EFFECT OF VARIETY AND HARVEST DATE ON TUBER SUGARS AND CHIP COLOR[1]

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Abstract

The major tuber sugars — glucose, fructose and sucrose — in tubers of the Red Pontiac, Kennebec and Monona potato varieties harvested five times during the 1970 growing season were determined quantitatively by a gas-liquid chromatographic technique. Also, chips were made from tubers and chip color was measured objectively and reported as Rd values. Red Pontiac tubers produced the darkest-colored chips (Rd-15.5), and its tubers tended to accumulate the highest levels of the three sugars. The major difference between Monona, which produced chips with the lightest color (Rd-21.1), and Kennebec (Rd-19.5) was the very low level of glucose found in the tubers of Monona.

Varieties produced chips lightest in color at the second (8/31) or third (9/15) harvest dates. Conversely, darkest-colored chips were obtained from each variety at the fourth harvest date (9/28). This was attributed to the cool, wet weather. Sugar content also varied during the harvesting schedule. Glucose content changed little until late in the season when an increase occurred. Fructose tended to decline until the final harvest when a distinct increase was obtained. Sucrose declined significantly through the third harvest, but changed little thereafter.

Resumen

Se determinó el contenido de glucosa, fructosa, y sacarosa en tubérculos de papa de los cultivares Red Pontiac, Kennebec, y Monona, provenientes de 5 épocas de cosecha en 1970. El contenido de azúcar fué medido por cromatografía de gas y líquido y el calor de los chips por Rd (reflectancia). Los tubérculos de Red Pontiac produjeron los chips más oscuros (Rd-15.5) y fueron los de mayor contenido de azúcar. Monona produjo chips más claros (Rd-21.1) que Kennebec (Rd-19.5) y tuvieron menos glucosa.

El color de los chips se hizo más claro hasta la tercera cosecha y luego declinaron severamente en las 2 últimas cosechas, debido probablemente al clima frío y húmedo. El contenido de azúcar también varió durante la estación. La glucosa fue estable hasta el fin de la estación. La fructosa

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declinó hasta la cosecha final donde se incrementó muy claramente. La sacarosa declinó significativamente hasta la tercera cosecha, pero no cambió en adelante.

Introduction

Since color is a very important visual criterion for marketing potato chips, chip color has long been of major concern to the chipping industry. Previous research has established that chip browning is primarily the result of Maillard browning reactions between tuber constituents, especially sugars and free amino acids, during the frying operation (6). Tuber composition, however, is influenced by a number of factors including variety, tuber maturity and tuber temperature (14). The inherent differences which exist with respect to chip color among the many varieties are well documented, and processors prefer varieties that are best suited to the production of light chips. While the effect of tuber maturity on chip color is less certain, there is evidence that immature tubers may chip darker than mature tubers (14).

To correlate chip color with tuber composition, previous research has concentrated on total reducing sugar content. Few data are available on the levels of the major individual sugars, i.e., glucose, fructose and sucrose, in known poor and good chipping varieties. In addition, the change in the levels of the major tuber sugars during the harvesting period has not been well established. Hence, this investigation was initiated with the objectives as follows: 1) to determine the glucose, fructose and sucrose content of selected varieties known to produce chips with poor to good color; 2) to evaluate the effect of harvest date on varietal chip color and tuber sugar content.

Materials and Methods

The varieties chosen for this study were: Red Pontiac, an unacceptable chipper; Kennebec, an acceptable chipper; and Monona, an acceptable chipper (recently released, 1965). Potato varieties were grown at the Pennsylvania State University Agronomy Research Farm near Rock Springs, Pa. (Centre County) in 1970. The field design employed was a split plot with 3 replications; varieties were considered the main plots and harvest dates were treated as subplots.

Tubers were harvested by hand 5 times during the growing season at about 15-day intervals starting August 17, 105 days after planting (Table 1). At each harvest approximately 11 kg (25 lb) of tubers were dug from each replicated plot. After sizing, tubers from 4.7 to 7.8 cm (1⅞ to 3⅛ in) in diameter were selected, washed in a rotary washer and air dried. Chips were made and samples prepared for analysis within 8 hr of harvest.

