Tomato Maturity Evaluation Using Color Image Analysis

K. Choi, G. Lee, Y. J. Han, J. M. Bunn

Abstract. *A color image analysis procedure was developed to classify fresh tomatoes into six maturity stages according to the USDA standard classification: Green, Breakers, Turning, Pink, Light Red, and Red. RGB (Red, Green, and Blue) images of each tomato were captured and converted to HSI (Hue, Saturation, and Intensity) values. Classification was based on the aggregated percent surface area below certain hue angles. A Tomato Maturity Index (TMI) was developed to indicate the degree of maturity within each stage and to provide a continuous index over the complete maturity range. Classification results agreed with manual grading in 77% of the tested tomatoes, and all samples were classified within one maturity stage difference.* ***Keywords.*** *Image analysis, Tomatoes, Maturity.*

Maturity is one of the most important factors associated with the quality evaluation of fruits and vegetables. Common criteria for judging maturity include physical attributes such as skin color, flesh firmness, size, shape, and moisture or solids contents; chemical attributes such as sugar, starch, or acid contents; estimation of development stage; and morphological evaluation. Among these, skin color has long been recognized as an acceptable maturity index for many fruits such as peaches and tomatoes.

Several studies have examined relationships between tomato maturity and their optical characteristics (Heron and Zachariah, 1974; O'Brien and Sarkar, 1974; Goddard et al., 1975; Moini and O'Brien, 1978). Most of these studies utilized a spectrophotometer or a light-sensitive cell (such as photodiode, photomultiplier, or photovoltaic cell) as light sensors to quantify light reflectance, transmittance, or absorbance characteristics. These sensors evaluate only a few locations around the fruit, or estimate overall average light reflectance from the entire fruit surface. Recent advancements in machine vision/image processing technology can overcome this limitation by evaluating thousands of pixels (picture elements) on a fruit, and allow the analysis of light reflectance from surfaces of fruit locally and globally.

An application of such a light reflectance measurement system, as reported here, was the evaluation of tomato maturity during an artificial ripening process. Watada (1986) reported that it has become a common practice in the tomato packing industry to use ethylene gas as a ripening agent before shipping tomatoes to retail outlets. Research on alternative methods for controlled ripening of mature-green tomatoes is being conducted in the Department of Agricultural and Biological Engineering at Clemson University. A color image analysis system which can establish stage of maturity and constantly monitor changes and variability of skin color of tomatoes as they ripen would be an important asset to this research.

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Mention of specific products is for information only and not to the exclusion of others that may be suitable.

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Objectives

The objectives of this research project were to:

- Develop a color image analysis procedure to estimate maturity stage of fresh tomatoes.
- Evaluate the classification performance of the image analysis system compared to human visual inspection and tomato firmness.

Literature Review

The USDA grade standard for fresh tomatoes (CFR, 1991) describes size, color, tolerance and damage. Table 1 shows the color classification requirements of the USDA standard, which classifies the maturity or ripeness of tomato into six stages (Green, Breakers, Turning, Pink, Light Red, and Red) based on the predominant color ratio. Sarkar and Wolfe (1985a; 1985b) developed classification algorithms using digital image analysis and pattern recognition techniques for sorting tomatoes. Mean gray levels of four areas except the center of stem and blossom end were measured with a resolution of 60×64 pixels at four bits. Maturity was classified into two stages: Light Red and Red tomatoes were considered to be ripe, and the other ripeness stages were considered as green.

Slaughter and Harrel (1987) demonstrated that hue and saturation thresholds could be used to differentiate orange fruits from background foliages, sky, clouds, and soil. Wiggers et al. (1988) used a color image processing system to detect and classify fungal-damaged soybeans with the hue and the ratios of the red, green, and blue signals. They reported that the color ratio was more reliable than the hue method for detecting color differences. Miller and Delwiche (1989) developed a color computer vision

Table 1. Color classification requirements in U.S. Standards for grades of fresh tomatoes*

Ripeness Stage	Description
Green	The surface of the tomato is completely green in color. The shade of green color may vary from light to dark.
Breakers	There is a definite break in color from green to tannish-yellow, pink or red on not more than 10% of the surface.
Turning	More than 10% but not more than 30% of the surface, in the aggregate, shows a definite change in color from green to tannish-yellow, pink, red or a combination thereof.
Pink	More than 30% but not more than 60% of the surface, in the aggregate, shows pink or red color.
Light Red	More than 60% of the surface, in the aggregate, shows pinkish-red or red. (Provided, that not more than 90% of the surface is red color.)
Red	More than 90% of the surface, in the aggregate, shows red color.

