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# Measuring the green color of vegetables from digital images using image analysis

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A B S T R A C T

When analyzing the color of foods, a measurement device consisting of a digital camera and image analysis software is an attractive alternative to traditional instruments such as spectrophotometers, colorimeters and sensory evaluations. The device enables the measuring of the surface of a sample pixel-by-pixel and offers versatile possibilities for new imaging-based analysis strategies for food research. Our objective was to evaluate if this apparatus could detect differences in colors existing in green vegetables. We showed that the device separated batches of green vegetables and detected color differences that existed in vegetables with different degrees of green color. We demonstrated that this device could measure the color change of green vegetables during heat treatments. We conclude that this experimental setup has the potential to evaluate the healthiness of a diet by analyzing the proportion and quality of green vegetables for use in a serving at a buffet table or dinner plate.



## 1. Introduction

Food is typically first sensed through visual perception (Cardello, 1996). Colors are the most important factor in sight and this influences the sensed safety, pleasantness and acceptability of food (Clydesdale, 1993). The sensed color also affects other sensory perceptions, such as the taste of food (Cardello, 1996). Vegetables with higher chroma and thus more vivid colors, such as vegetables with a bright green color, are associated with freshness and better color quality compared to vegetables with a dull color (Canjura, Schwartz, & Nunes, 1991; Lee, Lee, Lee, & Song, 2013). Thus accurate measurement of the intensity and the hue of green color and also the quantity of green in a food serving are important as indicators of freshness, sensory quality and overall healthiness of the diet (WHO, 2014). Earlier, several studies have investigated both the changes and maintaining of green colors in vegetables (Canjura et al., 1991; Clydesdale & Francis, 1968; Haisman & Clarke, 1975; Schwartz & von Elbe, 1983; Tijskens, Schijvens, & Biekman, 2001). However, the methods introduced in these studies are time-consuming and often require intensive sample preparation. In food quality research, a reliable measurement of colors, such as the amount and intensity of greens in the diet, is needed.

Green colors present in fruits and vegetables are due to chlorophyll molecules, mainly due to chlorophyll a and b, which are found in higher plants at approximately a ratio of 3:1 (Schwartz & Lorenzo, 1990). According to DeMan (1999, chap. 6), the magnesium atoms of chlorophylls are easily removed by acids that naturally occur in plant tissues giving pheophytins with olive-green colors. In undamaged plant tissues, chlorophylls are bound to lipoproteins and protected from acids, but for example, heating causes the coagulation of these proteins and lowers their protective effect (DeMan, 1999, chap. 6). During prolonged heating, pheophytins degrade further to pyropheophytins *via* decarbomethoxylation (Schwartz & von Elbe, 1983; Schwartz, Woo, & von Elbe, 1981; Teng & Chen, 1999).

Food color can be measured either by visual or instrumental determinations (Hunt & Pointer, 2011, chap. 5). By eye, visual color measurements are time-consuming, often laborious to perform and are subjective and call for accurate instrumental measurements (Hunt & Pointer, 2011, chap. 5). One of the most common systems to describe the color quantitatively are CIELAB-coordinates. These coordinates describe color by using three quantities: $L^*$, $a^*$ and $b^*$ (CIE Technical Report: Colorimetry, 2004; HunterLab, 2001). Coordinate $L^*$ describes the lightness of a sample, location in the gray axis from black to white and coordinates $a^*$ and $b^*$ describe the

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color, from green to red and from blue to yellow, respectively (HunterLab, 2001). The chroma, $C^*$, of the samples can be expressed as a square root of squares of coordinates $a^*$ and $b^*$ ($= \sqrt{a^{*2} + b^{*2}}$) (CIE Technical Report: Colorimetry, 2004). The total color difference expressed as: $\Delta E$ $\left(= \sqrt{(L_1^* - L_2^*)^2 + (a_1^* - a_2^*)^2 + (b_1^* - b_2^*)^2}\right)$ describes the color distance in this three-dimensional color space (CIE Technical Report: Colorimetry, 2004). Color differences of 1 and 2.3 units are barely noticeable by sensorial analysis (Hill, Roger, & Vorhagen, 1997; Mahy, Eycken, & Oosterlinck, 1994).

