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Development of a computer vision system to measure the color of potato chips

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Abstract

The objective of this research was to design and implement an inexpensive computer vision system for measuring the color of a highly heterogeneous food material not only in shape as well in color such as potato chips in $L^*a^*b^*$ units from RGB images. The system was composed of (i) a digital color camera for acquiring the images in a digital format, (ii) a computer for storage the images, (c) image analysis routines integrated into a software programmed in Matlab that converts the color RGB of the food image into $L^*a^*b^*$ units. In this way the color of potato chips can be calculated in $L^*a^*b^*$ units over representative areas and in a reproducible way. The kinetics of color changes in potato slices during frying at four temperatures was followed using the implemented computer vision system (CVS). Color values in $L^*a^*b^*$ units were recorded at different sampling times during frying at the four oil temperatures using the total color change parameter (ΔE). Chips fried at higher temperatures get darker as expected and showed by the CVS. The implemented computer vision system can be used to study as well foods different from potato chips by selecting their proper settings for image acquisition and digital image processing.

Keywords: Potato chips; Frying; Color; Computer vision; $L^*a^*b^*$; Image processing

1. Introduction

Commercial deep-fat frying has been estimated to be worth £45 billion in the United States and at least twice this amount for the rest of the world (Blumenthal, 1996). Potato (*Solanum tuberosum*) is one of the world's major agricultural crops and it is consumed daily by millions of people from diverse cultural backgrounds. Potato chips have been popular salty snacks for 150 years and its retail sales in US are about $6 billion/year representing 33% of the total sales on this market (Clark, 2003; Garayo & Moreira, 2002).

Among the different classes of physical properties of foods and foodstuffs, color is considered the most important visual attribute in the perception of product quality. Color of potato chips is an extremely important criterion for the potato processing industry and it is strictly related to consumer perception (Scanlon, Roller, Mazza, & Pritchard, 1994). The aspect and color of the food surface is the first quality parameter evaluated by consumers and is critical in the acceptance of the product, even before it enters the mouth. Consumers tend to associate color with flavor, safety, storage time, nutrition and level of satisfaction due to the fact that it correlates well with physical, chemical and sensorial evaluations of food quality.

Conditions in immersion frying lead to high heat transfer rates, rapid cooking, browning, texture and flavor

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development. Color development only begins when sufficient amount of drying has occurred in potato slices and depends also on the drying rate and the heat transfer coefficient during the different stages of frying. Color of potato chips is the result of the Maillard reaction that depends on the content of reducing sugars and amino acids or proteins at the surface, and the temperature and time of frying (Márquez & Añón, 1986). Some authors have associated the Maillard reaction and the color with the formation of the toxic compound acrylamide in fried potatoes (Mottram & Wedzicha, 2002; Pedreschi, Kaack, & Granby, 2006; Pedreschi, Moyano, Kaack, & Granby, 2005; Stadler et al., 2002).

In defining and quantifying color, a color system must be selected, usually among four alternatives: $L^*a^*b^*$, RGB (red, green, blue), XYZ and CMYK (cyan, magenta, yellow, black). Color of fried potatoes has been measured usually in units $L^*a^*b^*$ using either a colorimeter or specific data acquisition and image processing systems. $L^*a^*b^*$ is an international standard for color measurements, adopted by the Commission Internationale d'Eclairage (CIE) in 1976. This color model creates a consistent color regardless of the device used to generate the image (e.g., monitor, printer or scanner). L^* is the luminance or lightness component, which ranges from 0 to 100, and parameters a^* (from green to red) and b^* (from blue to yellow) are the two chromatic components, which range from −120 to 120 (Papadakis, Abdul-Malek, Kamdem, & Yam, 2000). In contrast with other color models such as RGB and XYZ, in the $L^*a^*b^*$ space the color perception is uniform. This means that the Euclidean distance between two colors corresponds approximately to the color difference perceived by the human eye (Hunt, 1991).

