Influence of Storage upon Light-Induced Chlorogenic Acid Accumulation in Potato Tubers (*Solanum tuberosum* L.)

Glynn C. Percival* and Lynn Baird

Department of Plant Biology, Scottish Agricultural College, Auchincruive, Ayr KA6 5HW, United Kingdom

The influence of 2 weeks and 3 months of dark storage upon light-induced chlorogenic acid accumulation within tuber tissue of four potato cultivars and upon 5-, 4-, and 3-caffeoylquinic acid concentrations within cv. King Edward was determined. Storage period significantly affected ($P < 0.05$) the magnitude of the light-induced chlorogenic acid response with accumulation rates 3−4 times higher in tubers exposed to light after 2 weeks compared with those placed under light after 3 months. Comparison of chlorogenic acid concentrations in controls after 2 and 3 months of dark storage indicated that tuber chlorogenic concentrations decline during prolonged cold store at 5 °C. Rates of accumulation in response to light were cultivar-dependent with cv. Fianna the most light-sensitive and cv. Maris Piper relatively light-insensitive. In virtually all cases exposure to sodium and fluorescent light promoted higher rates of accumulation than did exposure to high-pressure mercury light sources. Chlorogenic acid values steadily increased over 15 days of illumination with, in the majority of cases, no indication of cessation. Light exposure increased 5-, 4-, and 3-caffeoylquinic acid accumulation rates in cv. King Edward. Irrespective of storage period and light source, ratios of 5-:4-:3-caffeoylquinic acid were ca. 85:15:0 at day 0 and 52:42:6 by day 15.

Keywords: *Chlorogenic acid; 5-, 4-, and 3-caffeoylquinic acid; potato; light; storage; Solanum tuberosum L.*

INTRODUCTION

Chlorogenic acid is one of the principal phenolic compounds found in potato tubers, accounting for up to 90% of the total phenolic compounds (Dao and Friedman, 1992). Several isomeric chlorogenic acids have now been discovered in potatoes. The major one, designated 5-caffeoylquinic acid by the International Union of Pure and Applied Chemistry, is complimented by 3- and 4-caffeoylquinic acid (Friedman, 1997). The presence of chlorogenic acids in plants has been linked with defense mechanisms against insects and fungal and bacteria pathogens in vitro (Friedman, 1997). Chlorogenic acid in potato tubers is also associated with the phenomenon referred to as after-cooking blackening (ACB). In the flesh of susceptible cultivars a colorless iron−chlorogenic acid chelate is formed during the cooking process which, on exposure to air, is oxidized to a bluish gray ferric compound (Griffiths et al., 1995). The discoloration is regarded as a severe quality defect, although it does not affect taste or nutritive value (Dale and Mackay, 1994). The degree of blackening is cultivar-dependent and influenced by environmental factors such as fertilization, soil, climatic conditions, storage period, and light (Griffiths and Bain, 1997; Olsson, 1989). Because potatoes are inevitably exposed to light (daylight, fluorescent, and incandescent) during processing and marketing, stimulation of chlorogenic acid can result in tubers of a lower quality at the end point of sale. Previous investigations into the effect of light upon chlorogenic acid accumulation in potato tubers are limited and rely predominantly on results obtained from exposure to high-pressure sodium light (Griffiths and Bain, 1997; Griffiths et al., 1995). A range of high- and low-pressure light sources (sodium, fluorescent, mercury) is available to growers for the production of horticultural crops (Anonymous, 1981). Exposure of a range of potato cultivars to these light sources had marked effects on the rate of accumulation of glycoalkaloids and chlorophylls, compounds for which synthesis is also promoted within tuber tissue in response to light (Percival, 1999). Whether such a response occurs with respect to chlorogenic acid remains unknown.

Objectives of this investigation were to, first, assess increases in chlorogenic acid concentrations within tuber tissue of four potato cultivars in response to 15 days of continuous illumination from four light sources (fluorescent, sodium, and high-pressure mercury types MB/U and MBFR/U), second, determine the effect of these light sources on the concentration and ratios of three isomers of chlorogenic acid (5-, 4-, and 3-caffeoylquinic acid; cv. King Edward only), and, third, determine the influence of short-term (2 weeks) and long-term (3 months) dark storage at 5 °C upon subsequent accumulation rates.

