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Color indices for the assessment of chlorophyll development and greening of fresh market potatoes

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Abstract

When displayed under supplemental lighting, potato (*Solanum tuberosum* L.) tubers develop chlorophyll, which leads to undesirable greening. Produce managers routinely cull potatoes that have greened; however, the process is subjective and variable, due to the absence of specific grading criteria and a lack of information on the time course and extent of greening under retail/fresh market conditions. The objectives of this study were to characterize the time course of greening/chlorophyll development for selected fresh market cultivars and to develop objectively-based scales of greening to subjectively sort tubers based on changes in visible color in retail markets. A survey of retail outlets showed that most potatoes are displayed at relatively low light intensities, ranging from 2 to 10 μmol quanta m^{-2} s^{-1} (400–700 nm). At 6.8 μmol quanta m^{-2} s^{-1}, chlorophyll concentrations in cells underlying the periderm of cultivars White Rose (WR), Yukon Gold (YG), Dark Red Norland (DRN), Russet Norkotah (RN), and Reba (R) increased linearly over a 5–7 day greening interval. The increased chlorophyll content affected changes in the *L*-value (darkness) and hue angle (color) of the periderm, characterizing the off color development unique to each cultivar. A greening scale was developed for each cultivar by subjectively selecting tubers from a population that had greened for 0–7 days to achieve a visually perceivable sequence of greening that spanned 8–10 levels, depending on the cultivar. Chlorophyll content increased linearly over the greening scales for WR, YG, and DRN ($R^2 = 0.95$–0.98, $P \leq 0.001$), whereas the relationships were quadratic ($R^2 = 0.96$–0.97, $P \leq 0.001$) for R and RN. These data calibrated the scales for chlorophyll concentration and indicated that the visible color changes were directly linked to chlorophyll development. The discoloration resulting from greening and characterized by changes in hue angle was dictated by chlorophyll in conjunction with the periderm color unique to each cultivar.

Keywords: *Solanum tuberosum*; Greening; Chlorophyll development; Light; Tubers

1. Introduction

Potatoes undergo a greening process when exposed to light, due to the transformation of amyloplasts to chloroplasts, along with assembly of the photosynthetic apparatus (Anstis and Northcote, 1973; Edwards, 1997; Pavlista, 2001). After a certain minimum time of exposure to light, chlorophyll production is induced in the cortical parenchyma tissue directly beneath the periderm (Petermann and Morris, 1985). The rate of chlorophyll synthesis is affected by many pre- and post-harvest factors including wounding, light exposure, temperature, and lighting conditions, as well as genotype (Smith, 1977; Reeves, 1988; Edwards and Cobb, 1997; Percival, 1999). The discoloration resulting from greening is a function of the green chlorophyll in conjunction with accessory pigments in the cortex and periderm, and is thus cultivar dependent.

The two main issues associated with potato greening are human health and marketability. Human health is a concern because of the independent and parallel development of steroidal glycoalkaloids in green tubers (Smith, 1977; Edwards and Cobb, 1997). Glycoalkaloids are a naturally occurring and toxic group of secondary plant compounds found throughout the foliage and tubers of members of the Solanaceae. In small amounts, glycoalkaloids contribute to potato flavor (Edwards, 1997). However, at higher levels, glycoalkaloid consumption can result in symptoms ranging from

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nausea to coma and even death in extreme cases (Morris and Lee, 1984; van Gelder, 1990). Glycoalkaloids impart a bitter flavor to the potato when levels exceed 15 mg per 100 g fresh weight (fwt) and the FDA has established an upper limit of 20 mg per 100 g fwt for new cultivars (Phlak and Sporns, 1992).

Although no metabolic connection between chlorophyll and glycoalkaloid development has been established, by association, green tubers are considered less fit for human consumption and are usually discriminated against by both consumers and processors. It has been estimated that between 14 and 17% of the U.S. potato crop is lost annually due to greening of tubers (see refs. in Morris and Lee, 1984). While produce managers routinely cull potatoes that have greened, the process is subjective and variable, due to the absence of specific grading criteria.