Computer vision (CV) is a technology for acquiring and analyzing an image of a real scene by computers to obtain information or to control processes (Brosnan & Sun, 2003). CV analysis is a non-destructive method to objectively measure color patterns in non-uniformly colored surfaces, and also determine other physical features such as image texture, morphological elements and defects (Mendoza & Aguilera, 2004; Pedreschi, Mery, Mendoza, & Aguilera, 2004). CV has been used in the food industry for quality evaluation, detection of defects, identification, grading and sorting of fruits and vegetables, meat and fish, bakery products and prepared goods, among others (Gerrard, Gao, & Tan, 1996; Gunasekaram & Ding, 1994; Leemans, Magein, & Destain, 1998; Luzuriaga, Balaban, & Yeralan, 1997; Shanin & Symons, 2001; Shanin & Symons, 2003; Sun, 2000). In particular, CV has been used to measure objectively the color of fried potatoes. Color of potato chips was measured using computerized video image processing by mean of gray level values (Scanlon et al., 1994). A computer-based video system was developed to quantify the color of potato chips in the $L^*a^*b^*$ color space that correlated well with the perception of the human eye (Segnini, Dejmek, & Öste, 1999). The video image analysis technique had some obvious advantages over a conventional colorimeter, namely, the possibility of analyzing the whole surface of the chips, and quantifying characteristics such as brown spots and other defects.

Basically, a computer vision system (CVS) consists of a digital or video camera for image acquisition, standard settings illuminants, and a computer software for image analysis (Brosnan & Sun, 2003; Papadakis et al., 2000). Image processing and image analysis are the core of CV with numerous algorithms and methods capable of objectively measuring and assessing the appearance quality of several agricultural products. In image analysis for food products, color is an influential attribute and powerful descriptor that often implies object extraction and identification and that can be used to quantify the color distribution of non-homogeneous samples (Brosnan & Sun, 2003).

The use of CV for color quality assessment require an absolute color calibration technique based on a common interchange format for color data and a knowledge of which features from an image can be best correlated with product quality. Rapid advances in hardware and software for digital processing have motivated several studies on the development of CVS to evaluate the quality of diverse raw and processed foods (Brosnan & Sun, 2003). Color imaging analysis not only offers a methodology for specification of uneven coloration to the specification of other attributes of total appearance. CVS is also recognized as the integrated use of devices for non-contact optical sensing, and computing and decision processes to receive and interpret an image of real scene. The technology aims to replace human vision by electronically perceiving and understanding an image (Brosnan & Sun, 2003).

The objective of this research was: (i) to design and implement a computer vision system to measure representatively and precisely the color of potato chips in $L^*a^*b^*$ units from RGB images. In this part, routines previously programmed for digital pre-processing, segmentation, feature extraction and color transformation from RGB to $L^*a^*b^*$ were integrated into a computational program; (ii) to follow the kinetics of color changes of potato slices fried at four temperatures using the implemented computer vision system.

2. Materials and methods

2.1. Materials

Potatoes (variety Desiree, ∼23% of dry solids; 0.3% reducing sugars) and vegetable oil (Chef, COPRONA, Chile) were the raw materials. Potatoes stored at 8 °C and 95% of relative humidity were washed and peeled before cutting. Slices (thickness of 2.2 mm) were cut from the pith of the parenchymatous region of potato tubers using an electric slicing machine (Berkel, model EAS65). A circular cutting mold was used to make circular slices with a diameter of 37 mm. Slices were rinsed immediately after cutting for 1 min in distilled water to eliminate some starch adhering to the surface prior to frying.

2.2. Frying conditions

Ten slices per sampling time were deep-fried in 5 l of hot oil contained in an electrical fryer (Beckers, Model F1-C, Italy) at each of the four temperatures (120, 140, 160 and 180 °C). Frying temperature was kept almost constant (±1 °C). Slices were fried at different time intervals until a final moisture content of ~1.8% (wet basis) was reached. Previously, the corresponding total frying times and the sampling intervals for each frying temperature were determined experimentally. The oil was preheated for 1 h prior to frying, and discarded after 6 h of use (Blumenthal, 1991).