* Exceprt from U. S. Standards for Grades of Fresh Tomatoes [CFR §51.1860].

algorithm to inspect and grade fresh market peaches. Machine and manual classification agreed with only 54% of the samples. Large differences between machine and manual results occurred mostly on peaches with portions of surface area that were speckled with red color but not fully blushed. Varghese et al. (1991) developed a computer vision system to inspect and assess fresh apples by color, defect, shape, and size. Apples were classified for color with very high accuracy using a hue histogram and its linear discriminant analysis. Shearer and Payne (1990) investigated machine vision for sorting bell peppers by mapping the RGB values to hues and statistically classifying the frequency distribution.

Flesh firmness is also affected by maturity of fruit. Kader et al. (1978) showed that the values obtained by puncture (a destructive method) and deformation tests (a nondestructive method) were highly correlated with subjective evaluation scores based on finger feel. Watada and Abbot (1985) stated that there were highly significant correlations between apple firmness and sensory intensity scores of crispness, hardness, and toughness, although the degree of correlation varied with cultivar. Shewfelt et al. (1987) monitored quality characteristics of fresh market tomatoes throughout the postharvest handling system and concluded that tomatoes harvested at earlier stages of maturity maintained firmness longer and remained lighter in color as the hue changed from pink to red than those harvested at later stages.

Materials and Methods

Imaging Equipment

The image processing hardware used in this study included a PCVISIONplus frame grabber board (Imaging Technology, Inc.) running on a 66 MHz 80486 microcomputer. The frame grabber has a 512 × 480 spatial resolution with 256 gray levels. Color images of tomatoes were captured by a Pulnix TMC-514 CCD color camera with 12.5-75 mm F1.2 zoom lens and displayed on a Sony PVM-1271Q high resolution RGB analog monitor. The camera was also equipped with two close-up lenses (Tiffen Co., diopter +1, +2) and a polarizing filter (Photoco Co., No. 52203) to reduce glare from surface reflectance. The camera's RGB output signal was multiplexed by a monolithic analog multiplexer used by Shin et al. (1989) and sequentially fed to the frame grabber board.

A cylindrical illumination chamber of 59 cm in diameter and 45 cm in length was constructed as shown in figure 1. The inside of the chamber was coated with a flat white latex paint to provide uniform and diffused illumination and to reduce glare and specular reflection. A 60 mm diameter hole was bored in the top center of the chamber for camera mounting. Six 100 W soft white incandescent light bulbs were mounted 15 cm apart along both sides of the bottom of the chamber. A white plate, 16 cm in width and 48 cm in length, was mounted between the upper wall of the chamber and the light bulbs so that tomatoes placed on the plate were exposed only to indirect diffuse lighting. With this setup, it was possible to capture tomato images with negligible shadows and without specular reflection.

Firmness Measurement

The flesh firmness was assessed with an Instron Universal Tester (Model 4201) which records maximum longitudinal load. A circular flat plate with a 57 mm diameter was used to compress the whole fruit nondestructively in a direction perpendicular to the fruit axis from the blossom end to the stem end. The firmness value was recorded when the fruit was compressed a distance of 1 mm.

Color Specification and Calibration

There are many color models in use today including RGB (Red, Green, and Blue) models for the television industry and color video cameras; CMY (Cyan, Magenta, and Yellow) models for color printers; YIQ (Luminance, Inphase, and Quadrature) models for television broadcast standard; and HSI (Hue, Saturation, and Intensity) models for easy color manipulation. The color models most often used for image processing applications are RGB, YIQ, and HSI models.

