Development of Grading Scales to Assess Tuber Greening in Retail Markets

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Potato tubers undergo an undesirable greening process when exposed to light, which is due to the development of chloroplasts in the cortical parenchyma tissue directly beneath the periderm (skin). The resulting discoloration is largely a function of the green chlorophyll contained within chloroplasts in conjunction with the natural skin color of a particular cultivar. The rate of greening depends on many factors, including pre- and post-harvest stresses, wounding, light exposure, temperature, lighting conditions, and genotype.

There are two main issues associated with potato greening: human health and marketability. Human health is a concern because of the independent and parallel development of steroidal glycoalkaloids in green tubers (Smith 1997, Edwards and Cobb, 1999). Glycoalkaloids are a naturally occurring and toxic group of secondary plant compounds found commonly in the foliage and tubers of members of the Solanaceae. Although no metabolic connection between greening and glycoalkaloid development has been established, green tubers are considered less fit for human consumption and are usually discriminated against by consumers. It has been estimated that between 14 and 27% of the U.S. potato crop is lost annually due to greening of tubers (see references in Morris and Lee, 1984). While produce managers routinely cull out potatoes that have greened, the process is very subjective and variable, due to the absence of specific grading criteria. Also, very little information exists regarding the time course and extent of greening under retail/fresh market conditions.

Accordingly, the U.S. Potato Board approached us to develop greening scales for selected fresh market cultivars that growers, shippers, and retailers could use for quality control. The objectives of the project were to: (1) characterize the time course of greening/chlorophyll development for selected fresh market cultivars; (2) develop an objective scale of greening for each cultivar that could be used by growers, shippers, and retailers to subjectively sort tubers based on changes in visible color; and (3) evaluate the effects of light intensity, photoperiod, and packaging on the greening process of tubers of selected cultivars. To accomplish these objectives we:

- Surveyed retail outlets for light intensities in various potato displays
- Acquired non-greened tubers from wholesalers
- Subjected the tubers to greening conditions characteristic of retail potato displays
- Quantified color changes of the tubers in relation to chlorophyll content
- Developed greening scales based on chlorophyll content
- Evaluated the utility of the greening scales for each cultivar by surveying the extent of greening in retail outlets

Determined the effects of light intensity, photoperiod, temperature, and packaging on the greening process.

Greening scales were developed for cvs. White Rose, Dark Red Norland, Yukon Gold, Norkotah Russet, and Reba. Because the changes in tuber color with progressive greening were subtle and can not be resolved in this publication, only a portion of the results for cv. White Rose are presented. We direct interested readers to view the high resolution pictures of the greening scales for each cultivar on our website www.wsu.edu/~fullern (click on 'Greening Indices for Fresh Market Potatoes').

General Methods

Plant Materials and General Procedures

Potato tubers (cvs. White Rose, Yukon Gold, Norkotah Russet, Dark Red Norland) were purchased in 50 pound boxes from a local grocery store directly off the supply truck. These potatoes, therefore, represented those that would be subject to greening in stores. The U.S. Potato Board provided samples of cv. Reba tubers. All tubers were stored at 4°C and 90% relative humidity in darkness prior to use.

Light intensities and temperatures for the various greening studies were chosen to match those typically found in grocery stores. Light intensity measurements from retail potato displays were compared among seven grocery outlets in the local area (Fig. 1). All stores displayed potatoes under relatively low levels of ambient light, either bagged (bagged/stacked bins) or piled without packaging on shelves (loose bins) at room temperature. Most of the stores also had tubers in lighted displays on cooler shelves. At tuber level, the average light intensities in the low-light, non-refrigerated areas and in the high-light, refrigerated displays averaged 6.3 mE m^{-2} sec^{-1} and 26 mE m^{-2} sec^{-1}, respectively (Fig. 1). Hence, unless otherwise specified, most of the greening studies were conducted at room temperature (23°C) and 6.8 mE m^{-2} sec^{-1} or 29.8 mE m^{-2} sec^{-1} light intensities.