2.3. Measuring color by computer vision

For studying the kinetics of color evolution of potato slices fried at different oil temperatures, the following CVS was implemented to measure representatively and accurately the color of the potato chips. The general methodology to convert RGB images into $L^*a^*b^*$ units is shown in Fig. 1. A brief description of each step follows:

(i) *Image acquisition:* Images were captured using an image acquisition system for color digital camera similar to that developed by Papadakis et al. (2000) (Fig. 2), namely:
   (a) Samples were illuminated using four fluorescent lamps (length of 60 cm) with a color temperature of 6500 °C (Philips, Natural Daylight, 18W) and a color rendering index (Ra) close to 95%. The four lamps were arranged as a square 35 cm above the sample and at an angle of 45° with the sample plane to give a uniform light intensity over the food sample.
   (b) A color digital camera (CDC) Power Shot G3 (Canon, Japan) was located vertically at a distance of 22.5 cm from the sample. The angle between the camera lens axis and the lighting sources was around 45°. Sample illuminators and the CDC were inside a wood box whose internal walls were painted black to avoid the light and reflection from the room. The white balance of the camera was set using a standardized gray color chart from Kodak. Color standards were photographed and analyzed periodically to ensure that the lighting system and the CDC were working properly.
   (c) Images were captured with the mentioned CDC at its maximum resolution (2272 × 1704 pixels) and connected to the USB port of a Pentium IV, 1200 MHz computer. Canon Remote Capture Software (version 2.7.0) was used for acquiring the images directly in the computer in TIFF format without compression.

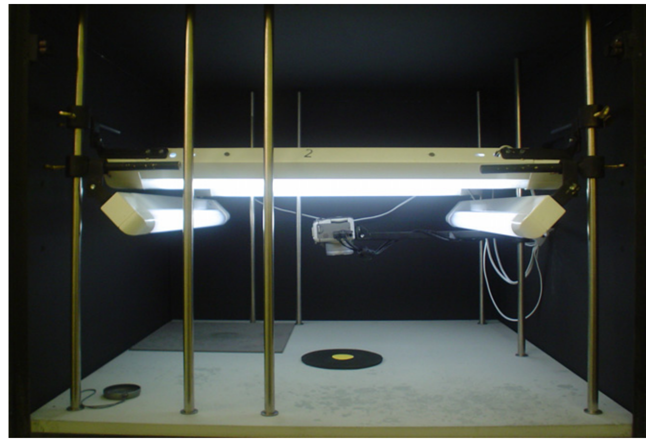

Fig. 2. Potato chip image acquisition system.

(ii) *Image pre-processing:* The digital images must be preprocessed to improve their quality before they are analyzed. Using digital filtering the noise of the image can be removed and the contrast can be enhanced. In addition, in this step the color image is converted to a

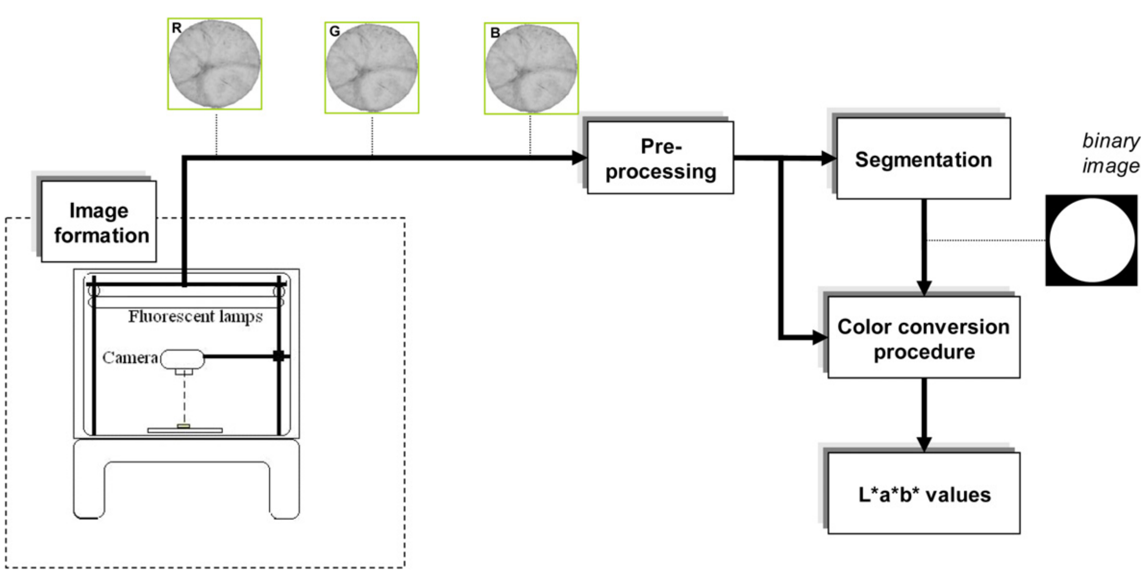

Fig. 1. Schematic representation of the color conversion process from RGB images to $L^*a^*b^*$ units.

grayscale image, called the intensity image [I]. In order to reduce the computational time of processing the images were sub-sampled to 1136×852 pixels. A linear Gaussian low pass filter (Castleman, 1996) was applied in order to reduce the noise in the images.

