the sugar content of genetically different potato tubers responds to storage and/or reconditioning.

Materials and Methods

Russet Burbank, Kennebec, Norchip, Lenape, White Rose, and Red La Soda potatoes were grown at the University of California, Tulelake Field Station, in Northeastern California. Cultural practices, storage, selection and preparation of tuber for storage and chemical analysis have been previously described (21).

Chemical Analysis

One gram of ground freeze-dried tissue from a specific part of the tuber was placed in a 500 ml beaker with 75 ml of 75% ethanol, and the mixture boiled under reflux for 1 hr on a crude fiber extractor. The ethanol extract was filtered through a Buchner funnel, and the filtrate, after being made to 100 ml with 75% ethanol, was stored at −23 C until analyzed. Extractions were made in triplicate for all samples. Portions, .05 to 8 ml, of each extract were prepared in duplicate and used to determine total sugar, total reducing sugar, glucose, fructose, and sucrose contents (17). All data were statistically analyzed and presented on a dry weight basis.

Results

Table I shows the variables studied and their statistical significance based on analysis of variance procedures applied to data on sugar composition. Subsequent tables show the results of Tukey's multiple comparison test applied to means of the measured variables for effects found significant in Table 1. Cultivars differed significantly in their content of different sugar fractions, and these fractions changed in concentration due to storage treatments. Only sucrose was uniformly distributed throughout the three tuber parts investigated. Relationships among different parts of the tuber for content of the different sugar fractions, except for fructose and sucrose,

TABLE 1. —*Sources of variation and their significance on sugar composition of potato tubers.*

Sources of variation	D.F.	Total Sugars	Reducing sugar	Glucose	Fructose	Sucrose
Cultivar (C)	5	5878**[1]	5657**[1]	1988**[1]	966**[1]	80**[1]
Part (P)	2	483**	623**	281**	175**	12NS
Storage (S)	4	3902**	2375**	617**	948**	215**
C×P	10	223**	217**	124**	41NS	5NS
C×S	20	202**	157**	51**	70**	31**
P×S	8	45NS	28NS	14NS	24NS	14NS
C×P×S	40	28	27	15	25	6

[1]** = Significant effect at the 0.01 probability level.
NS = at the 0.05 probability level.

were dependent upon the the specific cultivar, but were not changed for any of the sugar fractions, in any of the cultivars, by storage treatments.

Sugar Content in Different Parts of Potato Tubers

Total Sugar Content–As shown in Table 2, total sugar content was not significantly different among the 3 parts of Russet Burbank or Lenape tubers. Total sugar content of bud-end and stem-end tissue was similar in tubers of Kennebec and Red La Soda and was significantly less at either end than in the core tissue of either of these cultivars. Bud-end and core tissue of White Rose were similar in total sugar content and higher than stem-end tissue. In Norchip, stem-end tissue had more total sugar than bud-end tissue, and total sugar content in core tissue was not significantly different from that in tissues at either end of the tuber.

The relationships among cultivars for total sugar content differed significantly when compared using tissue from different parts of the tuber (Table 2).

TABLE 2. — *Total sugar content in 3 parts of tubers of 6 potato cultivars.*

Part of[2] tuber	Cultivar[1]					
	White Rose	Red La Soda	Kennebec	Russet Burbank	Lenape	Norchip
	Total Sugar (mg/g dry wt)					
Bud	51 aw	46 bw	34 bx	28 ax	16 ay	17 b y
Core	54 aw	57 aw	41 ax	24 ay	15 az	21 abyz
Stem	40 bw	44 bw	29 bx	23 axy	17 ay	24 axy

[1] Means for each part of the tuber for each cultivar not having a common letter (a, b), are different at the .05 level of significance.
[2] Means for cultivars not having a common letter (w to z) for each part of the tuber analyzed, are different at the .05 level of significance.
Means for total sugar content for each cultivar for each tuber part were calculated after combining data from all storage treatments.

Reducing Sugar Content – The relationships among different parts of the tuber for reducing sugar content (Table 3) within each cultivar were identical to what they were for total sugar content (Table 2) for each of the 6 cultivars.

The relationships among cultivars for reducing sugar content differed significantly when compared using tissue from different parts of the tuber (Table 3). White Rose and Red La Soda, consistently had more reducing sugar than the other cultivars, regardless of which part of the tuber was analyzed.