TABLE 1.—*Chip color and tuber sugar levels for 3 potato varieties at 5 harvests in 1970. (Values are the means of 3 replications).*

Variable[1]	Variety[2]	Harvest No., Date, and Days After Planting				
		1 8/17-105	2 8/31-119	3 9/15-134	4 9/28-147	5 10/14-163
Chip color	Red Pontiac	17.6	17.3	18.1	10.6	13.9
	Kennebec	20.4	21.8	18.4	16.6	20.2
	Monona	19.2	20.7	28.0	16.5	21.0
Glucose	Red Pontiac	0.11	0.21	0.18	0.51	0.75
	Kennebec	0.26	0.21	0.24	0.29	0.39
	Monona	0.07	0.05	0.07	0.07	0.06
Fructose	Red Pontiac	0.88	0.88	0.17	0.13	1.45
	Kennebec	0.72	0.98	0.35	0.26	1.04
	Monona	0.67	0.74	0.40	0.05	1.16
Sucrose	Red Pontiac	2.78	2.11	1.55	1.76	1.86
	Kennebec	1.25	0.46	0.45	0.57	0.54
	Monona	0.75	0.75	0.55	0.68	0.51

[1]Chip color determined as Rd units; sugars, as g/100 g potato tissue (dry basis).
[2]Significance of variety x harvest — chip color, NS; glucose, at the 1% level; fructose, NS; sucrose, at the 1% level.

From the tubers retained for each replicate, a random sample of approximately 12 potatoes was selected for chipping and chemical analysis. A stainless steel tube, 0.8 cm (5/16 in) i.d., was used to remove a plug of tissue from each tuber; the remainder of the tuber was used for making chips. Tissue plugs comprising a sample were combined, weighed (ca 50g) and blended with 110 ml absolute ethanol in an Omnimixer homogenizer at 15,000 rpm for 5 min. The resultant slurry was held in a water bath maintained at 78°C for 1.5 hr. After cooling, the slurry weight was adjusted to 200 g with distilled water and the weight of tissue per gram of slurry was calculated. Aliquots of the slurry were used for the determination of total solids and sugars. Total solids were obtained by pipetting a weighed portion of slurry into a tared aluminum moisture dish, evaporating to near dryness on a hot plate and heating at 70°C for 6 hr in a vacuum oven (50 mm Hg). The percent solids was calculated from the weight of the dried residue. Sugars are reported as g/100 g of potato tissue on the dry basis.

Samples were prepared for sugar analysis by filtering a weighed portion of slurry through hardened filter paper using suction and diluting the filtrate to a known volume with distilled water. A 2.0 ml aliquot of this solution was freeze-dried in a 3 dram vial and stored in a desiccator at -30°C for subsequent analysis.

The method employed for the separation, identification and quantification of glucose, fructose and sucrose was essentially that of Sweeley, *et al.* (13). This procedure includes formation of volatile

trimethylsilyl (TMS) ethers of the sugars and separation by a gas-liquid chromatographic technique. TMS-sugar ethers were prepared by dissolving the dried material in 0.5 ml anhydrous pyridine and adding, in order, 0.1 ml hexamethyldisilazane and 0.05 ml trimethylchlorosilane. The vial was sealed with a cap fitted with a Teflon liner, shaken vigorously for 30 sec and allowed to stand at room temperature for 5 minutes. Approximately 1 ul of the solution was injected into a Varian Aerograph 1840-4 gas chromatograph equipped with a flame ionization detector. Separation of the TMS-sugars was accomplished using a 150 cm (5 ft) x 0.3 cm (1/8 in) stainless steel column packed with 3% SE-30 on 100/120 mesh Variport 30. The oven temperature was programmed from 160 to 260°C at 4°/min with a carrier gas (N_2) flow of 30 ml/min and an injector port temperature of 280°C. Identification of the sugars was made by comparing the retention times of the sample sugars with pure TMS-sugars. Quantification was achieved by means of an internal standard (sorbitol) of which a known quantity was added to the potato-alcohol mixture immediately before blending.

Potato chips were prepared for color evaluation by first peeling sample tubers (minus tissue plugs) in an abrasion peeler, cutting into slices 0.15 cm (1/16 in) thick and deep frying in fresh corn oil at 190°C until dehydration was essentially complete. Chip color was determined objectively as Rd (reflectance) units or values on a Gardner Automatic Color Difference Meter previously standardized with a specially prepared ceramic tile (Rd-61.5).