Currently, little information is available regarding the time course and extent of greening under retail/fresh market conditions. A number of studies have used various methods to rate the level of greening (Folsom, 1947; Hardenburg, 1954; Reeves, 1988); however, the bases for the subjective rating schemes were never described adequately nor related to objective criteria to the extent that would allow their use by industry. Hence, there are currently no specific grading criteria based on objective measures of color and chlorophyll content that can be used for subjectively evaluating the extent of greening in fresh market cultivars.

This study characterizes the process of greening in relation to color changes in a number of fresh market cultivars. The main objective was to develop greening scales, based on changes in chlorophyll concentration and the associated changes in periderm color at a light intensity characteristic of local retail outlets, for subjectively sorting red-, russet-, and white-skinned cultivars for greening during handling, distribution, and marketing. The validity of the scales for evaluating and grading the color changes associated with greening of potatoes has been demonstrated in surveys of the extent of greening in local retail outlets (Grunenfelder, 2005).

2. Materials and methods

2.1. Plant materials and general procedures

Potato (*Solanum tuberosum* L.) tubers (cvs. White Rose,WR; Yukon Gold, YG; Russet Norkotah, RN; Dark Red Norland, DRN) were purchased in 22.7-kg boxes from a local grocery store directly off the supply truck. These potatoes thus represent those that would be subject to greening under lighting conditions present in the retail market. The U.S. Potato Board provided samples of cv. Reba tubers. All tubers were stored at 4 °C and 95% 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, as determined in initial surveys. Light intensity measurements from various retail potato displays were compared among seven major grocery retailers in the local area (Fig. 1). All stores displayed the majority of their 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 refrigerated shelves. At tuber level, the average light intensities in the low-light, non-refrigerated areas was 6.8 μmol quanta m^{-2} s^{-1} (400–700 nm) while the tubers stored in the high-light, refrigerated displays averaged nearly 28 μmol quanta m^{-2} s^{-1} (Fig. 1). The light intensities were approximately the same upon return visits over the 2-year study period. Hence, the greening studies were conducted at room temperature (23 °C) and 6.8 μmol quanta m^{-2} s^{-1} light intensity to represent the low light areas of the retail outlets.

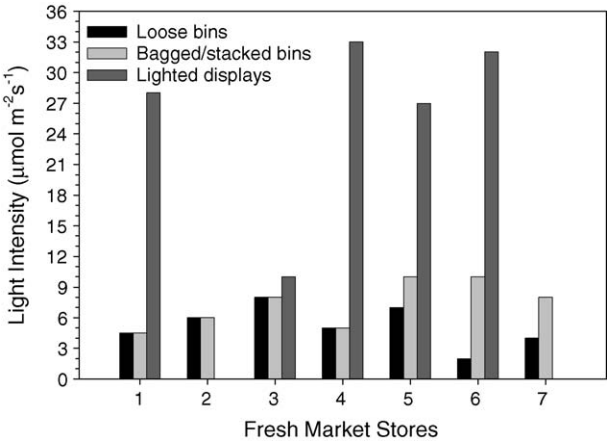

Fig. 1. Survey of light-intensities in displays of potatoes at local grocery stores. Light intensities were measured at tuber height in μmol quanta m^{-2} s^{-1} (PPFD, 400–700 nm).

Light intensity was measured with a quantum sensor (Model LI-185B, Li-Cor, Inc., Lincoln, NB) as photosynthetic photon flux density (PPFD, μmol quanta m^{-2} s^{-1}) in the 400–700 nm range. Photographs to document the extent of greening were taken using a Nikon Cool-Pix 950 digital camera (Nikon Corp., New York). A ventilation hood with fluorescent lighting (Sylvania RapidStart SuperSaver 34 W Cool White fluorescent tubes) was used as a light table for the greening experiments with a 24-h photoperiod averaging 6.8 μmol quanta m^{-2} s^{-1} at tuber level, simulating standard retail conditions. The fluorescent lights had spectral peaks at approximately 360, 410, 435, 545, and 575 nm.

2.2. Color assessment

Objective color measurements (CIELAB units L*a*b*) of the undamaged surface of potato tubers were assessed using a Minolta Chroma Meter CIE 1976 (Model CR-200, Minolta Corporation, Ramsey, NJ). CIELAB measurements were taken at three points on the light-exposed surface of each potato tuber (five replicates), including the basal, middle, and