Glucose – Glucose content was similar in tissues of the 3 parts of Norchip, Kennebec and Lenape (Table 4). Bud-end tissue of White Rose

TABLE 3. — *Reducing sugar content in 3 parts of tubers of 6 potato cultivars.*

Part of[2] tuber	Cultivars[1] White Rose	Red La Soda	Kennebec	Russet Burbank	Lenape	Norchip
	Reducing sugar (mg/g dry wt)					
Bud	42 aw	35 bx	27 by	21 ay	5 az	7 b z
Core	46 aw	46 aw	34 ax	18 ay	7 az	11 abyz
Stem	29 bvw	33 bv	23 bwx	17 axy	8 az	14 a yz

[1] Means for the different parts of the tuber for each cultivar not having a common letter (a or b), are different at the .05 level of significance.
[2] Means for cultivars not having a common letter (v to z) for each part of the tuber sampled, are different at the .05 level of significance.
Means for reducing sugar content of each variety for each tuber part were calculated after combining data from all storage treatments.

TABLE 4. — *Glucose content in 3 parts of tubers of 6 potato cultivars.*

Part of[2] tuber	Cultivars[1] White Rose	Red La Soda	Kennebec	Russet Burbank	Lenape	Norchip
	Glucose (mg/g dry wt)					
Bud	26 aw	19 bx	14 axy	12 a y	3 az	3 az
Core	25 aw	25 aw	15 ax	8 aby	3 ay	4 ay
Stem	12 bx	19 bw	11 axy	6 byz	3 az	5 az

[1] Means for each part of the tuber for each cultivar not having a common letter (a or b), are different at the .05 level of significance.
[2] Means for cultivars not having a common letter (w to z) for each part of the tuber sampled, are different at the .05 level of significance.
Means for glucose content of each tuber part was calculated after combining data from all storage treatments.

had more glucose than stem-end tissue, but was similar in glucose content to that of core tissue. In Russet Burbank, bud-end tissue also had more glucose than stem-end tissue, but glucose content of core tissue was not significantly different from that of tissue at either end of the tuber. In Red La Soda, stem- and bud-end tissues were identical in glucose content, and both end tissues had significantly less glucose than core tissue.

The relationships among cultivars for glucose content differed significantly when cultivars were compared using tissue from different parts of the tuber (Table 4).

Fructose – For all cultivars, core tissue had significantly more fructose (13.7 mg/g dry wt) than either bud-end (10.3 mg/g dry wt) or stem-end (11.3

mg/g dry wt) tissues. Fructose contents of tissues at the two ends of the tuber were not significantly different.

Sucrose – Sucrose content was similar in bud-end, stem-end and core tissues, and this uniformity was found in tubers of all cultivars tested (Table 1).

Effects of Storage on Sugar Composition

In this study, there were significant differences in sugar content among cultivars in response to storage treatments (Table 1).

Total and Reducing Sugars

Only tubers of White Rose and Lenape failed to increase significantly in total (Table 5) and reducing sugars (Table 6) during the first 2 mo of storage at 7 C. During the second 2 mo of storage (4 mo at 7 C), thc total sugar content increased in White Rose and Kennebec, decreased in Norchip, and did not significantly change in Russet Burbank, Lenape and Red La Soda (Table 5). Reducing sugar content significantly increased only in Kennebec during the second 2 mo at 7 C (Table 6). The reducing sugar content of the other cultivars was not changed by a second 2 mo of storage.

Reconditioning at 20 C, after either 2 or 4 mo storage at 7 C, resulted in a significant reduction in total sugars (Table 5) in all cultivars and a similar decrease in reducing sugars (Table 6) for all cultivars except Lenape.

TABLE 5. — *Total sugar content of potato tubers at harvest, after 2 and 4 mo storage at 7 C, and after reconditioning 3 wk at 20 C after storage.*

Storage[2] treatment	Cultivars[1] Red La Soda	White Rose	Kennebec	Russet Burbank	Lenape	Norchip
	Total sugar (mg/g dry wt)					
At harvest	46 b w	50 abw	29 c x	20 bxy	18 aby	13 cy
After 2 mo at 7 C	60 a w	49 b x	48 b x	35 ay	21 a z	41 axy
After 2 mo at 7 C + 3 wk at 20 C	36 cw	40 c w	15 d x	15 bx	8 c x	10 cx
After 4 mo at 7 C	58 a w	58 a w	59 a w	37 ax	22 ay	30 bxy
After 4 mo at 7 C + 3 wk at 20 C	44 bcw	44 bcw	22 cdx	17 bxy	11 bcy	11 cy

[1] Means for different storage treatments for each cultivar not having a common letter (a to d), are different at the .05 level of significance.

[2] Means for cultivars not having a common letter (w to z) for each storage treatment, are different at the .05 level of significance.

Means of total sugar content for each variety in each storage treatment were calculated after combining data from bud-end, stem-end and core tissues.