MATERIALS AND METHODS

Plant Material. Tubers of cvs. King Edward, Fianna, Marfona, and Maris Piper were grown in experimental plots at the Department of Plant Biology, SAC, Auchincruive, Ayr. Harvested tubers were cleaned of soil manually and skins allowed to set in a ventilated dark store at 8 °C for 14 days. Tubers were subjected to light treatments (i) immediately after skin set and (ii) after dark storage at 5 °C for 3 months. As required, tubers were washed under running tap water and hand dried prior to treatments.

Light Exposure. Tubers (60−80 g) were withdrawn and placed under 40 W fluorescent tubes (warm white), 400 W high-pressure sodium lamps (SON/T), or 400 W high-pressure

* Author to whom correspondence should be addressed (e-mail G.Percival@au.sac.ac.uk).

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mercury lamps (MB/U and MBFR/U) at such a distance from the illumination source that radiation photon flux density was 120 μmol of photons m^{-2} s^{-1} at the tuber surface with a temperature of 22 ± 2 °C. Tubers were rotated at 24 h intervals, ensuring complete exposure to light. Batches of six tubers were withdrawn at 0, 3, 6, 9, 12, and 15 day intervals, diced, sealed in polythene under vacuum using a Pifco Vac-Elut vacuum packer model 1101 (Fisons Scientific Equipment, Loughborough, U.K.), and stored at −20 °C for 24 h.

Chemical Analysis. Samples were then freeze-dried, weighed, and ground through a Retsh 0.5 mm cyclone mill type ZM-1 (SH Scientific Unit 37, Kitty Brewester, Blyth, Northumberland, U.K.). Each sample was repacked under vacuum and stored at −20 °C prior to chlorogenic acid analysis based on the sodium nitrite method of Griffiths et al. (1992). In addition, freeze-dried tubers of cv. King Edward were reanalyzed for total chlorogenic acid and 5-, 4-, and 3-caffeoylquinic acid concentrations using high-performance liquid chromatography (HPLC) and capillary electrophoresis based on that of Brandl and Herrmann (1984) and Fernandes et al. (1996). Results obtained from tubers stored in darkness were used as controls.

Statistical Analysis. Accumulation of chlorogenic acid with time was determined by linear regression ($y = a + bT$), where a represents chlorogenic acid at day 0, b the rate of chlorogenic acid accumulation, and T the time in days. Differences between treatment means were separated by the least significance difference (LSD) at $P > 0.05$.

RESULTS AND DISCUSSION

Rates of accumulation were markedly influenced by cultivar, storage period, and light source (Figure 1; Tables 1−4).

Storage. Results clearly show that storage period significantly affected ($P < 0.05$) the magnitude of the light-induced chlorogenic acid response (Figure 1). Accumulation rates were 3−4 times higher in tubers exposed to light immediately after skin set (2 weeks of storage) compared with those placed under light after 3 months of storage. Results for cv. Marfona, for example, typify those for all cultivars. Exposure to fluorescent, sodium, and mercury types MB/U and MBFR/U light after 2 weeks of storage resulted in accumulation rates of $85.20 + 14.70T$, $65.42 + 19.43T$, $54.34 + 12.81T$, and $62.13 + 13.55T$, respectively. Exposure to light after 3 months storage resulted in accumulation rates of $23.67 + 3.28T$, $18.50 + 4.50T$, $14.07 + 3.07T$, and $14.44 + 3.39T$, respectively (Tables 1 and 2).

