Title: The affect of light source on greening and other quality attributes of 'Russet Burbank' potatoes (Feb 2005-July 2005)

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Objective: The objective of this study was to evaluate the impact of various light sources on greening and other quality characteristics of exposed potato tubers.

Introduction:

The proper display and visibility of potatoes in the market retail stores are important for consumer awareness and purchase initiation. Displaying potatoes dictates exposure to ambient and artificial light. The recent use of accent or spotlight lighting in retail stores has focused the illumination on commodities for greater consumer eye-appeal and selection ability. Unfortunately, when potatoes are exposed to light, the surface of the tuber will turn a green color. This green pigmentation is due to chlorophyll formation and renders the potato unacceptable in the marketplace. Coinciding with the chlorophyll formation is an increase in glycoalkaloid levels. The chlorophyll formation may be aesthetically unappealing but does not impart a taste or toxicity concern like elevated glycoalkaloid levels. Elevated potato tuber glycoalkaloid levels can produce a bitter taste and levels of 20 mg/kg or higher can be a health concern for human consumption (Percival, 1999)

Light intensity, duration and quality will all impact the rate of greening in potatoes. A greater light intensity equates to a faster progression of greening and chlorophyll accumulation in the tuber. In a retail marketplace situation, light intensities in the photosynthetically active region ranged from 6.3 to 26 $\mu E\ s^{-1}m^{-2}$ (Grunenfelder, 2005). The accumulation of chlorophyll, the cause of visual greening, is an accumulative process, thereby the longer the exposure to a light source, an increase in greening occurs. Potatoes are more sensitive to chlorophyll accumulation when exposed to wavelengths of light in the blue (475 nm) and red (675 nm) regions of the light spectra (Petermann and Morris, 1985).

Materials and Methods

Potatoes (cv. Russet Burbank) were grown according to University of Idaho recommendations, harvested Sept. 24, 2004, and placed into storage at the Kimberly Potato Storage Research Facility. Harvested potatoes were cured at 55°F for 14 days and the storage temperature was decreased by 0.5°F per day to a final holding temperature of 42°F. Potatoes were treated with 22 ppm of chlorpropham (CIPC; Decco, Elf Atochem North America, Monrovia, CA) by thermal aerosol application 56 days after harvest. Randomly selected tubers (5 to 17 oz.) were used in the following experiments to evaluate the impact of light source on greening. Two experiments were conducted with 5 light sources evaluated in Experiment 1 and 4 light sources evaluated in Experiment 2 as described in Table1. Each experiment was repeated (identified as test). All tubers were washed and air-dried prior to each test.

Table 1. Light source treatments, specifications and light intensity values.

Experiment #	Light source	Light specifications	Light intensity (foot candles)
1*	Fiber optic (FO)	Fiberstars EFO	129
	Ceramic Metal Halide (CMH)	Philips CDM35/PAR20/M/FL	127
	Fluorescent	Sylvania Octron FO32/735/ECO	130
	Fluorescent with filter	Sylvania Octron FO32/735/ECO with a Spectrum Environmental Lighting Filter (Spectrum 574)	129
	Dark	--	0
2**	Fiber optic (FO)	Fiberstars EFO	122
	Halogen	Ushio Q50MR16/FL-Glass Lens	121
	Fluorescent-P	Promolux (2 lamps FO32 T8 P129/6V8 and 1 lamp FO32 T8 Platinum 3)	119
	Dark	--	0

* Test 1 initiated 171 days after harvest (DAH), test 2 initiated 192 DAH
** Test 3 initiated 234 DAH, test 4 initiated 255 DAH

Four individual light rooms (4’ wide x 4’deep x 7’5” high) were manufactured from plywood board for the use of these studies. The rooms were designed with approximately a 2 inch gap between the walls and floor and walls and ceiling to allow for air movement. These manufactured rooms were located in a larger room at ambient room temperature (approximately 72°F). The only light source in each room was the treatment light source. Light sources (listed in Table 1) were suspended from the ceiling to a given level from the potatoes for a consistent light intensity reading between treatments (Table 1). Tubers were exposed to 22 hours of light per day. Potatoes (n=45) were randomly placed on two trays (15” x 20”) elevated off of the floor for each treatment. Potatoes were also placed in a light-proof cardboard box located in the same outer room to be used as the dark control treatment. Every tuber in each treatment was identified and weighed for

subsequent weight loss measurements and evaluations. Temperature sensors (Hobo, Onset Computer Co., Bourne, MA) were placed in each treatment room to record temperature every 30 minute. The temperature readings were averaged for each day of the experiment.