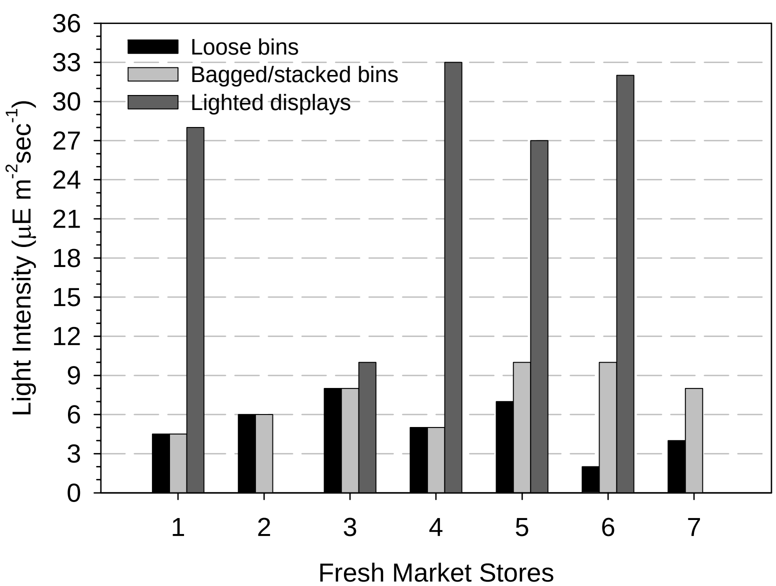

Fig. 1. Survey of light intensities in displays of potatoes at local grocery stores. Light intensities were measured at tuber height.

Color Assessment

Color of the undamaged surface of potato tubers was assessed using a Minolta Chroma Meter CIE 1976 (CIELAB). CIE refers to the Commission Internationale de I'Eclairage (International Commission on Illumination) and changes in tuber color during greening were quantified using the CIELAB color model. CIELAB is an opponent color system that integrates L, a, and b color axes to define color in three dimensions. L-values represent the change in lightness on a scale from 0 (black) to 100 (white). A-values represent color change from red (positive values) to green (negative values), while b-values show the change in color from yellow (positive values) to blue (negative values). The color at the origin of the three axes is gray. Hence, CIELAB uses a system of numerical coordinates to locate and thus define a particular color in a color sphere. Further information on CIELAB and the color sphere can be found at:

http://www.colourpeople.co.uk

http://adobe.com/support/techguides/color/colormodels/ceilab.html.

For each tuber, CIELAB measurements were taken at the stem end, middle, and bud end along the surface of the tuber facing the light. Hue angles (color saturation/intensity) were calculated and the values were averaged to characterize the color of a particular tuber. After the appropriate greening interval, chlorophyll was extracted from 1-mm-thick slices of periderm and was expressed as $\mu g/cm^2$ of potato tuber surface area.

Development of Greening Scales

To establish the subjective greening scales for industry use, tubers of each cultivar were placed daily on a light table (24-hour photoperiod, 6.8 $\mu E\ m^{-2}\ sec^{-1}$, 73^{o}F) and greened over a period ranging up to 10 days. The tubers were set out in reverse chronological order (the potatoes that would be greening for the longest were placed out first) so that all durations of greening could be sampled simultaneously at the end of the study. The tubers were re-randomized on the light table each day to minimize the effects of variation in light intensity. The color of each tuber was measured at zero time and at the end of greening. The tubers were photographed at the end of the study to document the variation in tuber greening due to light exposure time and among replicates. Tubers were selected visually for each cultivar, according to the degree of greening, to develop the scale of greening for each cultivar. The greening scales ranged from 0 to 7 or 0 to 9, depending on the cultivar (0 = no greening, 7 or 9 = maximum greening). Tuber color (CIELAB) was measured and chlorophyll was extracted and quantified from replicates of tubers representing each level of the greening scale.

Analysis of the Extent of Tuber Greening in Retail Markets

Tubers of each of four cultivars (White Rose, Yukon Gold, Dark Red Norland, and Russet Norkotah) were selected at random from the shelves of local grocery retailers. The tubers of each cultivar were then graded visually for color, using the greening scales developed in earlier experiments. The percentages of tubers falling into each greening level are reported for each cultivar (n = 120).

Greening of White Rose

Time Course of Greening

At room temperature and relatively low light intensity (24-h photoperiod), White Rose tubers underwent a change in color that could be quantified using the CIE (Commission Internationale del E'clairage) L*a*b color system (CIELAB). The L-value (measure of lightness) of tubers decreased linearly over the 5-day interval, reflecting a darkening of the tuber surface with progressive greening (Fig. 2). In contrast, the hue angle (red to green) of tubers increased over the greening period, in direct response to increases in chlorophyll content of the underlying cortical tissue (Fig. 2). These changes in color were induced at a light intensity (6.8 mE m^{-2} sec^{-1}) commonly found in retail markets.