Contrary to this, storage of nine potato cultivars for 4 months followed by illumination for 48 h under high-pressure sodium lights at 140 μmol m^{-2} s^{-1} did not appear to significantly affect chlorogenic acid concentrations in comparison with tubers placed under light immediately after harvest (Griffiths et al., 1995). Exposure of physiologically young and aged potato tubers to light has been shown to result in substantial increases of the potato glycoalkaloids, α-solanine and α-chaconine, with synthesis more active in tubers exposed to light 7 days after harvest compared with tubers exposed to light 4 months after harvest (Percival et al., 1994). Bomer and Mattis (1924) and Zitnak (1981) also reported potato tubers were most responsive to light-induced glycoalkaloid synthesis during a short phase immediately after harvest. It has been suggested that reduced responsiveness to light-induced chlorogenic acid and glycoalkaloid synthesis in older tubers could be linked to concentrations of reducing sugars during storage (Hasegawa et al., 1966; Zitnak, 1961). However, no information about sugar concentrations was recorded in this paper. Such information may help us to understand the role of sugars during chlorogenic acid synthesis and the difference in the response to light between young and old tubers.

The effects of storage temperature on tuber chlorogenic acid concentrations have been studied in only a few cultivars using a limited number of temperature regimes. Initial tuber chlorogenic acid concentrations in unilluminated controls were higher in all four cultivars after 2 weeks, compared with those after 3 months of storage. This indicates a decline in chlorogenic acid concentrations during prolonged dark storage at 5 °C. In support of this Rogozinska et al. (1986) in a 2-year study showed a steady decrease in chlorogenic acid during 4 months of storage. However, in one year the level rose in two of the nine cultivars tested. According to Griffiths et al. (1995), a short storage period of 6 days did not have any significant effect on the chlorogenic acid content in potato tubers. Although a slight increase in chlorogenic acid in individual cultivars was observed with time, this difference was not statistically significant when averaged over all cultivars. In addition, Wellving (1976) found no changes in chlorogenic acid content of potato tubers after storage at 3 or 10 °C for 6 months, whereas studies conducted by Hasegawa et al. (1966) have indicated that storage at <5 °C may result in a significant increase in the chlorogenic acid content of potato tubers. Certain factors during crop growth such as the ratio of soil nitrogen to potassium and cool wet seasons can affect tuber chlorogenic acid concentrations (Storey and Davies, 1992). Similarly, initial concentrations and tuber responses to elicitors of chlorogenic acid synthesis are known to be highly cultivar-dependent (Griffiths et al., 1995). Little attention has been given to the effects and/or interactions these factors have upon chlorogenic acid accumulation during storage, which may account for conflicting results obtained by various researchers.

Cultivar. Although rates of chlorogenic acid accumulation of the cultivars used in this investigation have not been reported, results clearly indicate a cultivar-dependent effect in response to light (Figure 1; Tables 1 and 2). Such a response has been reported by workers elsewhere not only for chlorogenic acid but also for other metabolites promoted within tuber tissue in response to light such as glycoalkaloids and chlorophylls (Griffiths et al., 1995; Hellenas et al., 1995; Percival and Dixon, 1996). Previous research by Griffiths et al. (1995) found that exposure to light for a short time period (48 h) resulted in a significant increase in total chlorogenic acid content, which was highest in cultivars with a relatively high intrinsic content, the magnitude of the increase thus being correlated to the initial value of unexposed tubers. Selecting for breeding lines with intrinsically low chlorogenic acid content is therefore likely to result in selection of lines with low rates of chlorogenic acid increase on light exposure. No such relationship between initial concentrations and subsequent accumulation rates over a longer time period of 15 days was demonstrated in this investigation. Cultivar Marfona, for example, proved to be a light-sensitive cultivar and cv. Maris Piper relatively light-insensitive. Initial chlorogenic acid concentrations in both cultivars were similar at 43.35 and 48.56 mg/100 g of FDM after 2 weeks of storage but differed from 11.07 to 38.13 mg/100 g of FDM after 3 months of storage. Following light exposure, however, accumulation rates were almost