At the initiation of each test, light intensity was measured on 12 areas on the trays for a calculated average light intensity for the treatment using a Minolta CL-200 (Konica Minolta, Tokyo, Japan). Photosynthetically active region (PAR) light intensity measurements were obtained in 6 locations on the trays using a LI-190SA Quantum Sensor (LI-COR, Lincoln, NE). PAR measurements provide light intensity measurements in the photosynthetically active region of 450 to 670 nm.

At the initiation of each test (day 0), 6 randomly selected tubers (each tuber considered a rep) were selected for greening rating and chlorophyll analysis as described below. An additional 16 tubers (4 reps of 4 tubers) were analyzed for glycoalkaloid content using the procedures of Berger (1980).

Samples of 6 tubers (each tuber considered a rep) for each treatment were taken after 2, 4, 7 and 9 days under the light source treatments. At each sampling time, tubers were removed from the light rooms, weighed, rated for degree of greening based upon Grunenfelder (2005), and analyzed for chlorophyll content. At day 9, four reps of four tubers were analyzed for glycoalkaloid content.

Chlorophyll analysis. Tuber chlorophyll was extracted and measured using the method of Petermann and Morris (1985) with modifications. At each sampling time, one longitudinal strip of 1mm thickness was removed from each potato (6 tubers per treatment; each tuber considered a rep) using a standard Swiss carbon-steel blade vegetable peeler (Kuhn Rikon, Switzerland). The flesh of the peeled area of the potato was rated for degree of greening in the laboratory under fluorescent lights using the scale developed by Grunenfelder (2005). The scale rates from 0 to 7 with 0 being no green color and 7 being intense green color (Figure 1). Using a stainless steel cork borer, two 15 mm cores were taken from each peeled strip and combined for a single tuber sample analysis. The two cores were diced into 1 mm squares using a single edge razor blade, tissue placed in 20 ml scintillation vials, weighed, and then frozen (-15°C) in a light-proof container. Vials were removed from the freezer, 12 ml of N,N-dimethlyformamide (DMF) added to each vial, and kept dark at 4 °C for 24 hours. A 10 ml aliquot was measured on a DR/4000V spectrophotometer (Hach Company, Loveland, CO) at 603, 647, and 664nm. Tissue chlorophyll content was calculated using formulae of Moran (1982) and expressed as total chlorophyll on a fresh weight basis.

Statistical design was a completely randomized design with 6 replicates per treatment. Analysis of variance was performed utilizing SAS (GLM) and means separated by LSD at α=0.05. Regression analysis was run using SAS on chlorophyll and visual greening separately for each treatment using a linear model plotted over time. The linear model was $y = \beta_0 + \beta_1 x + e$ where β_0 = intercept, β_1 = slope and e = residuals. After fitting each treatment, contrasts were run to compare slopes and intercepts among treatments.

Results and Discussion

The distance from the light source to the potato tubers were set to give approximately the same overall light intensity on the tubers between treatments (Table 1). These relatively low light intensities (125 foot candles or 11.6 lux) are comparable to levels experienced in retail markets. The measured light levels account for radiant energy that is visible to the consumer's eye in the wavelengths of approximately 390 to 760 nm. The increase in green pigmentation of the tuber when exposed to light is due to amyloplasts converting to chloroplasts. The chloroplast accumulate chlorophyll with exposure to light. Light intensity measurements in the photosynthetically active region (PAR) of 450 to 670 nm gives an indication of the intensity of light within this region. Petermann and Morris (1985) indicate that the wavelengths of 475 nm (blue region) and 675 nm (red region) maximized chlorophyll synthesis in potato tubers whereas the least amount of accumulation occurred between 525 and 575 nm. Light quality and spectra of the light source will impact chlorophyll accumulation and visual greening of the exposed tuber. Light intensity within the PAR region was significantly lower for the FO light source compared to the other treatments in both experiments (Table 2). In experiment 1, CMH had the highest PAR light level and there was no significant difference Fluorescent and Fluorescent with filter in PAR light levels. The Fluorescent-P and Halogen light sources were not significantly different from each other in experiment 2.