Development of Greening Scale

White Rose tubers that had greened over the 5-day interval were sorted visually, based on the extent of greening, to create a ten-level scale that industry can use to sort tubers subjectively, as they move through the various distribution channels (Fig. 3). A high-resolution rendition of Figure 3 can be viewed at www.wsu.edu/~fullern/greening/Greening.htm. As tuber greening increased from zero to nine, L-values and hue angles changed to reflect those expected for each level of greening (Fig. 4). Moreover, chlorophyll content of tuber tissue increased linearly over the greening scale, effectively calibrating the scale for chlorophyll concentration. Note that green-9 tubers contain approximately 2.3-fold more chlorophyll than green-3 tubers (Fig. 4) and that the time required to green from stage three to nine was about 4 days (Fig. 5). At 6.8 mE m^{-2} sec^{-1}, this particular lot of White Rose tubers advanced by one level on our greening scale (Fig. 3) for every 17 h of photoperiod. Hence, the ten-level greening scale (Fig. 3), together with the derived time course of greening (Fig. 5), provide a guide for quality control and estimating the shelf life of White Rose potatoes in retail markets. Accordingly, these two figures have been combined into a single plate to constitute the greening scale and guide for White Rose potatoes (see www.wsu.edu/~fullern/greening/Greening.htm). It should be noted, however, that the physiological status of tubers, which no doubt varies among tuber lots, will likely influence the rate of greening and thus estimates of remaining shelf life. Physiological and chronological age, degree of periderm development, storage temperature, etc., all interact to affect tuber physiological status.

Color Range of Tubers in Retail Markets

Tubers were sampled from four grocery stores and the extent of greening was assessed to validate the utility of the White Rose greening scale. The majority of tubers (89%) fell into the range of zero to three, with the extent of greening never exceeding seven on the scale (Fig. 6). The relatively low percentage of tubers in the four to seven range is likely a consequence of quality control efforts imposed by produce managers, in combination with consumer-dependent turnover of potatoes on the shelves. Interestingly, there was much variation among stores with regard to the proportion of tubers in each category, reflecting variable quality control. Clearly, there is a need for the development and implementation of more consistent grading procedures and methods to reduce greening in retail markets.

Greening scales for Dark Red Norland, Russet Norkotah, Yukon Gold, and Reba were developed using the same approach as that described for White Rose. These scales can be accessed at www.wsu.edu/~fullern/greening/Greening.htm. We are currently quantifying glycoalkaloid content of tubers at each level of greening.

Summary & Conclusions

- Tuber color changed rapidly (within 6 days) as chlorophyll concentration increased in response to light intensities and temperatures identical to those found in potato displays in local grocery stores.
- The visual perception of greening was most apparent in the white-skinned cultivar, White Rose, as compared to the red- and russet-skin cultivars.
- Variation among cultivars in periderm thickness, color and presence of accessory pigments interact to affect the degree of discoloration during greening, which will no doubt influence the degree of discrimination by consumers for potatoes that have greened. Therefore, cut-off values on the various greening scales, beyond which tuber color is unacceptable, will vary among cultivars.
- While the remaining shelf lives of 'White Rose', 'Yukon Gold', 'Dark Red Norland', and 'Norkotah Russet' tubers can be estimated from derived plots of greening scales vs. time, the physiological status of a particular lot of potatoes can affect the rate of greening.
- Much variation exists among retail outlets for the extent of greening in potatoes on the shelves, underscoring a need for the development and implementation of more consistent grading procedures.
- The greening scales developed in this project were shown to be effective for subjectively grading tubers from local markets for color.
- Reducing light intensity directly, or indirectly through packaging had little effect on the rate of greening. Tubers are highly sensitive to low levels of light for chlorophyll development, which is likely a consequence of the involvement of phytochrome in the response.
- Reducing the photoperiod from 24 to 18 hours did not slow the greening process, suggesting that covering tubers in retail markets with light-tight 'blankets' will likely not be effective for attenuating greening.
- Reduced temperature slowed the rate of greening; however, use of refrigerated shelf space for bulk potatoes in retail markets must be justified economically.