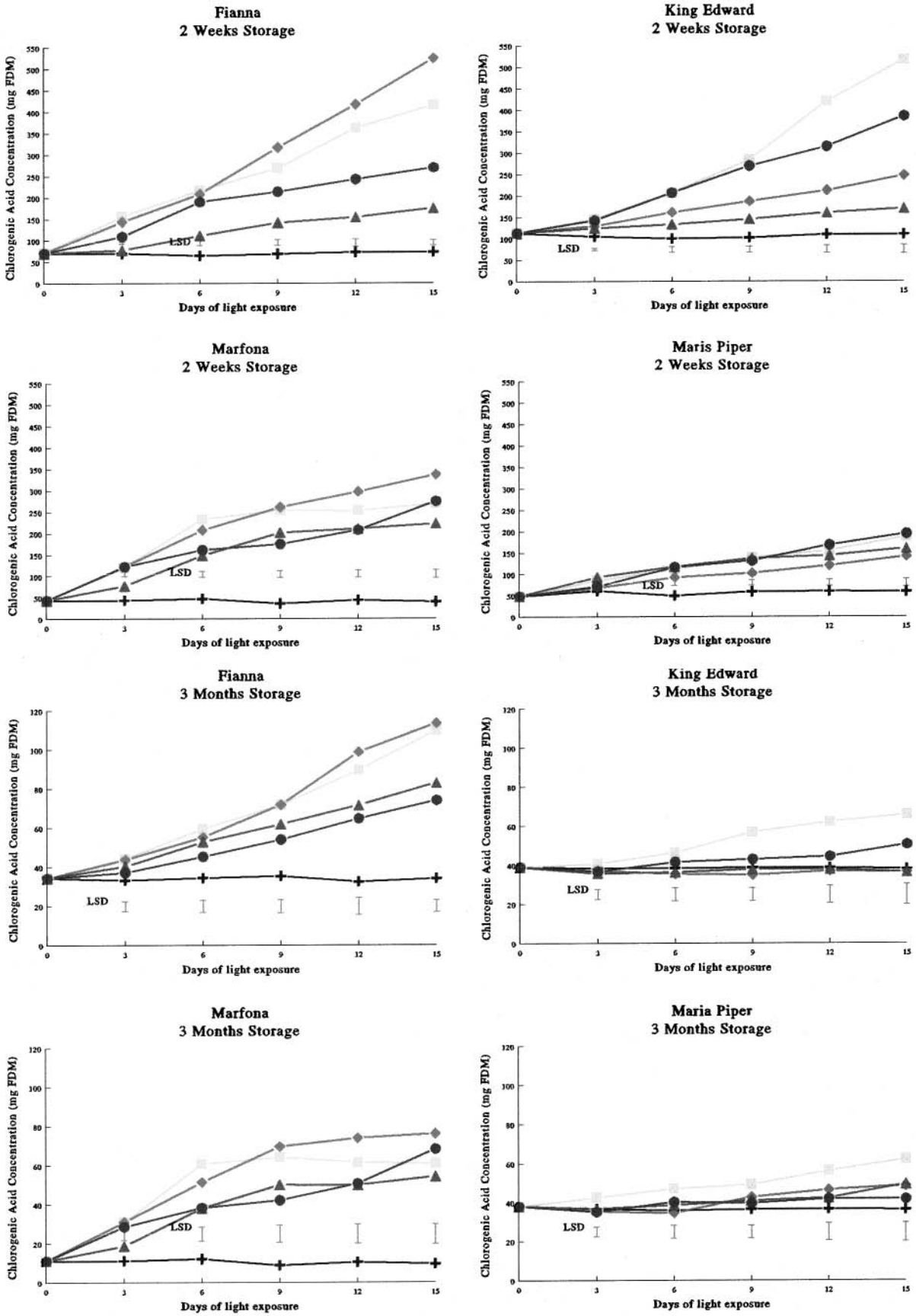

Figure 1. Chlorogenic acid accumulation (mg/100 g^{-1} FDM) in four potato cultivars following exposure to light after 2 weeks and 3 months of dark storage: (+) dark; (■) fluorescent; (◆) sodium; (▲) mercury type MB/U; (●) mercury type MBFR/U. LSD, least significant difference at $P < 0.05$.

twice as high in cv. Marfona compared with cv. Maris Piper (Figure 1; Tables 1 and 2). This demonstrates that selection of cultivars possessing slow rates of chlorogenic acid accumulation is important to achieve low initial