Daily temperatures at tuber level were averaged over the course of the experiment (9 days) and the temperature differentials between each treatment and the dark control were calculated (Table 2). The FO light treatment had a significantly lower temperature differential between the dark control in both experiments compared to the other light treatments. This lower differential translated to smaller increase in ambient air temperature surrounding the potatoes under the FO lights compared to the other light treatments relative to the dark control. There were no differences in temperature differentials between the other light sources within each experiment.

Although there were significant differences in temperature differentials between treatments, it did not equate to weight loss differences over the 9-day study (Table 3). In experiment 2, the Fluorescent-P showed significantly greater weight loss at 4 and 9 days compared to the other treatments.

The elevated glycoalkaloid levels with exposure to light are generally not a health concern until 20 mg/100 g fresh weight is reached (Percival, 1999). After 9 days in 22-hour daily illumination, no tuber in any treatment reached the potentially toxic level (Table 4). All light source treatments increased total glycoalkaloid levels compared to the dark control. There were no significant differences between the light sources in glycoalkaloid accumulation. The dark control did not significantly differ from the initial glycoalkaloid concentrations at the initiation of experiment 1 (4.1 mg/100 g fresh tissue) and experiment 2 (3.4 mg/100 g fresh tissue).

Measuring the concentration of chlorophyll in the tuber tissue quantifies the amount of biochemical product that causes the green pigmentation. In experiment 1 at the day 2 sampling time, potatoes exposed to the FO light source had significantly lower chlorophyll content compared to tubers exposed to Fluorescent with filter. There was no significant difference in tuber chlorophyll content between the FO, CMH and Fluorescent illuminate tubers. By day 4, tubers illuminated by the CMH light source had significantly

higher chlorophyll content compared to the other light treatments. At day 7, the FO exposed tubers had significantly lower chlorophyll content compared to the CMH and Fluorescent with filter illuminated tubers. CMH exposed tubers had significantly the highest chlorophyll content at this sampling day. By day 9, CMH exposed tubers had significantly higher tuber chlorophyll content compared to the Fluorescent and FO. Placing a filter on the fluorescent light source did not impact the level of chlorophyll extracted from the exposed tubers. The dark control always had the lowest chlorophyll content in the experiment.

In experiment 2, tuber chlorophyll differences between light treatments were not apparent until day 4 when the FO exposed tubers had significantly lower chlorophyll content compared to the other light treatments. The results were similar for day 7. By day 9, the FO illuminated tubers had significantly lower chlorophyll content compared to the Halogen illuminated tubers. There was no difference in chlorophyll content between the FO and Fluorescent-P exposed tubers and the Halogen and Fluorescent-P exposed tubers. The dark control had the lowest chlorophyll content in the experiment.

Chlorophyll accumulation over the 9-day study was influenced by light source in a linear manner as indicated by the r^2-values listed in Table 6 for both experiments. The slope of the linear equation is an indicator of the rate of chlorophyll accumulation in the tuber as impacted by light source. Figures 2 and 3 plot the regression lines for chlorophyll accumulation over time between the light sources. In experiment 1, the FO, Fluorescent, and Fluorescent with filter illuminated tubers showed a significantly slower development of chlorophyll content with time compared to the CMH light source. There was no significant difference in the rate of chlorophyll accumulation between the Fluorescent light source and Fluorescent with filter. In experiment 2, different light sources were compared to the FO from experiment 1. The FO illuminated tubers accumulated chlorophyll at a slower rate compared to the Halogen illuminated tubers. There were no significant differences between rate of tuber chlorophyll accumulation when exposed to FO and Fluorescent-P and between Fluorescent-P and Halogen.

The visual and subjective rating for tuber greening followed a scale from 0 (no green) to 7 (severe green) developed by Grunenfelder (2005; Figure 1). In experiment 1, there was no significant difference between light sources on visual tuber greening at day 2 (Table 7). At day 4 and 7, the FO illuminated tubers had significantly less visual greening compared to tubers illuminated by the other light sources tested. By day 9, all tubers showed the same level of greening. There was no significant difference in visual greening of tubers under the CMH, Fluorescent and Fluorescent with filter light treatments. Tubers held in the dark had negligible visual greening. In experiment 2, by day 2 the FO exposed tubers had significantly less visual greening compared to the Halogen and Fluorescent-P illuminated tubers. By day 4, Halogen illuminated tubers had a significantly higher greening rating compared to FO exposed tubers, but there were no differences between Fluorescent-P and Halogen and Fluorescent-P and FO. At day 7, the FO treated tubers showed significantly less greening compared to the other light treatments. At day 9, Halogen illuminated tubers had a significantly higher greening rating compared to the FO treated tubers.