(iii) *Segmentation:* The intensity image is used to identify disjoint regions of the image with the purpose of separating the part of interest from the background. This segmented image [S] is a binary image consisting only of black and white pixels, where '0' (black) and '1' (white) mean background and object, respectively. Image segmentation (to separate the true image of the potato chips from the background) was performed using a threshold combined with an edge detection technique based on the Laplacian-of-Gaussian filter (Castleman, 1996; Mery & Filbert, 2002). In our case, the region of interest within the image corresponds to the area where the potato chip is located and a robust algorithm for proper potato image segmentation was previously developed and implemented (Mery & Pedreschi, 2005).

(iv) *Conversion of RGB images into $L^*a^*b^*$ units:* This methodology was developed previously and is carefully detailed by Leon, Mery, Pedreschi, and Leon (2006). Five models for the conversion from RGB images to $L^*a^*b^*$ units were developed and tested: linear, quadratic, gamma, direct, and neural network. In the evaluation of the performance of those models, the neural network model stands out with an error of only 0.96%. So it was possible to find in each pixel of the image a $L^*a^*b^*$ color measuring system that is appropriate for an accurate, exact and detailed characterization of a food item, thus improving quality control and providing a highly useful tool for the food industry based on a color digital camera.

3. Kinetics of color formation during frying

The kinetics of color formation of potato slices during frying at four different oil temperatures was followed by the parameter total color change (ΔE) which was calculated in the following way $\Delta E = ((L_0^* - L^*)^2 + (a_0^* - a^*)^2 + (b_0^* - b^*)^2)^{1/2}$. The $L^*a^*b^*$ values correspond to the values of potatoes slices fried at different frying times and the values of $L_0^*a_0^*b_0^*$ corresponds to the raw potato (frying time zero). Experimental data of chip color changes ΔE was fitted to the following empirical relationship:

$$\Delta E = b_1 + b_2 \exp\left(\frac{-t}{b_3}\right) \quad (1)$$

where t is the frying time, and b_1, b_2 and b_3 are regression coefficients. All frying kinetic experiments were done in triplicate.

4. Results and discussion

4.1. Implementation of a CVS

The CVS implemented in this research has principally two parts: (i) the image acquisition set up as showed in Fig. 2; (ii) the digital image processing part is composed of a set routines to pre-process the acquired and stored images, to segment the images and separate objects of interest from the background, and to convert RGB images of the objects of interest into $L^*a^*b^*$ units of color. In this research we focus on part (ii) integrating the digital image analysis routines programmed in Matlab code for pre-processing, segmentation and color conversion in order to develop a computer program and make easier and faster color determination in $L^*a^*b^*$ units. Digital RGB images were captured with a previously implemented image acquisition system and stored in a PC for future processing (Pedreschi et al., 2004).

The Matlab commands used in this system are explained in Table 1. The color image is firstly stored in a matrix I. In order to reduce the computational time of processing the images can be sub-sampled. If the images are noisy they can be filtered using a low pass filter (Mathworks, 2005). Afterwards, the RGB image is segmented using the algorithm outlined in Mery and Pedreschi (2005). In this step, the image of the potato chip is separated from the background producing a binary image R (Fig. 3). Finally, the RGB image is converted into a