Among these models, the HSI model is very useful in color machine vision, because it closely resembles the way

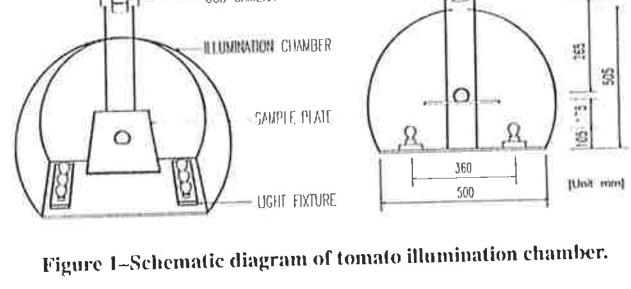

Figure 1–Schematic diagram of tomato illumination chamber.

human beings perceive color. Humans discern the color of an object in terms of its hue (dominant color), saturation (chroma, relative purity, or lightness), and intensity (brightness) by integrating some very complex signals into these three components. Another advantage of the HSI model is that the intensity is decoupled from the other color information in the model, which can minimize the effect from variations in illumination intensity.

Because of these reasons, the RGB values obtained by the camera were transformed into the HSI values using the following relations:

$$I = (R + G + B) / 3 \tag{1}$$

$$S = 1 - [\min(R, G, B)] / I \tag{2}$$

$$H = \cos^{-1}\left\{\frac{0.5*[(R-G)+(R-B)]}{[(R-G)^2+(R-B)(G-B)]^{1/2}}\right\} (\text{if } B \le G) \tag{3}$$

$$H = 360 - \cos^{-1}\left\{\frac{0.5*[(R-G)+(R-B)]}{[(R-G)^2+(R-B)(G-B)]^{1/2}}\right\} (\text{if } B > G) \tag{4}$$

where R, G, B = intensity values of red, green, and blue outputs, respectively.

The RGB outputs from the camera were calibrated using a standard Munsell color wheel. The hue gain of the camera was adjusted so that hue values transformed from the RGB values become 0°, 60°, 120°, 240° for red, yellow, green, and blue standard colors, respectively. A red ball and a green ball, both 7.5 cm in diameter, were also used to verify the calibration and to measure the uniformity of intensity in the illumination chamber. The relative pixel frequencies of red and green balls were 94% and 93% at hue angles 0° and 120°, respectively.

Spectral Characteristics of Tomato

Figure 2 shows a large difference between spectral distributions of a red tomato and a green tomato, measured by a spectrophotometer (Spectrogard Color System, BYK-Gardner, Inc.). The spectrophotometer had an aperture of 22 mm and measured light reflectance at visible wavelengths between 380 nm and 720 nm in 5 nm increments. This difference is due to the presence of chlorophyll in fresh green tomatoes which has a strong absorption band centered at 675 nm, and the presence of a major carotene (lycopene) in red tomatoes (Gross, 1991).

As a tomato ripens, its color changes from green to white through chlorophyll degradation and from white to red by carotenoid biosynthesis.

Several studies (Heron and Zachariah, 1974; O'Brien and Sarkar, 1974; Goddard et al., 1975; Moini and O'Brien, 1978) used a single wavelength or ratio of reflectance at two wavelengths to establish tomato sorting criteria, but could not provide enough information to classify tomatoes into six maturity stages as the USDA standard specifies. Since the USDA grade standard classifies tomato maturity based on the aggregated area ratio of the surface in green and red colors as shown in table 1, it was desired to design an image analysis system that can measure color of each pixel on the tomato surface and calculate cumulative pixel frequencies for each color to estimate the aggregated area ratio between green and red color.

Figure 3 shows the hue distributions of typical six maturity stages of fresh tomatoes when the colors of all pixels on a tomato surface were measured by the imaging system. It is difficult to discriminate maturity stages from this information due to a significant overlap for each stage. Although Green and Breakers stages have relatively low and wide distribution, all other four stages have significant portions of pixels, or surface area, at zero hue angle (red color). Figure 4 shows the cumulative relative frequency distribution of the same example. All six maturity stages are now well separated and ready for simple classification. Although it would be difficult to define a single hue threshold to classify all six stages, multiple criteria can be specified to discriminate each stage from others.