Unlike the differences between treatments in the rate of chlorophyll accumulation in tubers exposed to various light sources, there were no significant differences in the rate of visual greening over time (9 days) between treatments in both experiment 1 and 2

(Table 8). Figures 4 and 5 plot the regression lines for greening rating over time between the light sources for both experiments. Although the rate of greening is not significantly different between light source treatments, significant differences were observed between treatments on individual days (Table 7).

A retail market manager or consumer may have a range of levels that would be considered unacceptable greening in potatoes. Using the regression analysis equations for the rate of greening (Table 8), it would take 5.9 days (22-hour illuminated light per day) to reach a greening rating of 4 with tubers exposed to FO lighting compared to 5.4 days for Fluorescent with filter and 5.0 days with CMH and Fluorescent illumination. Under the Fluorescent-P it would take 4.5 days to reach a greening rating of 4, 4.3 days under Halogen, and 5.4 days under FO illumination. Using the FO light source to illuminate potatoes would provide approximately ½ to 1 day extended shelf- life compared to the other light sources tested in this study. The extension of potato shelf- life due to reduced greening with FO illumination is similar when using 2, 3 or 4 greening rating as a calculated unacceptable level.

Conclusions

The FO lights did not increase the ambient temperature around the illuminated tubers as great as the other light sources used in this study. Although differences in weight loss were not seen due to this temperature differential, it may have significant consequences on other fruits and vegetables with high transpiration rates.

The light intensities in the two experiments were maintained at levels comparable to those measured in the retail marketplace. Light intensity in the photosynthetically active region (PAR) was different between treatments such that the CMH light source had the highest PAR reading and the FO light source the lowest when compared in the same experiment. Higher readings with the Halogen light source compared to the FO light were also measured. Although the overall light intensity used to visually see the potato is comparable between light sources studied, the quality of light that influences chlorophyll production (red and blue regions of the light spectra) appears to be reduced under the FO lighting.

Depending upon the type of fluorescent light used, there were minimal differences between fluorescent (Sylvania) and FO illuminated tubers in both chlorophyll content and accumulation and greening response. Placing a filter on the fluorescent light did not impact the level of greening or chlorophyll content in the exposed tubers. In general, tubers exposed to the Promolux fluorescent light showed a higher level of greening and chlorophyll content compared to the FO. Overall, tubers exposed to FO light source did not accumulate chlorophyll as rapidly as tubers illuminated by the CMH and Halogen light sources. Differences between tuber greening on particular days was evident between FO, Halogen and CMH exposed tubers with FO tubers showing a lesser degree of greening.

It is important for the proper display and promotion of potatoes in the retail marketplace but to be accomplished in a manner to minimize the quality degradation that can accompany light exposure. The use of fiber optic lighting or a combination of fiber optic accent lighting and standard fluorescent lighting would help retard the progression of greening in the retail store yet highlight the commodity for consumer eye-appeal.