Data were analyzed as a factorial experiment by an analysis of variance computer program and main effect means associated with a significant source of variation were separated by Duncan's modified (Bayesian) least significant difference test.

Results

Effect of Variety at Five Harvest Dates

Means for chip color and tuber sugar levels for each of the three potato varieties at five harvest dates during the 1970 growing season are shown in Table 1.

Chip Color—Excepting the fourth harvest, there were only small varietal differences in the color of chips made from tubers for all harvest dates. Potato chips from tubers at Harvest 4 were much darker than chips from tubers at the other four harvests. Lightest-colored chips were obtained at each harvest date for Monona and Kennebec.

Sugars—Mean glucose levels for each variety indicated little change in the level of this sugar through the first three harvest dates. Except Monona, between Harvests 3 and 4 an increase in glucose was obtained which continued through the final harvest. The accumulation of glucose during the latter stages of plant maturity resulted in tubers from Harvest 5

containing significantly higher amounts than contained in tubers from the first four harvests.

Marked varietal differences existed with respect to glucose accumulation. Monona tubers exhibited little change in glucose throughout the entire growing season. Glucose in Kennebec was relatively consistent until Harvest 5 when it increased markedly. In Red Pontiac glucose appeared to increase slightly from Harvest 1 through 3 followed by large increases in Harvests 4 and 5.

Notable varietal differences in fructose levels, too, were found among harvest dates. High fructose concentrations at Harvests 1 and 2 declined significantly at Harvests 3 and 4. However, by Harvest 5 fructose increased to a very high level which was significantly higher than found in varietal tubers from any of the previous harvests.

A significant and steady decline in varietal sucrose levels occurred from Harvest 1 through 3, followed by slight increases at subsequent harvests. Overall, a significant reduction in sucrose occurred between the first and the fifth harvest dates.

Effect of Variety

In Table 2 is shown the means for chip color and tuber sugars for each of the three potato varieties in 1970.

TABLE 2.—*Chip color and tuber sugar levels for 3 potato varieties in 1970. (Values are the means of 3 replications and 5 harvests).*

Variable[1]	Variety		
	Red Pontiac	Kennebec	Monona
Chip color	15.5 a[2]	19.5 b	21.1 b
Glucose	0.35 a	0.28 a	0.06 b
Fructose	0.70 a	0.67 a	0.60 a
Sucrose	2.01 a	0.66 b	0.65 b

[1]Chip color determined as Rd units; sugars, as g/100 g potato tissue (dry basis).

[2]Means followed horizontally by the same letter are not significantly different at the 1% level according to Duncan's modified (Bayesian) least significant difference test.

Chip Color—Chips from Red Pontiac (Rd-15.5) were significantly darker than chips made from either Kennebec (Rd-19.5) or Monona (Rd-21.1). Differences in chip color between Monona and Kennebec were not significant although chips made from the former were slightly lighter in color.

Sugars—The glucose content of Monona tubers, 0.06 g/100 g, was much lower than found in the other varieties. While Red Pontiac tubers contained 25% more glucose than Kennebec tubers, the difference was statistically nonsignificant.

Tuber fructose level was highest in Red Pontiac (0.70 g/100 g) and lowest in Monona (0.60 g/100 g); however, differences among varieties were not significant.

Kennebec and Monona tubers contained equivalent amounts of sucrose (ca 0.65 g/100 g) while Red Pontiac tubers accumulated a much greater quantity (2.01 g/100 g) of this disaccharide.

Effect of Harvest Dates

Means for chip color and tuber sugar levels at the five harvest dates in 1970 are presented in Table 3.

TABLE 3.—*Chip color and tuber sugar levels at 5 harvests in 1970. (Values are the means of 3 replications and 3 varieties).*

	Harvest No., Date, and Days After Planting				
Variable[1]	1 8/17-105	2 8/13-119	3 9/15-134	4 9/28-147	5 10/14-163
Chip color	19.1 a[2]	19.9 a	21.5 a	14.6 b	18.4 a
Glucose	0.15 a	0.16 a	0.16 a	0.29 ab	0.40 b
Fructose	0.76 a	0.87 a	0.31 b	0.15 b	1.22 c
Sucrose	1.59 a	1.11 b	0.85 c	1.00 bc	0.97 bc

[1]Chip color determined as Rd units; sugars, as g/100 g potato tissue (dry basis).
[2]Means followed horizontally by the same letter are not significantly different at the 1% level according to Duncan's modified (Bayesian) least significant difference test.