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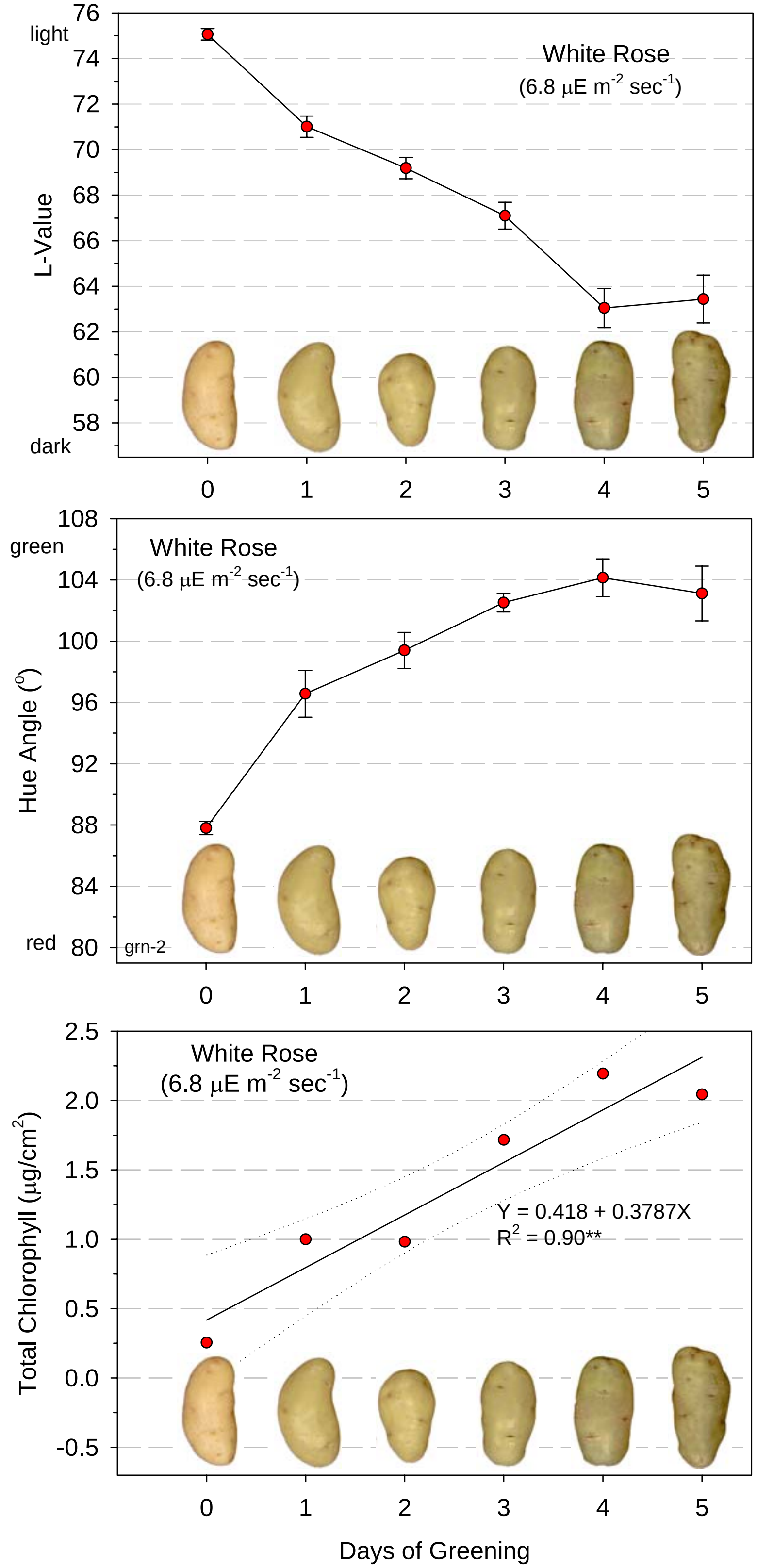

Fig. 2. Changes in L-value (relative darkness), hue angle (red to green) and total chlorophyll content of White Rose tubers during 5 days of greening at 73^{o}F. Tubers were incubated under cool white fluorescent light (6.8 mE m^{-2} sec^{-1}) for 24 h per day. Chlorophyll was extracted from 1-mm-thick x 1.5-cm-diameter discs of periderm from the side of the tubers facing the light. Dotted lines indicate 95% confidence intervals.