Image Analysis

Image Acquisition

The frame grabber board used in this study had a 512 × 480 spatial resolution with 256 gray levels. Three images of a tomato in red, green, and blue bands were

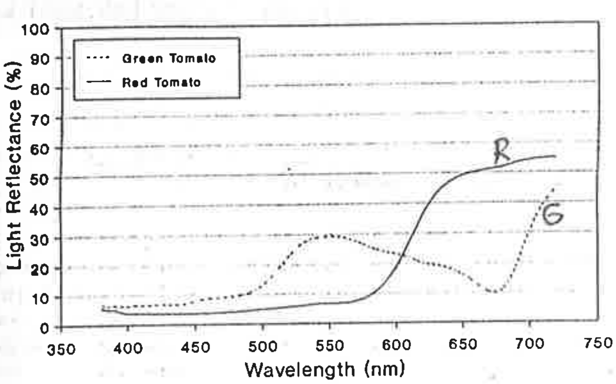

Figure 2–Spectral distribution of typical green and red tomatoes.

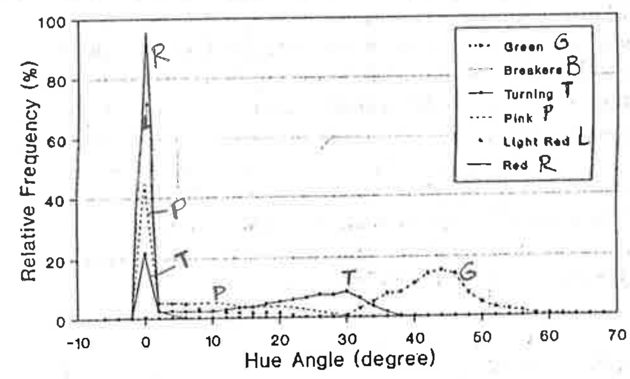

Figure 3–Hue distribution of typical six maturity stages of fresh tomatoes.

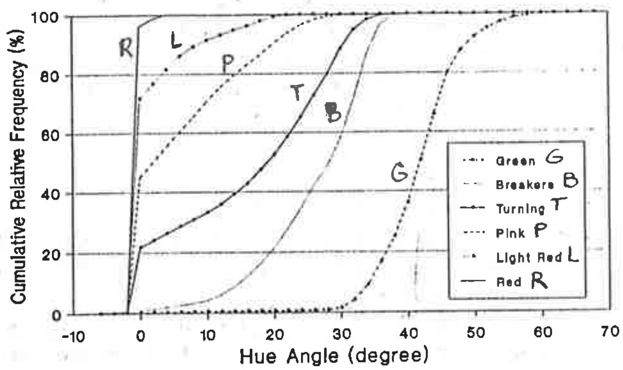

Figure 4–Cumulative hue distribution of typical six maturity stages of fresh tomatoes.

captured in sequence at this resolution, and were reduced to 256 × 240 spatial resolution by replacing each 2 × 2 pixel region of each image by one pixel with an intensity equal to the average of the original four-pixel region. There are several advantages in reducing spatial resolution. First, it serves as a low-pass filter to reduce noise. Second, the computation time needed to process an image is drastically reduced. Third, images in all three color bands can be displayed on one monitor screen at the same time. In this study, tomato images were taken only from the blossom end of the tomato for convenience. When the feasibility of the image analysis is proven, other perspectives of tomato will be included for evaluation of the whole fruit.

Image Segmentation and Edge Detection

In order to measure pixel colors on the tomato surface, the tomato in the field of view must be located and its edges must be identified. A preliminary experiment showed that the blue band of actual tomato surface has nearly zero intensity, which makes high contrast against the bright white background. Therefore, a global threshold was applied on the blue band of the image to segment the tomato from the background. An iterative automatic threshold selection technique developed by Ridler and Calvard (1978) was used to determine the global threshold value. The actual algorithm implemented was that of Trussell's (1979), who improved Ridler's technique for faster computation using only histogram data. The method arbitrarily divided the histogram of the image into two parts and calculated mean gray levels of each part. The average of these two mean values became the threshold value for the next iteration, and the process was repeated until a stable estimate of the threshold value emerged. In practice the operator has the option of changing the suggested threshold value when clean edges are not obtained.

Since there can be more than one object in the segmented image, the image was scanned once to obtain a linked list of objects with location and area information using a blob analysis algorithm developed by Han and Quisenberry (1991). The object with the largest area was assumed to be the tomato of interest. This technique was proven useful when portions of other tomatoes were visible in the same field of view. The tomato to be analyzed can be correctly identified as long as it is the largest object in the image.