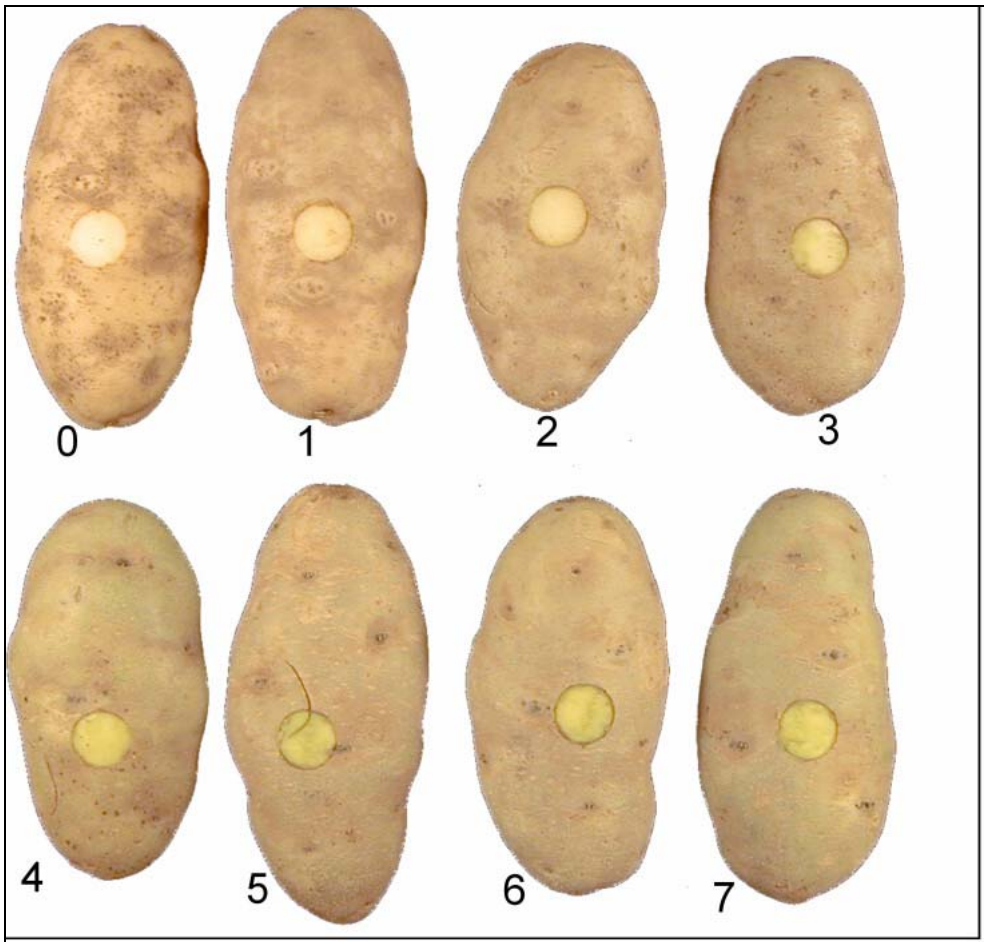

Figure 1. Greening rating scale developed by Grunenfelder (2005) for Russet Norkotah and adapted for Russet Burbank in this study.

Table 2. Photosynthetically active region (PAR) light measurements and temperature differential between the dark control and treatment. Values in the same column followed by the same letter are not significantly different at p=0.05.

Experiment #	Light source	PAR (µmol $s^{-1}m^{-2}$)	Temperature difference from dark control (°F)
1	FO	13.7 c	0.88 b
	CMH	20.3 a	1.81 a
	Fluorescent	17.2 b	1.78 a
	Fluorescent with filter	16.9 b	1.88 a
	$LSD_{0.05}$	1.2	0.18
2	FO	17.0 b	0.66 b
	Halogen	21.7 a	1.41 a
	Fluorescent-P	19.8 a	1.02 a
	$LSD_{0.05}$	2.5	0.43

Table 3. Percent weight loss of potatoes as influenced by days exposed to various light sources. Values in the same column followed by the same letter are not significantly different at p=0.05.

Experiment #	Light source	Day 2	Day 4	Day 7	Day 9
		% weight loss			
1	FO	0.33 a	0.63	0.93	1.05
	CMH	0.36 a	0.72	0.85	1.03
	Fluorescent	0.36 a	0.64	0.90	1.27
	Fluorescent with filter	0.38 a	0.63	0.87	1.03
	Dark	0.25 b	0.49	0.92	1.22
	$LSD_{0.05}$	0.07	ns	ns	ns
2	FO	0.35	0.58 b	0.96	1.09 b
	Halogen	0.40	0.62 b	0.92	1.15 b
	Fluorescent-P	0.43	0.72 a	0.95	1.38 a
	Dark	0.45	0.61 b	0.90	1.03 b
	$LSD_{0.05}$	ns	0.10	ns	0.21

Table 4. Total glycoalkaloid content (mg/100 g fresh tissue) of tubers as impacted by light source treatments. Initial glycoalkaloid content before treatments were 4.1 mg/100 g fresh tissue for Experiment 1 and 3.4 mg/100 g fresh tissue for Experiment 2 were not significantly different compared to the dark control. Values in the same column followed by the same letter are not significantly different at p=0.05.

Experiment #	Light source	Total Glycoalkaloids (mg/100 g fresh tissue)
1	FO	9.5 a
	CMH	11.0 a
	Fluorescent	10.3 a
	Fluorescent with filter	10.5 a
	Dark	3.5 b
	$LSD_{0.05}$	2.2
2	FO	7.2 a
	Halogen	9.3 a
	Fluorescent-P	9.0 a
	Dark	4.3 b
	$LSD_{0.05}$	2.1

Table 5. Total chlorophyll content (mg/g fresh weight) of tubers exposed to light sources sampled at various days during the experiment. Values in the same column followed by the same letter are not significantly different at p=0.05.