Chip Color—A gradual, but nonsignificant improvement in chip color occurred between the first and third harvests. However, at the fourth harvest date darkest-colored chips were obtained. Tubers from Harvest 5 produced chips which were significantly lighter than Harvest 4 chips, but slightly darker than chips made from the three earlier harvested tubers.

Sugars—Tuber glucose concentrations remained constant through the first three harvests, but a marked increase occurred near the end of the harvesting schedule.

A significant difference in tuber fructose was not noted between Harvests 1 and 2. However, tubers from the third and fourth harvests contained significantly less fructose than was found in early harvested tubers. By Harvest 5, fructose had increased to a level which was significantly higher than found in tubers from any of the four preceding harvests. Sucrose declined significantly through the third harvest, but differences among the third, fourth and fifth harvest dates were not significant.

Discussion

Since the varieties in this study were chosen intentionally to obtain chips with poor to good color, the reported chip color values were not surprising. Although some varieties including Kennebec and Monona usually produce light chips at harvest, Red Pontiac has been shown to produce unacceptably dark chips at all times (2, 3, 14).

Results of sugar analysis indicated that the glucose concentration was highest in Red Pontiac, the darkest-colored chipper, and lowest in Monona, the variety producing the lighest-colored chips. Lee, *et al.* (4)

found more than twice as much glucose in Norgold Russet, a dark chipping variety, than in the acceptable chipper, Kennebec. Also, Samotus and Schwimmer (8) detected higher levels of glucose in a poor chipping variety, White Rose, than in Kennebec.

Considering fructose, Lee, *et al.* (4) found no difference between Kennebec and Norgold Russet while Samotus and Schwimmer (8) found White Rose tubers contained only slightly more fructose than Kennebec tubers. The results of this experiment demonstrated no significant difference in fructose content of the varieties studied although Red Pontiac appeared to accumulate slightly more fructose than Monona tubers.

The finding that the poorest chipping variety, Red Pontiac, contained three times as much sucrose as did Kennebec or Monona tubers corroborates previous reports that dark chipping varieties inherently accumulate more sucrose than light chippers (2, 3, 8, 10).

A comparison of tuber sugar levels with chip color indicated that dark chips were associated primarily with the high glucose concentrations. Thus, the poorest chipper, Red Pontiac, contained almost six times as much glucose as Monona, the lighest-colored chipping variety. However, the suggested importance of glucose to chip browning does not explain the significant difference in color between Red Pontiac and Kennebec chips since these two varieties contained nearly equal amounts of glucose. But, it is possible that the color difference noted was related to their sucrose content (Table 2) as it has been demonstrated that sucrose, through hydrolysis during frying, can exert a significant effect on chip color (10).

The improvement in chip color noted through the third harvest is possibly a reflection of increased tuber maturity as suggested by several investigators (5, 14). Furthermore, the significant decline in color obtained at Harvest 4 was probably related to the cool, wet weather that prevailed immediately before harvest. Two days before harvest, 0.75 inches of rainfall was recorded, and for the same period minimum air temperatures were the lowest (ca 2°C) experienced during the entire harvesting schedule. Numerous investigators have reported on the adverse effects of low air and/or soil temperatures on chip color (5, 14, 15).

Previous research has demonstrated that reducing sugars usually decrease during tuber maturation, but can increase to relatively high levels if the tubers are exposed to low temperatures (8, 11, 12). Data obtained in this study indicated that of the two major reducing sugars, glucose appeared to be less responsive than fructose to tuber maturation and temperature changes. Glucose changed little until very late in the harvesting schedule when soil temperatures began to decline. Fructose levels tended to decrease through the fourth harvest, but increased to a very high level by the final harvest. Both Samotus and Schwimmer (8), and Schwimmer, *et al.* (9) observed that fructose is more responsive than glucose to temperature changes.

The gradual loss of sucrose during tuber maturation has been reported by several investigators (1, 8, 11, 12). A similar trend was found in this study except that near the end of the harvest schedule little change in sucrose occurred. Pressey (7) reported tuber sucrose synthetase favors sucrose cleavage and that the level of this enzyme in fully mature tubers is only a fraction of that in the developing tuber. It is probable that our findings were, too, a reflection of sucrose synthetase activity during the harvesting schedule.

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