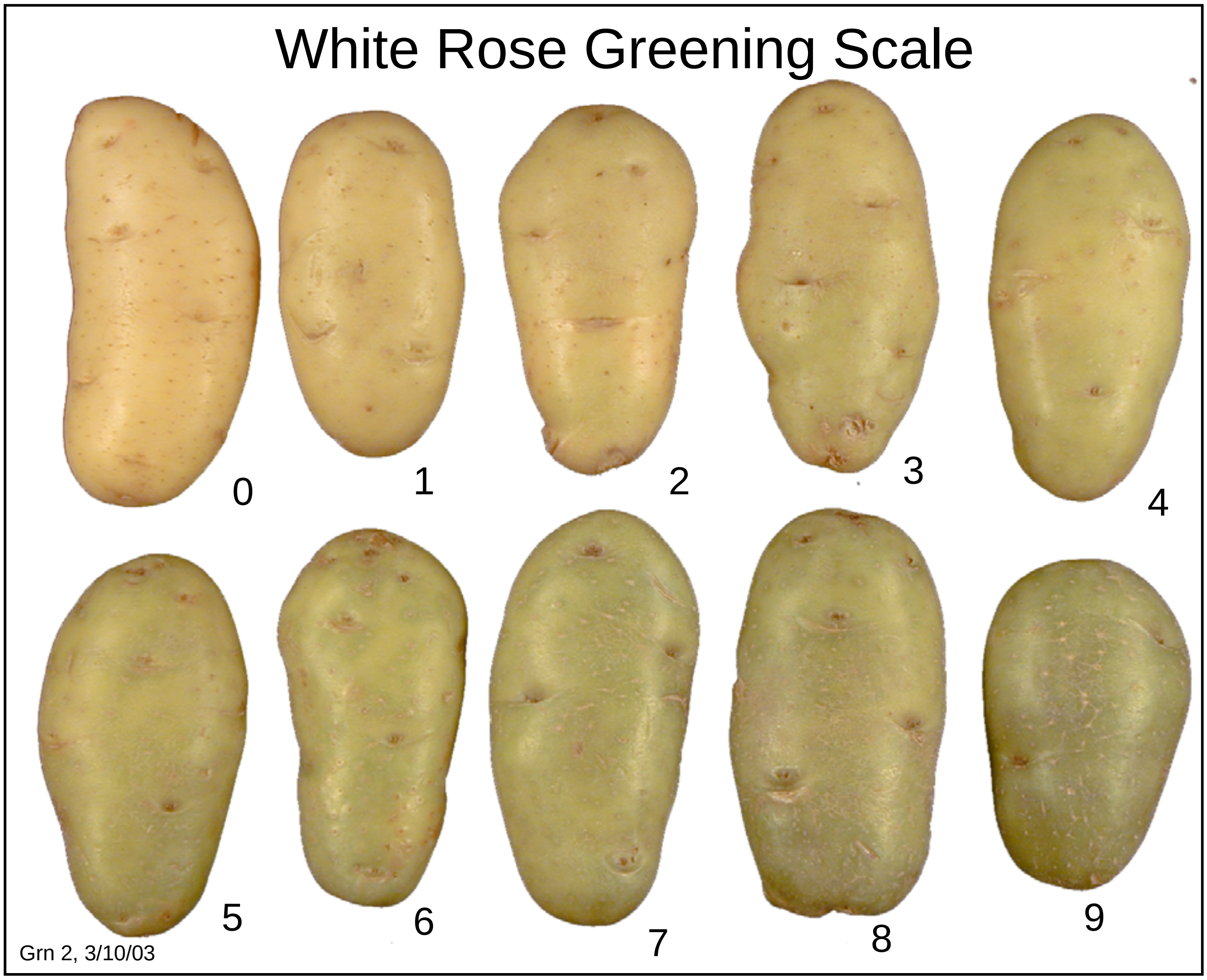

Fig. 3. Greening scale for White Rose tubers. Tubers were greened for 5 days under fluorescent light and then sorted subjectively (based on visual differences in color) into ten greening levels. Color and total chlorophyll content of tubers in each greening level are quantified in Fig. 4. This greening scale can be viewed in high-resolution color at www.wsu.edu/~fullern/