Table 1. Linear Regressions of Chlorogenic Acid (mg/100 g^{-1} FDM) with Time in Potato Cultivars Stored for 2 Weeks prior to Exposure to Light (Standard Errors and Estimated Regression Coefficients Are Given in Parentheses)[a]

cultivar	light source	regression,[b] $y = a + bT$
Marfona	dark	$44.53 - 0.28T$
		(3.500) (0.385)
	fluorescent	$85.20 + 14.70T$
		(13.205) (1.451)
	sodium	$65.42 + 19.43T$
		(8.072) (0.888)
	mercury high-pressure type MB/U	$54.34 + 12.81T$
		(7.390) (0.814)
	mercury high-pressure type MBFR/U	$62.13 + 13.55T$
		(6.091) (0.671)
King Edward	dark	$106.75 - 0.01T$
		(3.850) (0.424)
	fluorescent	$72.50 + 27.81T$
		(12.505) (1.385)
	sodium	$107.58 + 8.95T$
		(3.660) (0.403)
	mercury high-pressure type MB/U	$112.17 + 3.82T$
		(2.610) (0.287)
	mercury high-pressure type MBFR/U	$100.06 + 18.47T$
		(6.400) (0.705)
Fianna	dark	$68.27 + 0.23T$
		(2.810) (0.309)
	fluorescent	$78.95 + 23.01T$
		(4.600) (0.506)
	sodium	$51.61 + 30.47T$
		(6.810) (0.749)
	mercury high-pressure type MB/U	$65.65 + 7.46T$
		(3.610) (0.397)
	mercury high-pressure type MBFR/U	$81.12 + 13.52T$
		(5.792) (0.637)
Maris Piper	dark	$52.03 + 0.57T$
		(2.810) (0.309)
	fluorescent	$54.58 + 8.87T$
		(2.590) (0.285)
	sodium	$50.45 + 6.00T$
		(3.660) (0.403)
	mercury high-pressure type MB/U	$64.56 + 6.94T$
		(4.367) (0.480)
	mercury high-pressure type MBFR/U	$47.72 + 9.85T$
		(3.743) (0.412)

[a] Light = **, storage = **, cultivar = **; ** = $P < 0.01$. [b] y = chlorogenic acid concentration, a = total chlorogenic acid at day 0 (calculated intercept), b = rate of chlorogenic acid accumulation, T = time in days. All values are the mean of six tubers.

Table 2. Linear Regressions of Chlorogenic Acid (mg/100 g^{-1} FDM) with Time in Potato Cultivars Stored for 3 Months prior to Exposure to Light (Standard Errors and Estimated Regression Coefficients Are Given in Parentheses)[a]

cultivar	light source	regression,[b] $y = a + bT$
Marfona	dark	$11.47 - 0.13T$
		(0.884) (0.097)
	fluorescent	$23.67 + 3.28T$
		(3.520) (0.388)
	sodium	$18.50 + 4.50T$
		(2.430) (0.267)
	mercury high-pressure type MB/U	$14.07 + 3.07T$
		(1.880) (0.207)
	mercury high-pressure type MBFR/U	$14.44 + 3.39T$
		(1.350) (0.149)
King Edward	dark	$38.76 - 0.03T$
		(0.875) (0.096)
	fluorescent	$36.86 + 1.20T$
		(1.050) (0.115)
	sodium	$37.54 - 0.12T$
		(0.768) (0.085)
	mercury high-pressure type MB/U	$37.51 - 0.04T$
		(0.751) (0.083)
	mercury high-pressure type MBFR/U	$36.60 + 0.79T$
		(0.846) (0.093)
Fianna	dark	$34.11 - 0.02T$
		(0.948) (0.103)
	fluorescent	$30.58 + 5.02T$
		(1.770) (0.195)
	sodium	$28.29 + 5.50T$
		(1.910) (0.210)
	mercury high-pressure type MB/U	$32.50 + 3.30T$
		(1.500) (0.165)
	mercury high-pressure type MBFR/U	$30.81 + 2.77T$
		(1.231) (0.135)
Maris Piper	dark	$37.34 - 0.08T$
		(0.842) (0.093)
	fluorescent	$37.60 + 1.56T$
		(0.578) (0.064)
	sodium	$34.37 + 0.90T$
		(0.957) (0.105)
	mercury high-pressure type MB/U	$35.73 + 0.72T$
		(0.751) (0.083)
	mercury high-pressure type MBFR/U	$36.85 + 0.36T$
		(0.699) (0.077)