The edge of the tomato was defined as the outermost pixels of the tomato on each horizontal scan line. Red, green, and blue intensity values of each pixel within the edge of the tomato were read and converted to hue, saturation, and intensity values using equations 1 through 4.

Grading Criteria

Since the blue band image of an actual tomato surface has nearly zero intensity, saturation values in HSI scale were nearly 1.0 by equation 2. This makes the saturation value irrelevant to the grading criteria. It is also desirable to disregard the intensity information to minimize the effect from variations in illumination intensity. Therefore, only the hue angles were considered in the grading criteria.

In order to determine the hue threshold values, a total of 81 tomatoes at various maturity stages were classified into six maturity stages by visual inspection based on the USDA color chart. These tomatoes were then processed by the imaging system to obtain hue and cumulative hue distributions similar to those shown in figures 3 and 4. Hue threshold values between each maturity stage were determined so that the aggregated surface areas below the hue threshold values become 10, 30, 60, and 90% for Turning, Pink, Light Red, and Red stages, respectively, as specified by USDA. The threshold of 0.5% in aggregated surface area was used as a criteria between Green and Breakers stages, although USDA specifies the Green stage as having a surface completely green in color. Three hue threshold values were identified to classify the sample tomatoes into six maturity stages: hue angle of 16 between Green and Breakers stages; hue angle of 10 between Breakers and Turning stages; and hue angle of 4 for classifying all other stages. The criteria and classification algorithm are summarized in table 2. In the table, P(i) denotes the cumulative relative frequency, or the aggregated percent surface area, below the hue angle of i.

A Tomato Maturity Index (TMI) was developed to estimate the degree of maturity within each stage and to provide a continuous index over all maturity stages. The TMI was derived from the aggregated percent surface area below the hue angles defined above, interpolated in Breakers and Turning stages, to provide a continuous index between 0 and 100. The TMI is zero for Green stage, between 1 and 9 for Breakers, between 10 and 29 for Turning, between 30 and 59 for Pink, between 60 and 89 for Light Red, and over 90 for Red stages, respectively. A complete definition of TMI can be found in table 2.

Table 2. Maturity classification algorithm and Tomato Maturity Index (TMI)

if	$P(16) \leq 0.5\%$	then	GREEN;	TMI = 0
else if	$P(10) < 10\%$	then	BREAKERS;	TMI = 1 + (P(10) * 0.9)
else if	$P(4) < 30\%$	then	TURNING;	TMI = 10 + (P(4) * 2/3)
else if	$P(4) < 60\%$	then	PINK;	TMI = P(4)
else if	$P(4) < 90\%$	then	LIGHT RED;	TMI = P(4)
else			RED;	TMI = P(4)

where, P(i) = aggregated percent surface area below a hue angle of i.

Classification Test

'Mountain Pride' fresh tomatoes used in the classification test were harvested from a tomato grower at Greenville, South Carolina. Fruits were picked at various stages of ripeness. Abnormally shaped or defective tomatoes were rejected. Subsamples of 20 tomatoes for each of six maturity stages were manually selected based on the USDA color chart, for a total of 120 tomatoes. Images of the blossom end of the tomatoes were obtained and processed by the machine vision system. Sample tomatoes were classified into one of the six maturity stages, and their TMI values were calculated according to the established grading criteria. Immediately following the classification, the flesh firmness of sample tomatoes were measured with the Instron Universal Tester.

Results and Discussion

Table 3 summarizes maturity classification results using the machine vision system compared to manual grading results. Among the 120 tomatoes tested, 93 tomatoes, or 77.5%, were correctly classified, and all samples were classified within one maturity stage difference. Most of the misclassification occurred between Green and Breakers stages, between Turning and Pink, and between Light Red and Red stages. If maturity was classified into only three stages, such as Green/Breakers, Turning/Pink, and Light Red/Red, only two samples would have been misclassified with 98.3% success ratio.

The misclassification ratio was particularly high between Green and Breakers stages. This was mainly due to the fact that some of the tomatoes in Breakers stage were mingled with tannish-yellow or greenish-yellow colors, which the vision system classified as light green. When the hue threshold value between Green and Breakers stages was shifted toward the yellow side, some of the Green tomatoes were classified as Breakers instead. Another possible reason may be the incandescent light source, which emits more light in red than in green. It was also observed that the overall classification efficiency of the machine vision system was better toward the red end of the ripeness stage.