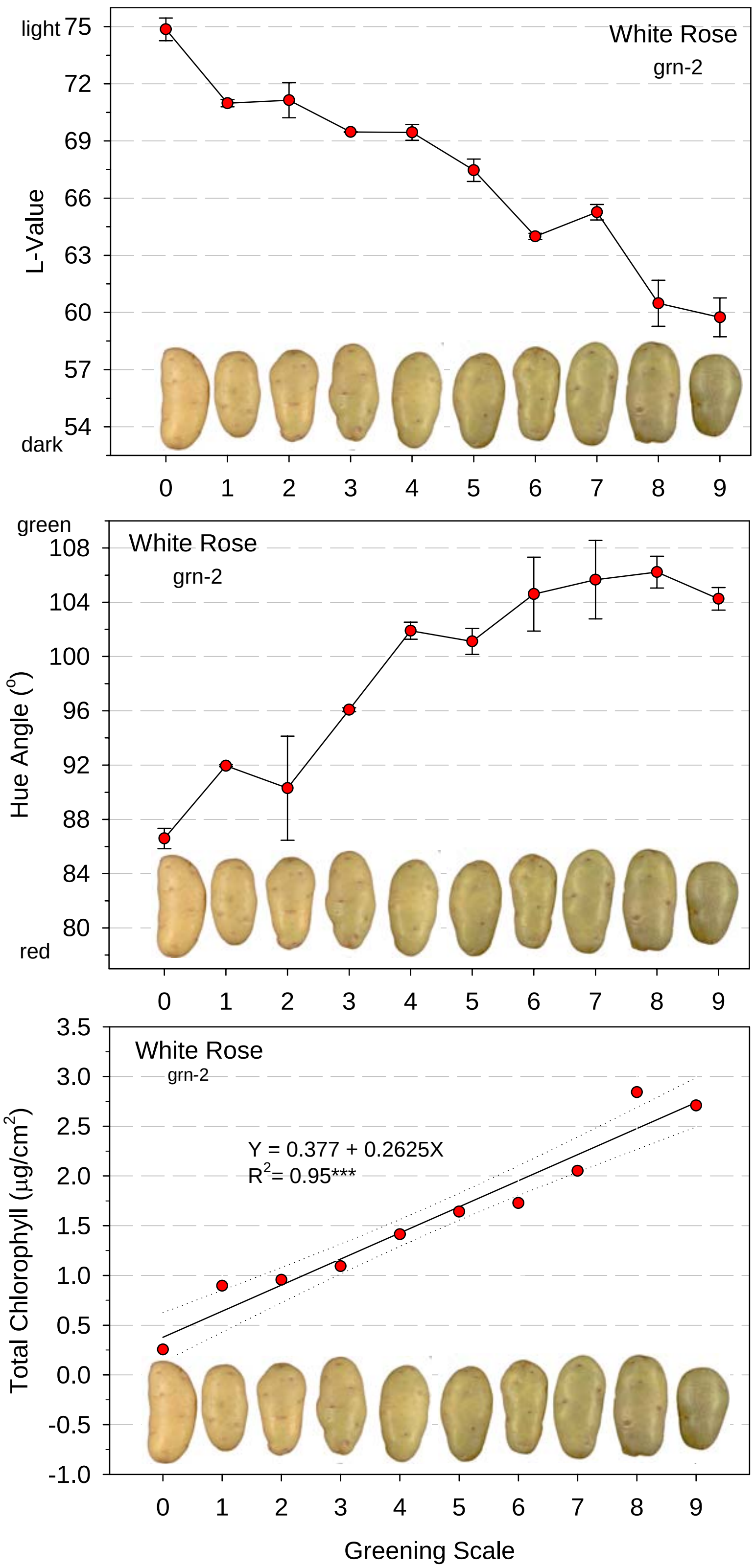

Fig. 4. Changes in L-value (relative darkness), hue angle (red to green) and total chlorophyll content of White Rose tubers over ten levels of greening. Tubers were greened for 5 days at 73°F and sorted into ten categories based on visual color differences (see Fig. 3). Note that the visual perception of greening in this cultivar is linear with respect to chlorophyll content of tubers. Dotted lines indicate 95% confidence intervals.

