Short Communication

Changes in Color and Sugar Content of Yellow-Fleshed Potatoes Stored at Three Different Temperatures

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ABSTRACT

Yellow-fleshed potatoes, Yukon Gold, Red Gold, Saginaw Gold, Augsberg Gold, and AO82283.1 were compared to white-fleshed cultivars, Russet Burbank and Norchip, in relation to flesh color and sugar content during long-term storage. Yellow-fleshed cultivars had higher hue angles (h°) and chroma values (C*) compared to the white-fleshed potatoes. These values were consistently higher at all storage temperatures. Chroma values were maximum for most yellow-fleshed tubers when stored at 8.3 C for 84 days. As expected, lower concentrations of sucrose, glucose, and fructose were observed in tubers stored at 10 C compared to those stored at 3.3 and 8.3 C. After storage at either 3.3 or 8.3 C, Saginaw Gold, Augsberg Gold, and AO82283.1 accumulated lower amounts of glucose or fructose compared to Norchip, Russet Burbank, Yukon Gold, and Red Gold. Although the yellow-fleshed clones accumulated up to 7.4 mg/g glucose or fructose when stored at 3.3 C, Saginaw Gold and Augsberg Gold responded well to reconditioning.

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INTRODUCTION

“Specialty potatoes” are those with blue, purple, yellow, orange, or even red flesh color. Although specialty cultivars have been considered to be of little economic value to processors, consumer and grower interest has increased (Sorensen and Holcomb 1992). The yellow or orange hues of these cultivars are due to the presence of carotenoids, primarily the oxygenated forms known as xanthophylls (Brown et al. 1993). Yellow-fleshed cultivars that have been released for fresh and possible processing uses include Yukon Gold, Red Gold, Saginaw Gold, and Augsberg Gold (Johnston and Rowberry 1981; Coffin et al. 1988; 1989).

A key attribute of cultivars destined for processing is the ability to maintain a low concentration of sugars during long-term storage. While storage of potatoes at low temperatures minimizes problems due to sprouting or diseases, tubers will accumulate reducing sugars, primarily glucose and fructose. This is of concern to processors because elevated concentrations of reducing sugars yield unacceptable dark color and/or off-flavor fried products (Pritchard and Adam 1994). Since reducing sugar accumulation differs between cultivars (Loiselle et al. 1990; Herrman et al. 1996), the objective of this research was to determine changes in color and sugar content of several yellow-fleshed potatoes during long-term storage at different temperatures. Furthermore, the response of the yellow-fleshed tubers to reconditioning after low-temperature storage was also evaluated.

MATERIALS AND METHODS

Harvesting and Storage

Seven potato cultivars were evaluated in this study; two white-fleshed cultivars (Norchip and Russet Burbank) and five yellow-fleshed cultivars/clone (Yukon Gold, Red Gold, Saginaw Gold, Augsberg Gold, and AO82283.1). Clone AO82283.1 was obtained from the USDA/ARS potato culture collection located in Prosser, WA. While Saginaw Gold was grown on a 0.1-ha field near Idaho Falls, ID, all others were obtained from a commercial farm near Pasco, WA. Growing time prior to harvest varied between Saginaw Gold (108 days), Norchip, Yukon Gold, and Red Gold (137 days), and Russet Burbank, Augsberg Gold, and AO 82283.1 (169 days). All potatoes were packed in burlap bags and transported to Washington State University (Pullman) for storage and analysis.

Upon arrival, tubers were placed in refrigerated rooms maintained at 3.3, 8.3, or 10 C (90 to 95% RH). Samples (10 kg) were removed for flesh color and sugar analysis after 84 days. Those tubers of round shape suitable for chipping (Norchip, Yukon Gold, Red Gold, Augsberg Gold and Saginaw Gold) stored at 3.3 C for 42 days were reconditioned by increasing the storage temperature to 21 C for an additional 28 days before analysis.

Color Analysis

Three tubers were cut in half along the latitudinal axis and cylindrical plugs were removed from the stem portion using a stainless steel 2.2-cm boring tube. A transverse cut was made in the plug approximately halfway between the center of the potato and the skin. The cut plugs were placed in Petri dishes and L*, a*, and b* were measured using a Minolta colorimeter (Model CM 2002, Minolta Camera Co. LTD, Japan), with measurements replicated five times. L* refers to lightness and ranges from black (L* = 0) to white (L* = 100) while a* (+a* = red; -a* = green) and b* (+b* = yellow; -b* = blue) represent coordinates for hue. From these values, chroma (C*) and hue angles (h°) were calculated based on $C^* = (a^{*2} + b^{*2})^{0.5}$ and h° = arctangent b*/a*. While h° is useful to quantify the hue expressed by an object, C* is somewhat analogous to color saturation (McGuire 1992).