Experiment #	Light source	Day 2	Day 4	Day 7	Day 9
		Chlorophyll concentration (mg/g fwt)			
1	FO	162.6 b	379.9 b	637.0 c	994.8 b
	CMH	205.6 ab	589.2 a	1109.9 a	1273.5 a
	Fluorescent	215.7 ab	445.6 b	759.9 bc	1005.2 b
	Fluorescent with filter	243.2 a	457.7 b	860.7 b	1046.6 ab
	Dark	52.9 c	78.2 c	70.3 d	69.8 c
	$LSD_{0.05}$	79.8	123.5	161.1	243.8
2	FO	105.0 a	323.0 b	658.1 b	1001.3 b
	Halogen	110.7 a	575.4 a	856.6 a	1235.0 a
	Fluorescent-P	117.8 a	504.8 a	839.6 a	1053.2 ab
	Dark	29.0 b	35.2 c	29.7 c	30.6 c
	$LSD_{0.05}$	46.4	130.5	173.2	233.3

Table 6. Regression analysis of chlorophyll concentration versus days of light exposure for each light treatment (standard errors of the estimated regression coefficients are given in parentheses).

Experiment #	**Light source**	**Slope**	**intercept**	**r^2**
1	**FO**	**104.90 (7.832)**	**-22.04 (43.414)**	**0.85**
	CMH	**147.62 (7.639)**	**-7.08 (40.718)**	**0.77**
	Fluorescent	**108.19 (7.667)**	**15.27 (41.007)**	**0.83**
	Fluorescent with filter	**113.92 (7.639)**	**30.72 (40.577)**	**0.80**
2	**FO**	**103.47 (11.498)**	**-68.74 (64.056)**	**0.75**
	Halogen	**144.44 (12.398)**	**-75.42 (69.068)**	**0.83**
	Fluorescent-P	**122.56 (8.493)**	**-24.15 (47.313)**	**0.89**

Table 7. Rating of greening of tubers exposed to light sources sampled at various days during the experiment. Rating scale is patterned after Grunenfelder (2005) with 0= no green, 7= severe greening. Values in the same column followed by the same letter are not significantly different at p=0.05.

Experiment #	Light source	Day 2	Day 4	Day 7	Day 9
		Greening rating			
1	FO	2.4 a	2.8 b	4.3 b	6.0 a
	CMH	2.7 a	3.8 a	5.9 a	5.8 a
	Fluorescent	2.8 a	3.9 a	5.5 a	5.8 a
	Fluorescent with filter	2.3 a	3.6 a	5.3 a	5.7 a
	Dark	0.1 b	0.1 c	0.2 c	0.0 b
	$LSD_{0.05}$	0.5	0.4	1.0	0.9
2	FO	1.8 b	3.5 b	5.1 b	6.3 b
	Halogen	2.8 a	4.2 a	6.5 a	6.9 a
	Fluorescent-P	2.8 a	3.8 ab	6.4 a	6.7 ab
	Dark	0.1 c	0.0 c	0.0 c	0.1 c
	$LSD_{0.05}$	0.7	0.5	0.5	0.4

Table 8. Regression analysis of visual greening rating (subjective) versus days of light exposure for each light treatment (standard errors of the estimated regression coefficients are given in parentheses).

Experiment #	Light source	Slope	intercept	r^2
1	FO	0.6009 (0.0356)	0.4561 (0.1949)	0.83
	CMH	0.6378 (0.0442)	0.8102 (0.2423)	0.78
	Fluorescent	0.6197 (0.0448)	0.8734 (0.2436)	0.77
	Fluorescent with filter	0.6184 (0.0422)	0.6623 (0.2313)	0.79
2	FO	0.6870 (0.0277)	0.3271 (0.1515)	0.91
	Halogen	0.7603 (0.0288)	0.7212 (0.1576)	0.92
	Fluorescent-P	0.7334 (0.0318)	0.7231 (0.2081)	0.87