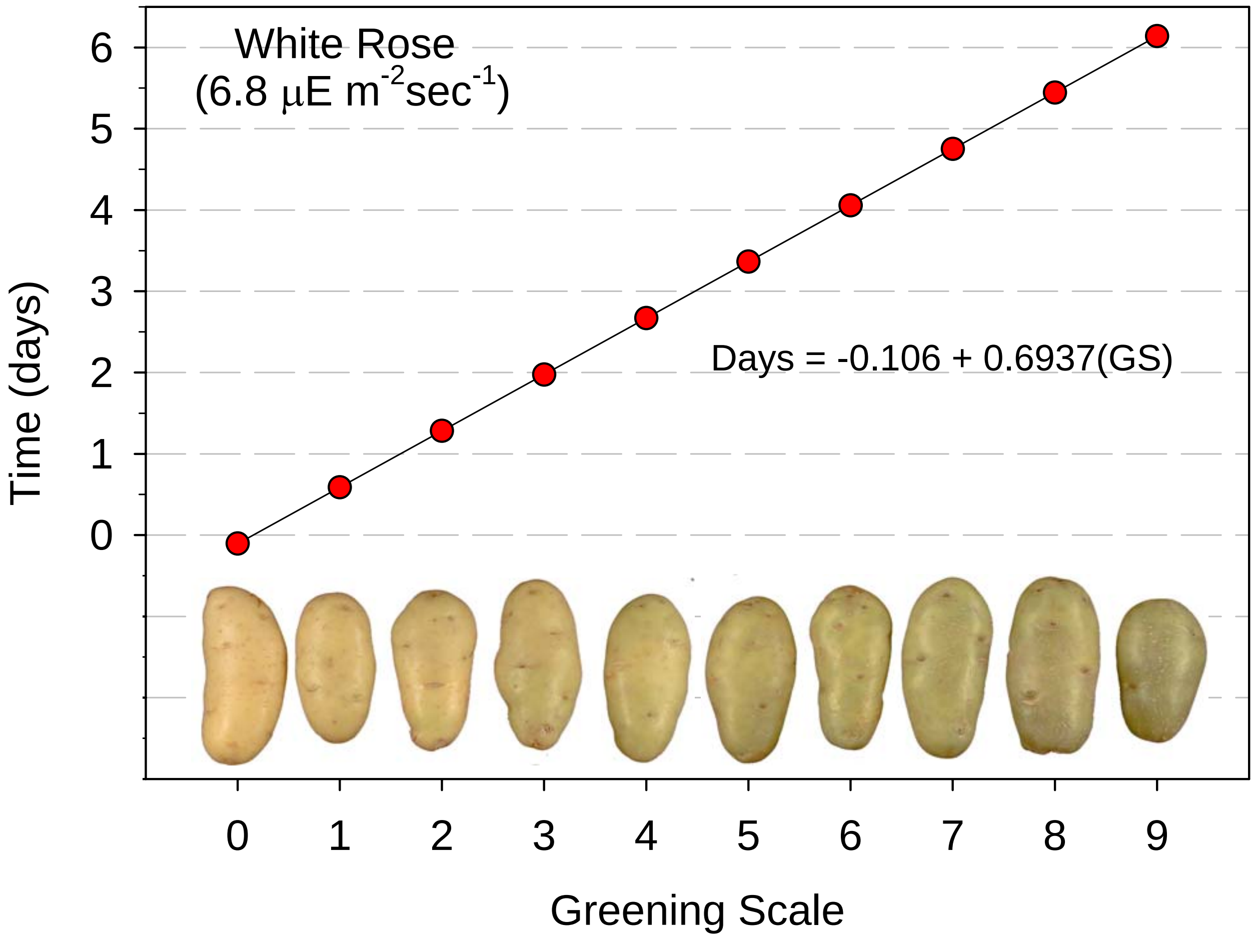

Fig. 5. Estimated time required for White Rose tubers to green over the ten-level greening scale. This graph was derived by calculating the chlorophyll content in tubers associated with each level of greening (Fig. 4 bottom) and then estimating the corresponding days of greening (from the linear equation at the bottom of Fig. 2). Note that about 17 h of constant (24-h) exposure to 6.8 mE m^{-2} sec^{-1} light intensity are required for tubers to change one level on the greening scale. This relationship can be used to estimate the remaining shelf life for any