Sugar Analysis

Glucose, fructose, and sucrose were analyzed and quantified by high pressure liquid chromatography (HPLC). Five tubers of each cultivar were cut into strips, dipped in liquid N_2, and freeze-dried using a Freezemobile 24 condenser and Unitop 600L shelf unit (Virtis Co., Gardiner, NY, USA) with shelf temperature set at 5 C. Freeze-dried samples were ground using a mortar and pestle and 4 g was transferred into 250 mL Erlenmeyer flasks (three replicates). A known amount of the internal standard, arabinose (Aldrich Chemical Co., Milwaukee, WI, USA), was dissolved in 50 mL 80% ethanol and added to the flasks. The flasks were sealed with Teflon stoppers and shaken with a Burrell wrist action shaker (Pittsburgh, PA, USA) while immersed in a Brinkmann RM-20 circulating water bath (San Francisco, CA, USA) at 55 C for 2 hr. Samples were then centrifuged at 1,400 x *g* for 15 min and 25 mL of supernatant was transferred to a rotary evaporator (Buchner Instruments, Fort Lee, NJ, USA) at 30 C. The concentrated solutions (<2 mL) were transferred into 50-mL volumetric flasks and brought to volume with deionized water. All samples were filtered using a 0.45-mm PTFE 13 mm Acrodisc syringe filter (Gelman Sciences, Ann Arbor, MI) and transferred into 3-mL vials prior to chromatographic analysis.

The HPLC consisted of an Isco model 2360 gradient programmer (Lincoln, NE, USA), an Isco model 2350 HPLC pump unit, a Hewlett Packard model 1050 autosampler (Wilmington, DE, USA) and a 300 x 7.8 mm Aminex HPX-87H ion exclusion column (Bio-Rad, Richmond, CA, USA). Chromatographic separation was accomplished by HPLC using a mobile phase of 0.013M H_2SO_4 filtered through a 0.45 mm filter previously purged with N_2. The flow rate was maintained at 0.50 mL/min. Detection of sugars was obtained using a differential refractive index detector (Waters Inc., San Francisco, CA, USA) coupled to a Hewlett Packard 3394A integrator. All peaks were identified based on retention times of known standards.

Statistical Analysis

The software program Statistica v. 4.0 and 6.0 (StatSoft Inc., Tulsa, OK, USA) was utilized with treatment means separated by $LSD_{0.05}$.

RESULTS AND DISCUSSION

Changes in Color

Both h° and C* were consistently higher for the yellow-fleshed cultivars/clone compared to the white-fleshed cultivars for both freshly harvested tubers and those stored at different temperatures for 84 days (Table 1). Chroma values were maximum for most yellow-fleshed tubers when stored at 8.3 C for 84

TABLE 1—*Changes in color of tubers freshly harvested or those stored at 3.3, 8.3, or 10 C for 84 days.*

	Freshly harvested			Stored at 3.3 C			Stored at 8.3 C			Stored at 10 C		
Cultivar	h°	C*	L*	h°	C*	L*	h°	C*	L*	h°	C*	L*
Norchip	81.8g^{b,w}	16.4^{c,z}	67.0^{b,x}	81.2^{c,wx}	19.3^{c,w}	71.2$^{b\ w}$	81.6^{c,w}	18.0^{d,x}	68.7^{c,wx}	80.8^{c,x}	17.1^{d,y}	71.1^{b,w}
Russet Burbank	79.9$^{c\ w}$	15.1^{d,y}	67.2^{b,x}	80.7^{c,w}	18.3^{c,w}	68.1$^{c\ w}$	80.5$^{c\ w}$	16.2^{e,x}	66.8^{d,x}	80.0^{c,w}	15.9^{e,xy}	66.8^{d,x}
Yukon Gold	82.2$^{b\ x}$	26.4^{a,x}	65.6^{c,y}	82.4^{b,x}	31.3^{a,w}	68.2^{c,x}	83.1^{b,w}	31.6^{bc,w}	71.3^{b,w}	83.0^{b,w}	30.8^{a,w}	71.6^{b,w}
Red Gold	82.3$^{b\ x}$	26.6$^{a\ y}$	62.7^{d,x}	82.8^{b,wx}	26.9^{b,y}	60.9^{d,y}	83.7^{b,w}	34.1^{a,w}	68.4^{c,w}	83.8^{ab,w}	31.0^{a,x}	68.2^{c,w}
Saginaw Gold	83.2^{a,x}	23.4^{b,z}	73.7^{a,xy}	84.1^{a,wx}	29.5^{a,x}	72.9^{a,y}	85.0^{a,w}	30.6^{c,w}	74.9^{a,x}	84.2^{a,wx}	27.4^{c,y}	77.1^{a,w}
Augsberg Gold	83.2^{a,wx}	25.6^{a,y}	64.7^{c,x}	83.2^{ab,wx}	29.0^{a,x}	60.5$^{d\ z}$	84.0^{b,w}	32.3^{b,w}	67.3^{d,w}	82.8^{b,x}	28.2^{b,x}	63.8^{e,y}
AO82283.1	83.7^{a,x}	22.4^{b,y}	65.5^{c,y}	83.6^{a,x}	30.2^{a,w}	70.4^{b,x}	85.1^{a,w}	31.1 ^{bc,w}	72.3$^{b\ w}$	84.3^{a,wx}	28.3^{b,x}	70.6^{b,x}