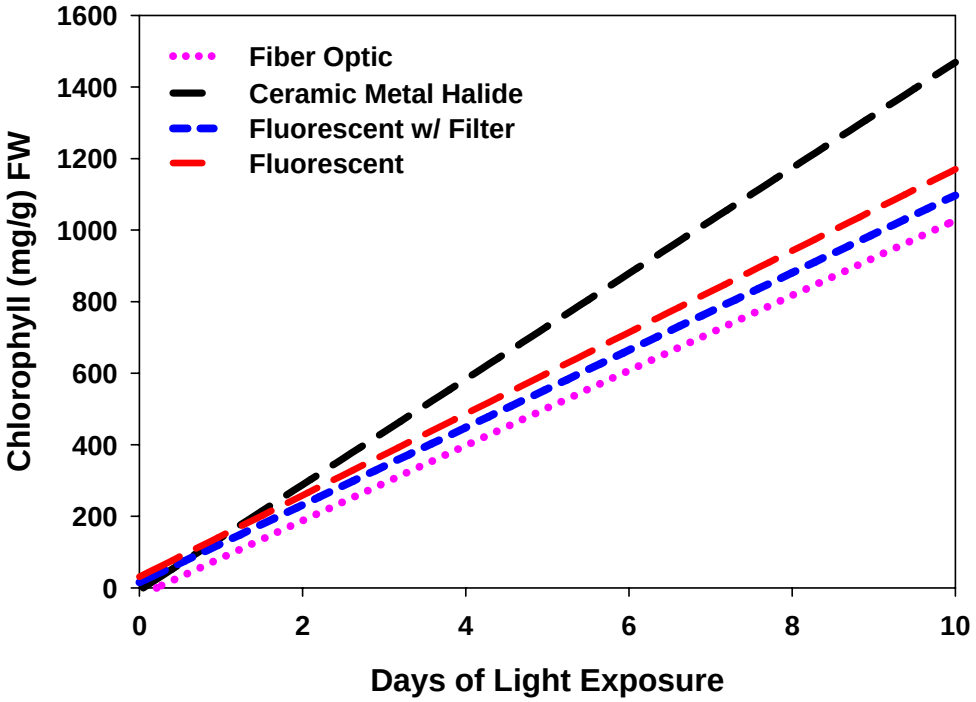

Figure 2. Linear regression equation of chlorophyll (mg/g fresh tissue) accumulation over time with various light sources.

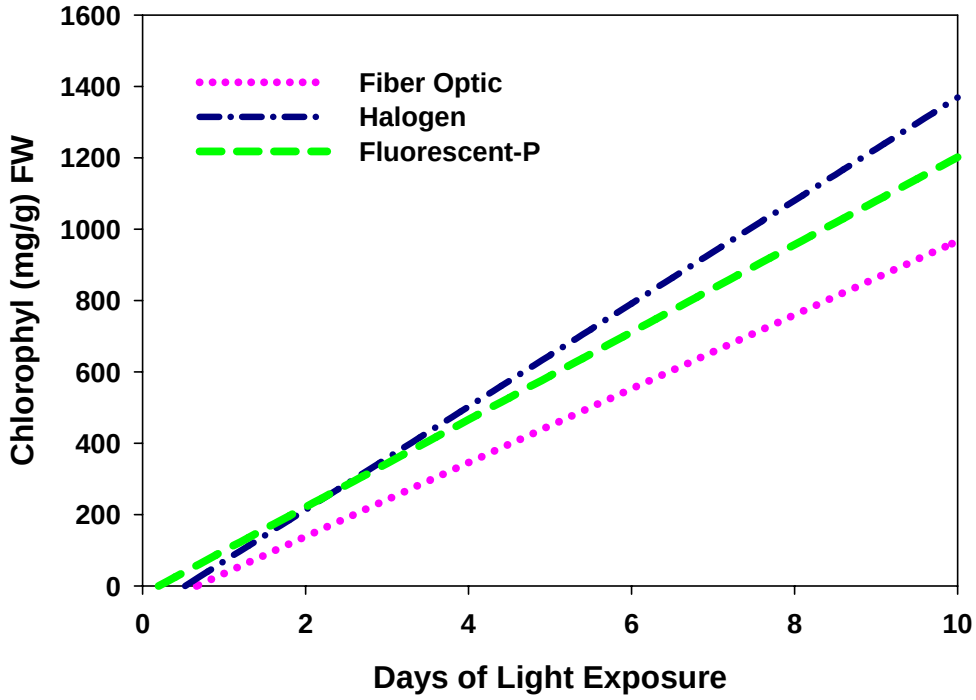

Figure 3. Linear regression equation of chlorophyll (mg/g fresh tissue) accumulation over time with various light sources.