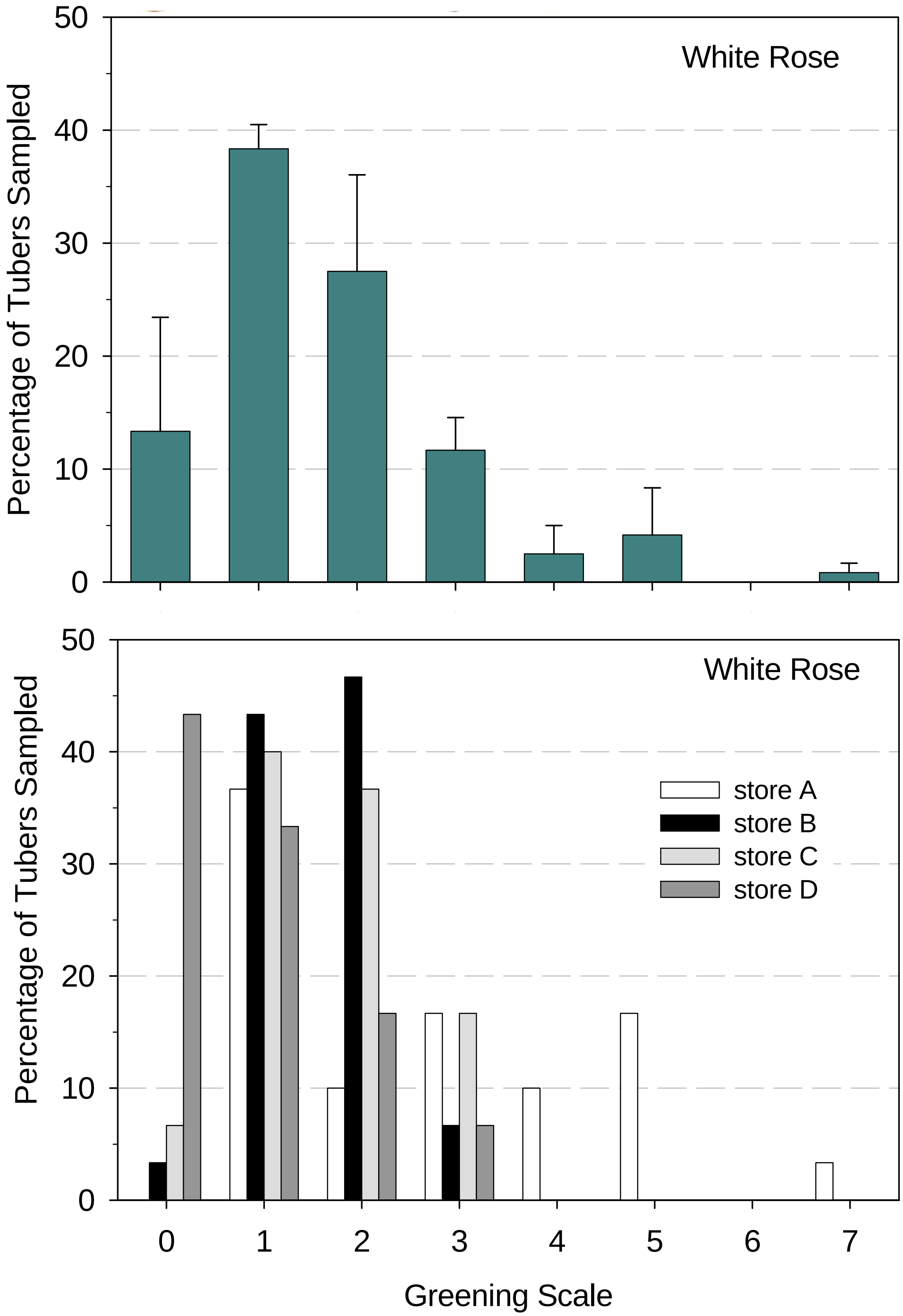

Fig. 6. Survey of the extent of greening of White Rose potatoes in retail outlets. Tubers were purchased from four stores and graded for color using the ten-level greening scale depicted in Fig. 5. Thirty tubers were sampled from each store. Upper graph shows the percentage of tubers in each category averaged over all stores. Lower graph shows the store-to-store variation in greening.