Traditionally, color coordinates are determined by using colorimeters or spectrophotometers (Balaban & Odabasi, 2006). Most commercial instruments demand that the surface measured is homogenous and moreover, complex shapes or small-sized samples can make the measurements difficult and thus, before measurements, the sample often needs to be prepared, for example, by grinding (Balaban & Odabasi, 2006; León, Mery, Pedreschi, & León, 2006; O'Sullivan et al., 2003; Segnini, Dejmek, & Öste, 1999; Yam & Papadakis, 2004). This takes time, renders the sample no longer usable and changes the sample color (Balaban & Odabasi, 2006; Yam & Papadakis, 2004). A measurement device that consists of a digital camera and image analysis software has made it possible to finely analyze the whole surface of sample pixel-by-pixel and offers versatile possibilities (O'Sullivan et al., 2003; Wu & Sun, 2013). Due to its versatility and simplicity, this kind of measurement device has emerged as an attractive alternative to traditional color measurement devices (Yam & Papadakis, 2004). Most of the devices reported are sophisticated computer vision systems, but also simpler measurement devices have been used (Yam & Papadakis, 2004). Various papers have studied the development of calibration and measurement methods (León et al., 2006; Valous, Mendoza, Sun, & Allen, 2009; Yam & Papadakis, 2004), detecting and analyzing unevenness from the surfaces of food samples and analyzing the color distributions from the surface of the samples with instruments based on digital camera technology (Segnini et al., 1999; Valous et al., 2009). Also methods for grading various food products such as mushrooms (Heinemann et al., 1994), strawberries (Liming & Yanchao, 2010) and apples and potatoes (Tao, Heinemann, Varghese, Morrow, & Sommer, 1995) have been developed. Furthermore, recently, a color measurement device based on image analysis has been used in determining the kinetics of color change in cookies during deep-fat frying (Abdollahi Moghaddam, Rafe, & Taghizadeh, 2014), real-time color changes that occur during hot air drying in apple slices (Nadian, Rafiee, Aghbashlo, Hosseinpour, & Mohtasebi, 2015) and quality change in whole and fresh-cut lettuce (Pace, Cefola, Da Pelo, Renna, & Attolico, 2014).

Here, we evaluated a color measurement device that used digital camera and image analysis technology to quantify the proportion and quality of green vegetables in a common meal. Our method was designed to detect the variation in greenness of the same vegetable material (green beans) as well as changes during heat treatment. Finally, the ability of the method of distinguishing between different shades of green and thus different vegetables was studied. The vegetable materials and processing methods were chosen so that they were similar to those available for consumers.

## 2. Materials and methods

### 2.1. Samples and reagents

Green beans (*Phaseolus vulgaris* L.) were bought from a local supermarket in the morning of examinations. Between measurements, the samples were kept in a refrigerator (+8 °C) protected from light. Both domestic (Finnish) and imported (Kenyan) batches (referring to a group of beans bought at the same time) were used. Other vegetables studied, leaf lettuce (*Lactuca sativa* L. var. *crispa* L.), cucumber (*Cucumis sativus* L.), frozen seeds of green peas (*Pisum sativum* L.) and basil (*Ocimum basilicum* L.), were bought in the morning of examinations from a supermarket and stored in a refrigerator (+8 °C) before and in-between examinations. All samples studied were from domestic breeders and all of the examinations were made during summer and autumn of 2013. Oxalic acid for acid treatments (purity ≥ 99.0%, dehydrated) was purchased from Sigma–Aldrich Co.

### 2.2. Instruments

The color of green vegetables was measured using a device consisting of a digital camera (Go − 5, Qimaging Ltd) with a zoom lens (Computar M6Z 1212-3S) attached to an adjustable stand (Kaiser RSX, *Kaiser Fototechnik Gmbh*) and image analysis software (Image Pro Plus 7.0, Media Cybernetics) with plugin programs ("Color Lab" and calibration macros by Cheos Co.). The measurement area was illuminated with two lamps imitating D65 lightning conditions. Lamps were attached at a 45° angle so that the geometry of measurements was 0°/45°. The camera was attached at a distance of 1 m. The background was covered with a white paper sheet. The photos taken with the camera were 48-bit and at a resolution of 2592 × 1944 and the exposure time was 50 ms. The zoom was set such that the target area was 400 × 300 mm. Information collected with the camera was sent to the computer *via* a USB-cable.

A calibration palette with 140 color patches (X-Rite, Colorchecker Digital, D50 lightning conditions, 2° standard observer) was used in calibrations. Calibration was performed using twenty carefully chosen colors (patches C9, D6, E2, E5, E9, F4, F9, G7, H2, H5, H7, H9, I3, I9, J5, J7, J8, J9, K9, L8) from the palette. The colors were chosen by visual evaluation such that they resembled the colors of the samples (greens and browns). Also, grayscale patches were chosen to adjust the white balance of images. Multiple sets of calibration colors were tested in order to produce a calibration that seemed to reproduce a photo of a sample on the screen of the computer such that the colors were mimicked on the photo as accurately as possible. Measured color coordinates of calibration batches were compared with the actual values provided by manufacturer of the color palette. Calibration functions known by the manufacturer of image analysis program are polynomial approximations to the power three (or two if only ten calibration colors are used). This method differs from the usual calibration method used with this device, where the measurement device is calibrated using ten colors (patches E2, E5, G3, H2, H5, I2, I3, I4, J2, J5) with a broad color range in order to measure colors with as wide of a range of colors possible. The accuracy of both methods to measure green and brown color was investigated in preliminary examinations by measuring green and brown colors from the calibration palette. In further studies, calibration designed for measuring green colors was used.

Calibrated photos were segmented using the tools of the software used. Area-based tools included a color selector that chose a similar or almost similar hues captured in the pictures. Border-based segmentation can be done either automatically (using selector based on color differences) or manually (ellipsoidal, rectangular or free selection).

### 2.3. Method development

Various layout and segmentation methods were tested during preliminary experiments. Based on these experiments (data not included), beans were set horizontally between light sources in two columns with even distances of approximately 1 cm. This