[a] Light = **, storage = **, cultivar = **; ** = $P < 0.01$. [b] y = chlorogenic acid concentration, a = total chlorogenic acid at day 0 (calculated intercept), b = rate of chlorogenic acid accumulation, T = time in days. All values are the mean of six tubers.

concentrations, and cultivars possessing similar initial concentrations can markedly differ in their rates of accumulation during light exposure. At present, tubers of new cultivars are routinely screened for base chlorogenic acid concentrations and not for stress-induced chlorogenic acids, which would be significantly more meaningful for growers, suppliers, and users of fresh potatoes and their processed products.

Light. Irrespective of cultivar, chlorogenic acid concentrations of tubers placed in the dark remained relatively constant from day 0 to day 15 (Figure 1). Rates of chlorogenic acid accumulation were, however, dependent on light source. After 2 weeks of storage maximal and minimal rates of accumulation were promoted by fluorescent and mercury type MB/U light (cv. King Edward), sodium and mercury type MB/U light (cvs. Marfona and Fianna), and mercury type MBFR/U and sodium light (cv. Maris Piper), respectively. After 3 months of storage maximal and minimal rates of accumulation were promoted by sodium and mercury type MB/U light (cv. Marfona), fluorescent and mercury type MB/U light (cv. King Edward), sodium and mercury type MBFR/U light (cv. Fianna), and fluorescent and mercury type MBFR/U (cv. Maris Piper). In virtually all cases, exposure to sodium and fluorescent light promoted higher rates of accumulation than did exposure to high-pressure mercury light sources. Previous research has shown that blue (<500 nm, especially ultraviolet light <300 nm) and infrared light (1300 nm) within the electromagnetic spectrum are active elicitors

Table 3. Total Chlorogenic Acid and 5-, 4-, and 3-Caffeoylquinic Acid Concentrations (mg/100 g of FDM) in Cv. King Edward following Exposure to Light after 2 Weeks of Storage As Determined by HPLC[a]

	exposure					
light source	0 days	3 days	6 days	9 days	12 days	15 days
			Total Chlorogenic Acid			
dark	113.1	105.2	100.1	102.3	109.7	109.8
fluorescent	113.1ns	145.6*	206.9*	284.0*	419.9*	517.2*
sodium	113.1ns	129.5*	160.9*	186.5*	211.8*	246.6*
mercury high-pressure type MB/U	113.1ns	124.2*	133.1*	145.0*	160.0*	169.5*
mercury high-pressure type MBFR/U	113.1ns	142.6*	206.7*	269.3*	314.6*	385.4*
LSD[b]	18.64	14.22	17.64	17.50	38.14	17.76
			5-Caffeoylquinic Acid			
dark	95.7ns	89.3	85.0	87.3	93.5	93.3
fluorescent	95.7ns	119.6*	149.4*	185.5*	248.1*	264.6*
sodium	95.7ns	108.7*	120.3*	125.3*	127.1*	131.7*
mercury high-pressure type MB/U	95.7ns	100.0ns	100.5*	98.7ns	98.1ns	92.2ns
mercury high-pressure type MBFR/U	95.7ns	112.7*	149.9*	172.6*	180.6*	196.6*
LSD	15.92	11.70	13.08	11.60	23.12	10.04
			4-Caffeoylquinic Acid			
dark	17.39	15.86	15.01	15.53	16.3	16.8
fluorescent	17.39ns	24.74*	49.54*	90.67*	154.4*	221.4*
sodium	17.39ns	23.18*	40.38*	62.11*	75.6*	98.7*
mercury high-pressure type MB/U	17.39ns	20.25*	30.08*	45.23*	55.0*	71.0*
mercury high-pressure type MBFR/U	17.39ns	26.81*	49.41*	90.48*	120.8*	158.4*
LSD	3.07	2.43	4.14	5.55	13.84	7.12
			3-Caffeoylquinic Acid			
dark	0.0	0.0	0.0	0.0	0.0	0.0
fluorescent	0.0ns	3.0*	4.3*	9.8*	16.8*	28.9*
sodium	0.0ns	2.7*	3.4*	4.7*	8.5*	13.6*
mercury high-pressure type MB/U	0.0ns	1.9*	3.1*	2.8*	6.3*	7.1*
mercury high-pressure type MBFR/U	0.0ns	2.9*	6.4*	8.4*	13.8*	27.0*
LSD	0.00	0.25	0.46	0.55	1.52	0.97