TABLE 6. —*Reducing sugar content of potato tubers sampled at harvest, after 2 and 4 mo storage at 7 C, and after reconditioning 3 wk at 20 C following storage.*

Storage[2] treatment	Cultivars[1] White Rose	Red La Soda	Kennebec	Russet Burbank	Lenape	Norchip
	Reducing sugars (mg/g dry wt)					
At harvest	40 bcw	36bw	23 c x	15 bxy	9 ay	7 by
After 2 mo at 7 C	41 abw	45 aw	38 b w	27 ax	8 ay	23 ax
After 2 mo at 7 C + 3 wk at 20 C	32 c w	29 bw	12 d x	10 bx	3 ax	4 bx
After 4 mo at 7 C	49 a w	45 aw	51 a w	30 ax	10 ay	17 ay
After 4 mo at 7 C + 3 wk at 20 C	34 bcw	35 bw	15 cdx	11 bxy	4 ay	5 by

[1] Means for different storage treatments for each cultivar not having common letter (a to d) are different at the .05 level of significance.
[2] Means for cultivars not having a common letter (w to y) for each storage treatment are different at the .05 level of significance.
Means of reducing sugar content for each variety in each storage treatment were calculated after combining data from bud-end, stem-end and core tissues.

When compared for the quantity of total or reducing sugars in tubers, the relationship among cultivars were significantly different with storage treatments and identical only in tuber tissue taken at harvest, and after 3 wk of reconditioning at 20 C following 4 mo of storage at 7 C (Tables 5 and 6).

Fructose and Glucose – Only White Rose and Lenape did not significantly increase in fructose from harvest through 2 mo of storage at 7 C (Table 7). Glucose did not change during the first 2 mo at 7 C in 5 cultivars, and significantly decreased in Kennebec (Table 8). No significant change in fructose content (Table 7) in any of the cultivars and a significant increase of glucose content only in White Rose and Kennebec (Table 8) occurred during the second 2 mo of storage. After 4 mo at 7 C only Kennebec had significantly more fructose (Table 7), and Kennebec and Russet Burbank more glucose (Table 8) than at harvest.

When compared for fructose content, the relationships among cultivars differed significantly with each storage treatment (Table 7). When compared for glucose content, the significant relationships among cultivars were identical only after reconditioning tubers for 3 wks at 20 C following storage at 7 C for 2 and 4 mo (Table 8).

Significant reductions in fructose due to reconditioning were found in tubers of Norchip, Kennebec and Red La Soda after 2 mo at 7 C and only in Kennebec after 4 mo at 7 C (Table 7). Significant reductions in glucose due

TABLE 7. —*Fructose content of potato tubers at harvest, after 2 and 4 mo storage at 7 C, and after reconditioning 3 wk at 20 C following storage.*

Storage[2] treatment	Cultivars[1] White Rose	Red La Soda	Kennebec	Russet Burbank	Lenape	Norchip
	Fructoe (mg/g dry wt)					
At harvest	19 aw	12 b wx	7 bxy	5 b xy	5 axy	3 b y
2 mo at 7 C	22 awx	24 a wx	29 aw	16 a x	7 ay	17 a x
2 mo at 7 C + 3 wk at 20 C	15 aw	13 b wx	6 bxy	8 abwxy	2 ay	2 b y
4 mo at 7 C	22 aw	20 abwx	24 aw	13 abxy	5 ay	10 aby
4 mo at 7 C + 3 wk at 20 C	14 awx	17 abw	8bxy	6 b xy	3 ay	4 b y

[1] Means for different storage treatments for each cultivar not having a common letter (a to c), are different at the .05 level of significance.
[2] Means for cultivars not having a common letter (w to y) for each storage treatment, are different at the .05 level of significance.
Means for each variety in each storage treatment were calculated after combining data from bud-end, stem-end and core tissues.

TABLE 8. —*Glucose content of potato tubers at harvest, after 2 and 4 mo storage at 7 C and after 3 wk at 20 C following storage.*

Storage[2] treatment	Cultivars[1] White Rose	Red La Soda	Kennebec	Russet Burbank	Lenape	Norchip
	Glucose (mg/g dry wt)					
At harvest	22 abwx	24 a w	16 bx	9 bcy	5 ay	4 ay
2 mo at 7 C	20 b w	22 abw	9 cx	11 abx	2 ay	5 axy
2 mo at 7 C + 3 wk at 20 C	17 b w	16 b w	6 cx	3 c x	1 ax	1 ax
4 mo at 7 C	28 a w	25 a w	27 aw	17 a x	4 ay	7 ay
4 mo at 7 C + 3 wk at 20 C	20 b w	19 abw	7 cx	4 c x	1 ax	2 ax

[1] Means for different storage treatments for each cultivar not having a common letter (a to c), are different at the .05 level of significance.
[2] Means for cultivars not having a common letter (w to y) for each storage treatment, are different at the .05 level of significance.
Means of glucose content for each cultivar of each storage treatment were calculated after combining data from bud-end, stem-end and core tissue.

to reconditioning were found only in Russet Burbank after 2 mo at 7 C and in White Rose, Kennebec and Russet Burbank after 4 mo at 7 C (Table 8).