Table 1
Matlab commands used in the computer vision system

Step	Matlab commands	Description	Reference
1	`I=imread(file_name);`	Read RGB image and store it in matrix `I`	Mathworks (2005)
2	`K=imresize(I,0.5);`	Reduce the size of the original image and store it in `K`	Mathworks (2005)
3	`[R,E,J]=SegFood(K);`	Segment RGB image and store binary image in `R`, edge image in `E` and grayscale image in `J`	Mery and Pedreschi (2005)
4	$[L,a,b]$ = rgb2lab(K);	Convert RGB image into $L^*a^*b^*$ color components (L^* image is stored in matrix `L`, a^* in `a`, b^* in `b`)	León et al. (2006)
5	`ii=find(R==1);` `Lm=mean(L);` `am=mean(a);` `bm=mean(b);`	Compute the mean value of L^*, a^* and b^* and store them in variables `Lm`, `am` and `bm`, respectively	Mathworks (2005)

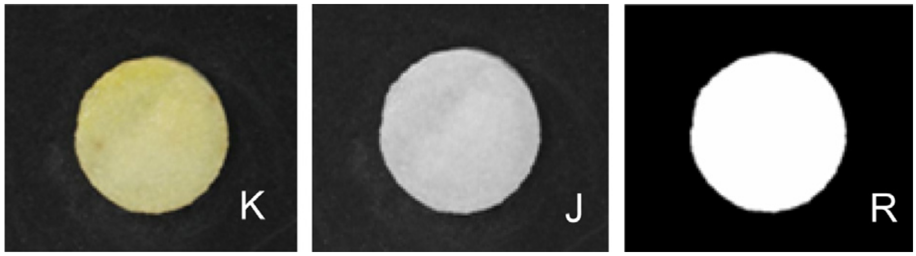

Fig. 3. (K) Color image of a potato chip; (J) grayscale image of the potato chip; (R) segmented image of the potato chip.

$L^*a^*b^*$ image using the approach described in (León et al., 2006). After this step, we have the matrices L, a and b, that correspond to the L^*, a^* and b^* values of the pixels of the digital image.

An important capability of the CVS is that once the image is obtained and the object of interest segmented, one can measure the color either over the entire surface of the food (Table 1, step 5) or into a very specific small region of interest to study (e.g. a black spot in a potato chip). Fig. 4 shows it is possible select a specific region of a food surface to find their respective $L^*a^*b^*$ values. Since the color surface of a potato chip is highly heterogeneous due the complex distribution of water, starch, reducing sugars, principally, it is generally important to compute the average color which is representative of the complete surface. In Fig. 4, the small region selected from the complete chip corresponds to a darkened place due to excessive non-enzymatic browning. The L^* value of the dark small selected zone is lower than that of the complete surface as expected (38.09 vs. 58.74). Besides the a^* and b^* values for the selected region are lower and higher, respectively than those corresponding to the complete chip (8.00 vs. 13.97 and 26.33 vs. 19.02, respectively) since the potato tissue tend to get more red and less yellow as the non-enzymatic browning is extreme. *The region of interest has to be selected manually but it will be possible to incorporate an algorithm in the CV to select the region of interest automatically once it is clearly defined by the user.*

It is important to indicate, that the transformation of RGB into $L^*a^*b^*$ is performed after a calibration process (León et al., 2006), in which images of representative color samples are analyzed in order to obtain a model for the transformation. Independently, RGB and $L^*a^*b^*$ color components are acquired from these samples. RGB values are obtained from the RGB digital color image used for the experiments, whereas $L^*a^*b^*$ are measured from a commercial colorimeter. A mathematical model transforms the RGB values into an estimation of the $L^*a^*b^*$ values. The calibration estimates the parameter of the model that minimizes the difference between the estimated $L^*a^*b^*$ values and the measured $L^*a^*b^*$ values. Once the parameters are estimated, i.e., the system is calibrated, other RGB images taken with the same camera can be converted into $L^*a^*b^*$ images as explained in Table 1.

The steps outlined in Table 1 are very simple and the processing of digital images can be performed in an easy way. The user only needs to execute few commands and the $L^*a^*b^*$ images are ready to be manipulated as illustrated in Fig. 4.