[a] Light = **, storage = **; ** = $P < 0.01$, * = $P < 0.05$, ns = not significant. All values are the mean of six tubers. [b] LSD, least significant difference.

of glycoalkaloid and chlorophyll synthesis compared with wavelengths such as yellow and orange (Jadhav et al., 1981). Mercury illumination contains few spectral lines (ultraviolet and infrared) likely to enhance glycoalkaloid and chlorophyll synthesis efficiently (Anonymous, 1981). In contrast, fluorescent light and sodium light contain ultraviolet and infrared spectra, respectively. Although speculative, differences in spectral composition between these light sources may account for the marked differences in accumulation rates observed in this investigation. Further research is required, however, to confirm this hypothesis.

After-cooking blackening is regarded as a severe quality defect. As during marketing and sale potatoes are displayed particularly under fluorescent light (Wu and Salunkhe, 1972) this will result in higher rates of chlorogenic acid accumulation. Previous work by Griffiths et al. (1992) showed that an increase of 16 mg/g offreeze-dried matter (FDM) in chlorogenic acid content at the stolon end of the tuber is approximately equivalent to a decrease of one point in the National Institute of Applied Biology (Cambridge, U.K.) (Anonymous, 1990) visual scoring assessment of cultivars for ACB. Consequently, it is likely that light exposure will increase the amount of ACB when tubers are used for human consumption. Results of this investigation show that replacement of fluorescent by mercury illumination, for example, during tuber sale and marketing would markedly reduce chlorogenic acid synthesis in the majority of cultivars tested, in turn improving tuber quality.

Although marked differences in rates of accumulation in response to light sources used in this investigation were observed, in all cases, except cvs. King Edward and Maris Piper exposed to sodium and mercury light after 3 months of storage, light exposure, irrespective of type, resulted in significantly increased ($P < 0.05$) chlorogenic acid concentrations by day 15 compared with dark controls (Figure 1), indicating reductions in chlorogenic acid synthesis and not total cessation.

Chlorogenic Acid Isomers. Although 15 days of illumination enhanced total chlorogenic and 5-, 4-, and 3- caffeoylquinic acid accumulation in cv. King Edward, effects on the ratios of individual isomers were similar, regardless of light source and time spent in storage. For example, ratios of 5-:4-:3- caffeoylquinic acid were ca. 85:15:0 at day 0, 81:17:2 at day 3, and 52:42:6 by day 15 (Tables 3 and 4). Similar trends in alterations of the relative proportions of individual isomers in response to sodium light by six potato cultivars have been reported elsewhere (Griffiths and Bain, 1997). Similarly in agreement with their study, 3-caffeoylquinic acid was not detected in controls, only in tubers exposed to light, and the predominant isomer was found to be 5-caffeoylquinic acid, accounting for 85% of the total chlorogenic acid present. Although the mechanistic basis of alterations in the relative amounts of the three isomers remains to be elucidated, it is unlikely that potato quality will be affected by these alterations as work by Griffiths and Bain (1997) also demonstrated that the development of ACB was dependent on total chlorogenic acid concentrations and unaffected by the relative