Sucrose – In tubers of White Rose and Russet Burbank the quantity of sucrose was not significantly changed by storage at 7 C, or by reconditioning for 3 wk at 20 C. (Table 9) Sucrose content was increased in Norchip and Red La Soda by holding tubers for 2 mo at 7 C. Sucrose content did not significantly change between 2 and 4 mo of storage at 7 C in tubers of any of the cultivars. In the cultivars where reconditioning for 3 wk at 20 C following storage at 7 C reduced the sucrose content, the reduction was only to a concentration similar to that at harvest.

When compared for sucrose content, the relationships among cultivars differed significantly with storage treatment (Table 9).

TABLE 9. — *Sucrose content of 6 potato varieties in tubers sampled at harvest, after 2 and 4 mo at 7 C, and after 3 wk at 20 C following each storage period.*

Storage[2] treatment	Cultivars[1] White Rose	Red La Soda	Kennebec	Russet Burbank	Lenape	Norchip
			Sucrose (mg/g dry wt)			
At harvest	10 aw	10 bcw	6 abw	6 aw	9 abw	6 bw
2 mo 7 C	8 az	15 a wx	10 a yz	8 az	13 a xy	18 aw
2 mo at 7 C + 3 wk at 20 C	9 aw	7 c wx	4 b x	5 awx	6 b wx	6 bwx
4 mo at 7 C	9 axy	13 abwx	9 a xy	8 ay	12 a wxy	14 aw
4 mo at 7 C + 3 wk at 20 C	11 aw	9 bcwx	7 abwx	7 awx	7 bwx	6 bx

[1] Means for different storage treatments for each cultivar not having a common letter (a to b), are different at the .05 level of significance.
[2] Means for cultivars not having a common letter (w to z) for each storage treatment, are different at the .05 level of significance.
Means of sucrose content for each variety in each storage treatment were calculated after combining data from bud-end, stem-end and core tissues.

Discussion

The composition of potato tubers can vary in different areas of production, among tubers on the same plant (9), and in tissues from different parts of each tuber (2, 12, 20). If tubers were uniform in sugar content from end to end, and from skin to core, then adjustments in techniques used to manufacture a uniformly-colored fried potato product would be greatly simplified. However, each strip, throughout its length, may reflect the extremes in sugar concentration in the different parts of the tuber from which it was cut. Since it is impossible to modify a specific sugar removal process so that it would be effective on only those parts of each strip that contain the undesired levels of sugar, the overall treatment applied must be one that will handle the areas with the highest sugar content. However, such a treatment often results in over-processed potatoes. For this reason, the geneticist must search for, or develop, cultivars which have more uniform distribution of sugars.

Certain conclusions can be drawn from this study concerning the sugar content of potato tubers. 1) All potatoes, either established cultivars or new breeding selections, should be carried through preliminary screening to determine the kind and quantity of sugars present. This includes exposing tubers to the variations in environment and to the cultural and storage practices to which they are likely to be subjected commercially. 2) If the amount of a particular sugar, or a mixture of sugars is to be studied for its relationship to a specific processing problem, or product, the distribution of sugar content among different parts of the tuber should be determined. The stability of relationships for distribution of sugars among different parts of the tuber for a particular cultivar, under all storage conditions (Table 1), provides a means of estimating their concentration in other parts of the tuber by determining the concentration in only one part. Whether these relationships for distribution of sugar content among parts of the tuber of a particular cultivar during storage remain constant from year to year, and from location to location, has yet to be determined. 4) Once the tuber part to be studied is chosen, extreme care must be taken to assure that only tissue from that particular part is used for all comparisons. Since differences in all sugar fractions, except sucrose, were found among parts of tubers of many of the cultivars tested, careless removal of tissue can result in the inclusion of varying amounts of tissue from adjoining areas. Analysis of the composite of tissue could then result in large differences in the quantity of a specific sugar when compared to the analysis for the same sugar in tissue that was not carefully taken from only one specified part of the tuber. The inaccurate data could result in discarding desirable breeding selections, or retaining less desirable selections, which would then be carried through nonproductive, expensive, and time-consuming commercial evaluations.

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