5. Kinetics of color change

In this study we select two low frying temperatures (120 and 140 °C) and two high ones (160 and 180 °C) in order to evaluate the effect of the oil temperature over browning development in potato chips. Fried potato color is the result of Maillard, non-enzymatic browning reactions that

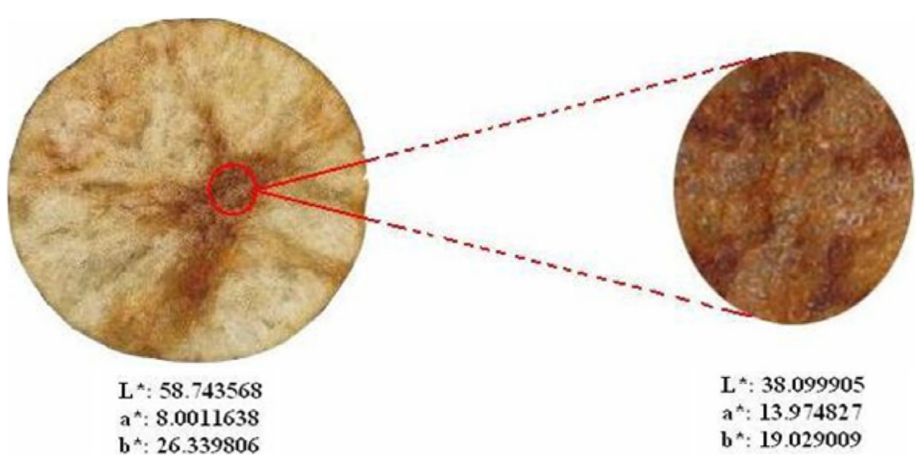

Fig. 4. Color of a complete potato chip and of a small circular region of it in $L^*a^*b^*$ units.

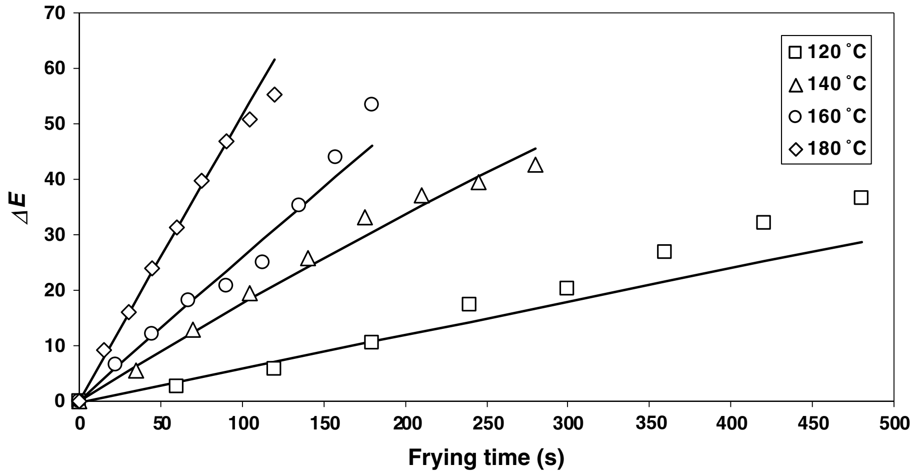

Fig. 5. Kinetics of color change in potato slices during frying at 120, 140, 160 and 180 °C followed by parameter ΔE. Symbols represent experimental data; solid lines represent data fitted to Eq. (1).

depends on the superficial reducing sugar content, and the temperature and frying period (Márquez & Añón, 1986). Low reducing sugar contents are required to minimize color development during frying (Mottur, 1989). Color changes in the potato slices during frying were followed using ΔE, since this color parameter showed notorious significant during frying. Potato slices tend to get darker as frying proceeds (as a result of surface non-enzymatic browning reactions) as indicated by the progressive increasing of ΔE values with frying time (Fig. 5). The higher the frying temperature the darker the potato chips get since non-enzymatic browning reactions are highly temperature dependant. *Since the color of potato chips is many times highly related to the acrylamide content, it will we useful to develop a CV on line which can automatically select and separate those chips with high acrylamide content from those with allowed acrylamide contents.*

6. Conclusions

The implemented CVS allows determining the color of potato slices from RGB images into $L^*a^*b^*$ units in an easy, precise, representative, objective and inexpensive way. This was achieved by integrating previously developed routines for image pre-processing, segmentation and color conversion into one computational program to make easier and faster the color measuring of potato chips in $L^*a^*b^*$ units. The CVS allows easy measurements of the color over the entire surface of a potato chip or over a small specific surface region of interest. ΔE decreased drastically as the frying temperature decreased from 180 to 120 °C. Lower frying temperatures generate less non-enzymatic browning in potato resulting in the production of paler chips.

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