Table 4. Total Chlorogenic Acid and 5-, 4-, and 3-Caffeoylquinic Acid Concentrations (mg/100 g of FDM) in Cv. King Edward following Exposure to Light after 3 Months of Storage As Determined by HPLC[a]

	exposure					
light source	0 days	3 days	6 days	9 days	12 days	15 days
			Total Chlorogenic Acid			
dark	38.9ns	38.4	38.4	38.8	38.7	38.1
fluorescent	38.9ns	40.7ns	46.4*	56.9*	62.2*	65.9*
sodium	38.9ns	37.0ns	35.5ns	35.0ns	37.0ns	36.6ns
mercury high-pressure type MB/U	38.9ns	35.7*	36.4ns	37.9ns	37.9ns	36.4ns
mercury high-pressure type MBFR/U	38.9ns	36.7ns	41.5ns	43.0*	44.4*	50.6*
LSD[b]	2.22	2.41	3.36	3.48	1.89	3.40
			5-Caffeoylquinic Acid			
dark	32.5	31.7	32.0	33.0	32.7	31.2
fluorescent	32.5ns	32.2ns	34.3ns	36.0*	37.3*	34.4*
sodium	32.5ns	29.9ns	25.7*	22.4*	22.0*	19.6*
mercury high-pressure type MB/U	32.5ns	29.4ns	27.2*	24.4*	21.9*	18.8*
mercury high-pressure type MBFR/U	32.5ns	30.9ns	31.2ns	28.9*	25.6*	28.3*
LSD	1.86	2.77	2.60	2.53	0.95	1.96
			4-Caffeoylquinic Acid			
dark	6.5	6.4	6.3	5.8	6.6	6.4
fluorescent	6.5ns	7.0*	11.2*	18.9*	22.0*	28.5*
sodium	6.5ns	6.7ns	9.1*	11.8*	13.7*	15.2*
mercury high-pressure type MB/U	6.5ns	6.1ns	8.6*	11.3*	14.7*	15.0*
mercury high-pressure type MBFR/U	6.5ns	5.5*	9.2*	13.7*	16.8*	19.7*
LSD	0.37	0.58	0.72	0.96	0.97	1.34
			3-Caffeoylquinic Acid			
dark	0.0	0.0	0.0	0.0	0.0	0.0
fluorescent	0.0ns	0.8*	1.3*	2.0*	3.1*	4.0*
sodium	0.0ns	0.7*	0.8*	1.2*	1.5*	2.2*
mercury high-pressure type MB/U	0.0ns	0.6*	0.7*	0.7*	1.5*	2.7*
mercury high-pressure type MBFR/U	0.0ns	0.7*	0.9*	1.9*	1.5*	3.9*
LSD	0.00	0.06	0.07	0.10	0.10	0.21

[a] Light = **, storage = **; ** = $P < 0.01$, * = $P < 0.05$, ns = not significant. All values are the mean of six tubers. [b] LSD, least significant difference.

concentration of individual isomers. Possible reasons for the alterations in chlorogenic isomer ratios observed in all cultivars may be due to the fact that phenolic compounds such as chlorogenic acid found with tuber tissue have been shown to function as deterrents against pathogenic fungi and bacteria, especially *Erwinia* soft rot, a major bacterial problem within Europe (Kumar et al., 1991). Although many plants respond to fungal invasion by the rapid synthesis of phytoalexins, the nature of insect and/or herbivore predation necessitates possession of a more permanent deterrent. Accumulation of chlorogenic acid, therefore, may have evolved initially in response to predation pressures. Evidence by Ghanekar et al. (1984) demonstrated that chlorogenic, caffeic, and ferulic acid were more effective against *Erwinia carotovora* when used as mixtures in the proportions found in the periderm of potatoes than when used individually. Consequently, alterations in isomer ratios may have evolved as an ecological strategy either from selection pressures produced by a single pest or pathogen or naturally among the potato kingdom to ensure greater protection against a range of predation pressures.

Conclusions. Results of this investigation clearly indicate that rates of chlorogenic acid accumulation are markedly influenced by cultivar, storage period, and light source. Potato tubers were most responsive to light-induced chlorogenic acid accumulation after a short 2 week storage period compared with a longer 3 month storage period. Rates of accumulation were also shown to be markedly influenced by cultivar. Consequently, selection for cultivars with low accumulation rates is an important consideration in the evaluation of the quality of new cultivars to the consumer. When tubers are exposed to light during processing and sale, use of mercury light over fluorescent light should be considered. Finally, alterations in chlorogenic acid isomer ratios, although having no effect on ACB, may influence their efficacy as plant defense compounds.

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