The TMI for each sample tomatoes was carefully examined to determine whether changes in TMI values showed any trend in color change within a maturity stage. Visual inspection verified that TMI was able to estimate the degree of maturity within each stage and provided a continuous index over all maturity stages. For example, in the Light Red stage, a general tendency of color change toward red color was observed as TMI changed from 60 to 89. Also, TMI values for misclassified tomatoes as shown in table 3 were generally close to the correct maturity stages.

Table 4 shows the range and the average of flesh firmness values for each stage of maturity. Although the firmness generally decreased as the fruit ripened, there were significant overlaps between stages, especially after Turning through Red stages. According to the Duncan's Multiple Range Test as shown in table 4, firmness values were not significantly different after Turning stage, thus did not contribute in maturity classification.

Considering the possibility that using a continuous index of maturity instead of six discrete stages could clarify the relationship between maturity and firmness, the firmness values were compared with the TMI values as shown in figure 5. To find a best-fit curve and the correlation between TMI and the flesh firmness, transformed regression analyses were performed with several possible models, including polynomial, exponential, logarithmic, and inverse functions. The best-fit curve found was:

$$Y = 1.63 - 0.23 \log_e(X + 1) \quad [R^2 = 0.6574] \quad (5)$$

where

Y = flesh firmness of tomato (kg)

X = tomato maturity index

Data in figure 5 also confirmed that although the firmness generally decreased as the fruit ripened, there were wide variations in the data between 0.25 and 1.23 kg after TMI of 10 (Turning stage). Therefore, it was concluded that the firmness values were not sufficient to classify tomato maturity into six stages.

Summary and Conclusions

A color image analysis procedure was developed to classify fresh tomatoes into six maturity stages according to the USDA standard classification: Green, Breakers, Turning, Pink, Light Red, and Red. The RGB images of each tomato were captured and converted to HSI values. Classification was based on the aggregated percent surface area below certain hue angles. Hue information was sufficient to successfully classify tomato maturity using image analysis. A TMI was developed to indicate the

Table 3. Maturity classification results by manual and machine vision classification

Manual Grading	Machine Vision Classification: Green	Breakers	Turning	Pink	Light Red	Red	Total
Green	20						20
Breakers	10	10					20
Turning			13	7			20
Pink			2	18			20
Light red				2	17	1	20
Red					5	15	20
Total	30	10	15	27	22	16	120

Table 4. Flesh firmness values of sample tomatoes for six maturity stages

Maturity Stages	Flesh Firmness (kg): Minimum	Maximum	Average
Green	1.43	2.71	1.955 a*
Breakers	0.82	2.02	1.164 b
Turning	0.60	1.12	0.853 c
Pink	0.51	1.04	0.759 cd
Light red	0.25	1.23	0.728 cd
Red	0.33	0.88	0.605 d

* Averages followed by the same letter are not significantly different at 95% confidence level using Duncan's Multiple Range Test.

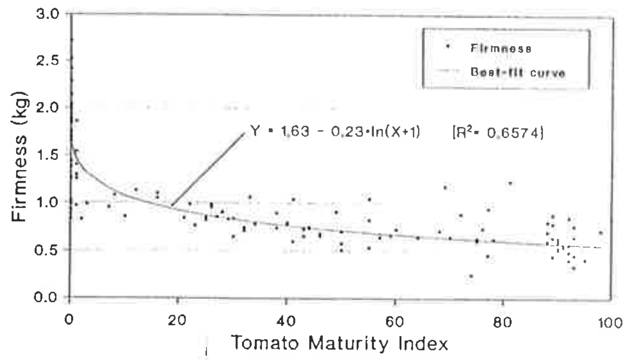

Figure 5–Relationship between TMI and flesh firmness.

degree of maturity in a continuous scale over all maturity stages. System performance was evaluated by comparing the classification results with manual grading and flesh firmness measurement. A classification test was conducted on 120 fresh market tomatoes and the following conclusions were made:

- Classification results agreed with manual grading in 77% of the tested tomatoes, and all samples were classified within one maturity stage difference.
- TMI was able to estimate the degree of maturity within each stage and to provide a continuous index over the complete maturity range.
- Flesh firmness information was not sufficient to classify tomato maturity into six stages.

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