$^{a\ to\ f}$ Means within a column followed by different letters are significantly different at $P \leq 0.05$.
$^{w\ to\ z}$ Means within a row for a given color attribute followed by different letters are significantly different at $P \leq 0.05$.

days. Based on h° and C*, the flesh color of Yukon Gold, Red Gold, Saginaw Gold, Augsberg Gold, and AO82283.1 can be described as being more "yellow" and "vivid" than that of Norchip or Russet Burbank before or after storage. L* values varied depending on cultivar/clone and storage temperature with no obvious trends (Table 1).

Flesh colors of yellow and white tubers are due to the presence or absence of carotenoids (Brown et al. 1993). In the case of yellow-fleshed cultivars, the dominant pigments found tend to be the xanthophylls violaxanthin, lutein, zeaxanthin, and lutein 5,6 epoxide. Brown et al. (1993) reported lutein and zeaxanthin to be present in an orange-fleshed clone at concentrations four times higher than the level previously reported for potatoes.

Accumulation of Sugars

At the time of harvest, Norchip, Russet Burbank, Yukon Gold, Red Gold, Saginaw Gold, Augsberg Gold and AO82283.1 contained <3 mg/g (fresh weight) of sucrose, glucose, or fructose (data not shown). These initial concentrations were similar to those reported previously for white-fleshed cultivars (Cottrell et al. 1993; Herrman et al. 1996).

After 84 days of storage at 3.3 C, sucrose concentrations increased for all cultivars, most notably Norchip and AO88283.1 where the concentrations were 9.9 and 10.0 mg/g, respectively (Table 2). Furthermore, the concentrations of glucose or fructose in tubers stored at 3.3 C were ≥10 mg/g for Norchip, Russet Burbank, Yukon Gold and Red Gold. Much lower accumulations of these sugars ≤7.4 mg/g) were noted for Saginaw Gold, Augsberg Gold, and AO82283.1 stored at 3.3 C. Although accumulations of reducing sugars were less at 8.3 C than at 3.3 C for all cultivars/clone, Saginaw Gold, Augsberg Gold, and AO82283.1 had significantly lower concentrations than other tubers when stored at 8.3 C. Far less sucrose, glucose, or fructose (≤2.7 mg/g) were found in all cultivars/clone stored at 10 C.

As the tendency for tubers to synthesize sucrose, glucose, and fructose during storage is influenced by variety (Loiselle et

TABLE 2.—*Concentrations of sucrose, glucose, and fructose (mg/g fresh weight) in tubers stored at 3.3, 8.3, or 10 C for 84 days.*

	Stored at 3.3 C			Stored at 8.3 C			Stored at 10 C		
Cultivar	Sucrose	Glucose	Fructose	Sucrose	Glucose	Fructose	Sucrose	Glucose	Fructose
Norchip	9 9^{a,x}	11.4^{c,x}	10.9^{b,x}	3.1^{c,y}	4.2^{c,y}	3.6^{b,y}	1.7^{a,z}	0.80^{d,z}	0.46^{d,z}
Russet Burbank	5.6^{c,x}	10.0^{d,x}	11.3^{b,x}	3.3^{b,y}	4.4^{bc,y}	3.2^{c,y}	1.7^{a,z}	1.2^{c,z}	0.32^{d,z}
Yukon Gold	4.7$^{e\ x}$	12.4^{b,x}	12.0^{a,x}	3.0^{c,y}	4.8$^{b\ y}$	5.3^{a,y}	1.4^{b,7}	2.7^{a,z}	2.1^{a,z}
Red Gold	6 5^{b,x}	13.0^{a,x}	12.5^{a,x}	4.1^{a,y}	6.1^{a,y}	5.4^{a,y}	1.3^{b,z}	1.4^{bc,z}	1.2^{c,z}
Saginaw Gold	5.1$^{d\ x}$	6.6^{f,x}	6.0^{c,x}	1.4^{e,y}	1.3^{f,y}	0.50^{f,y}	0.86^{d,y}	0.19^{e,z}	0.12^{e,z}
Augsberg Gold	3.7^{f,x}	5.0^{f,x}	5.0^{d,x}	1.5$^{e\ y}$	1.6^{e,y}	1.6^{d,y}	1.3^{b,y}	1.5^{b,y}	1.5^{b,y}
AO82283.1	10.0^{a,x}	7.4^{e,x}	5.9^{c,x}	2.3^{d,y}	2.4^{d,y}	0.73^{e,y}	1.1^{c,y}	trace	0.13^{e,z}