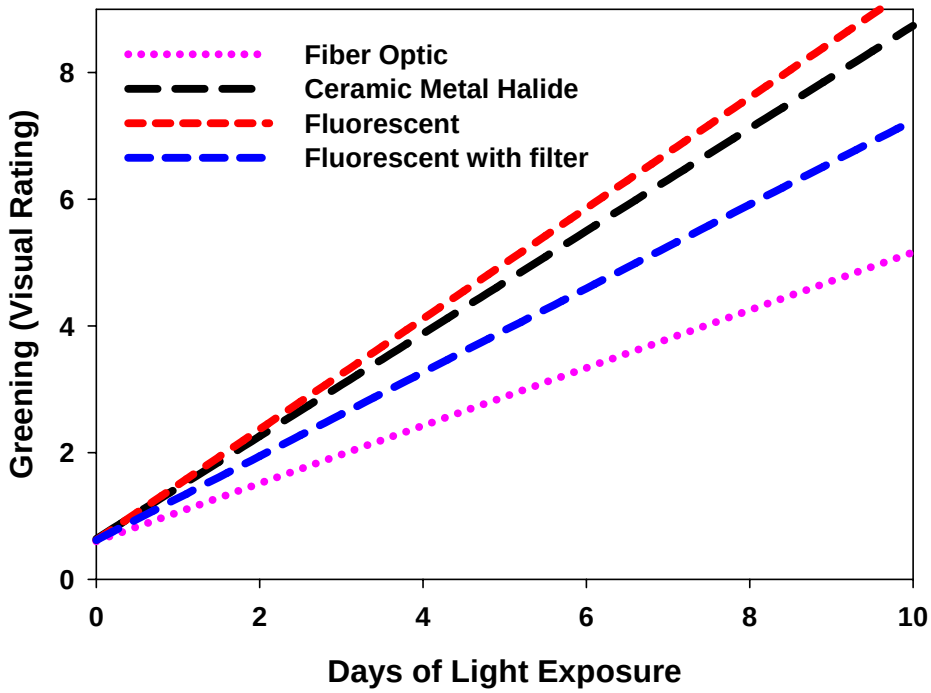

Figure 5. Linear regression equation of visual greening rating over time with various light sources.

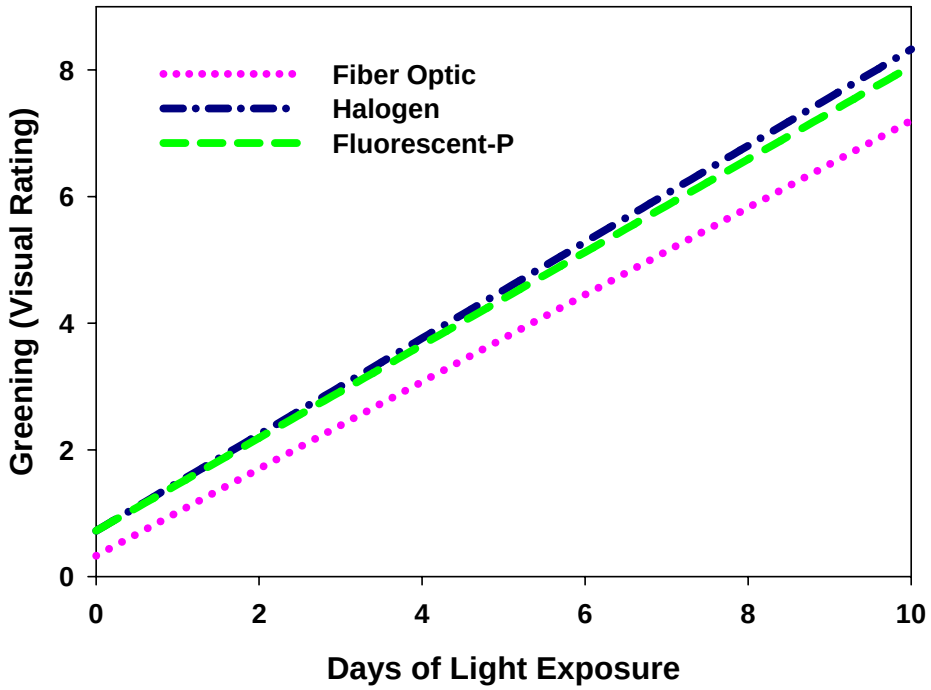

Figure 6. Linear regression equation of visual greening rating over time with various light sources.

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