$^{a\ to\ f}$ Means within a column followed by different letters are significantly different at $P \leq 0.05$.
$^{x\ to\ z}$ Means within a row for a given sugar followed by different letters are significantly different at $P \leq 0.05$.

al. 1990, Herrman et al. 1996), it was not surprising that the cultivars/clone in the present study accumulated different concentrations of these sugars. Besides variety, harvest time (Hertog et al. 1997) can also influence accumulation of reducing sugars. In addition, glucose: fructose ratios greater than one were observed (Table 2), a trend similarly reported by others (Hertog et al. 1997). Although sucrose is broken down by tubers to yield glucose and fructose, Merlo et al. (1993) noted that changes in glucose content of tubers did not correlate with either sucrose or fructose concentrations, probably reflecting the complicated aspects of cellular metabolism.

Reconditioning

Processing potatoes are held at temperatures low enough to delay sprouting and decay yet high enough to inhibit low temperature sweetening (LTS). The ideal temperature varies according to the type of processed product. In general, tubers for the french fry industry are normally held at 8 C with the extent of LTS dependent on cultivar and storage time. Tubers that have undergone LTS can be reconditioned by increasing the storage temperature to 15 to 20 C for up to 28 days prior to processing (Pritchard and Adam 1994). This reconditioning period decreases the concentrations of reducing sugars, thus reduces darkening during frying. The degree to which quality can be improved by reconditioning varies with cultivar and no information is available on the reconditioning abilities of these particular yellow-fleshed cultivars/clone.

All cultivars examined exhibited a significant decrease ($P \leq 0.05$) in sucrose, glucose, and fructose concentration after the reconditioning period (Table 3). While Norchip had the highest initial sucrose concentration of 8.81 mg/g, this amount decreased to 1.49 mg/g after reconditioning. For this cultivar, concentrations of glucose and fructose decreased from 7.55 and 6.78 mg/g down to 0.25 and 0.34 mg/g, respectively. After reconditioning, the concentrations of fructose in Yukon Gold, Red Gold, Saginaw Gold, and Augsberg Gold declined to only trace amounts. Although not present in Saginaw Gold or Augsberg Gold, glucose was found in Yukon Gold (1.63 mg/g) and Red Gold (1.50 mg/g).

As pointed out by Jeong et al. (1996) and Illeperuma et al. (1998), success of reconditioning is variable and depends upon different factors. The responses of the yellow-fleshed cultivars to reconditioning (Table 3) imply that some of these cultivars might be successfully used by the processing industry, most notably Saginaw Gold and Augsberg Gold. Moreover, preliminary sensory analysis indicated that chips or fries made from some of the yellow-fleshed cultivars may be of equal preference to those prepared from white-fleshed potatoes. However, additional sensory analysis of processed products is required in order to ascertain suitability of these particular cultivars for the processing industry.

TABLE 3.—*Concentrations of sucrose, glucose, and fructose (mg/g fresh weight) in tubers stored at 3.3 C for 42 days and then after reconditioning at 21 C for an additional 28 days.*

		Sugar		
Cultivar	Time of Analysis	Sucrose	Glucose	Fructose
Norchip	Before reconditioning	8.81[a]	7.55[a]	6.78[a]
	After reconditioning	1.49[b]	0.25[b]	0.34[b]
Yukon Gold	Before reconditioning	5.73[a]	8.4[a]	8.12
	After reconditioning	1.89[b]	1.63[b]	trace
Red Gold	Before reconditioning	8.76[a]	9.84[a]	9.39
	After reconditioning	1.74[b]	1.50[b]	trace
Saginaw Gold	Before reconditioning	7.17[a]	6.10	5.97
	After reconditioning	1.43[b]	trace	trace
Augsberg Gold	Before reconditioning	2.57[a]	6.28	5.98
	After reconditioning	1.29[b]	trace	trace

[a to b] Means within a column for a given cultivar followed by different letters are significantly different at $P \leq 0.05$.

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