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Light Reflectance Properties of Defects of Satsuma Mandarin

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Introduction

The quality of Satsuma mandarin has been evaluated by means of the appearances, such as surface color, shape, injuries, and so on. Although the packinghouse line of Satsuma mandarin is automated more than those of other fruits, the grading process still requires much amount of labors from a lot of trained workers. In order to establish an automatic grading system, investigations were carried out on the development of objective quality evaluation by non-destructive test with the use of optical method[1,2]. The optical property of Satsuma mandarin has been found to be related to their surface color and internal quality. There have been many attempts to develop non-destructive grading techniques which offer improvements over manual methods, neverthless they little reach practical application so far[3,6,7,9].

Seen from another point of view of grading, all injured fruits that entered packinghouse had to be removed from sound ones during the sorting. In United States, no less than several ten percents of fruits are usually sorted out in the packinghouse, and the majority are injured fruits of various kinds, therefore many papers in this field have been published[4,5,8]. In Japan, as fruits with surface defects are to be removed previously by farmers, the amount of injured fruits sorted out in the packinghouse is not so much as that in United States. As to the grading criteria of packinghouse those of Japan are as in following, normally, undersize, oversize, unacceptable color, surface defects, which are more detailed and severe than in United States. Typical packinghouse requires a large number of workers to sort out fruits not meeting the grading creteria, and manual grading can not help being subject to manual error and is not always as consistent as would be desired. Therefore, from a saving man power also it is hoped to investigate the method with high accuracy of grading free individual difference.

This purpose of this study is to obtain, with the use of typical kind of injured fruits, some basic data for the automation of grading process by clarifying the optical property depending on the degree of defect which are to be resulted from injury, decay, damages by blight and harmful insects, and so on, by means of light reflectance method of easy practical application.

Materials and Methods

1. Materials

Satsuma mandarin with various defects that entered Kogacho packinghouse (Kasuya District, Fukuoka Prefecture) were used in this experiment. Satsuma mandarin were visually selected to be approximatelly the same size and color. Selected samples concernig the most frequently occuring

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surface defects on Satsuma mandarin were presented in this paper. Description of various types of defects are given below.

(1) Sooty mold : Raised lesions, black in color, usually scattered upon fruit surface. Caused by fungi.

(2) Melanose : Raised lesions, mahogany or brown in color, usually scattered or forming lines, rings, or tearing streaks. Caused by fungi.

(3) Scales : Small deposits distributed over fruit surface. Caused by insects. There exist many types of scales of varying colors.

(4) Scabs : Irregular or rounded lesions, light in color. Caused by fungi.

(5) Wind scar : Light to dark tan discoloration caused by fruits being blown to be rubbed against twigs and leaves by wind.

(6) Puncture : Medium to deep concentrated scratches over fruit surface. Caused by being blown against thorns or twigs.

(7) Plug : Injury given to the fruit at a part where a portion of peel is removed at the stem end. Caused by improper picking off.

(8) Water rot : Swollon peel, brown in color, caused by fungi together with water permeated into fruit.

(9) Green rot : Typical fruit decay occuring in storage. Caused by penicillium fungi.

2. Measuring system of light reflectance properties

The basic features of the experimental apparatus are illustrated in Fig. 1. The illuminated area of Satsuma mandarin was kept constant by the use of sample port making remaining size differences less effective. Light from the halogen lamp illuminated Satsuma mandarin through the sample port and reflected light from Satsuma mandarin passed through a UV-filter to a monochrometor. The spectral reflectance properties were recorded over the visible region (400 to 800 nm) with a photomultiplier tube.

The spectral reflectance properties were measured at the blossom and stem ends of Satsuma mandarin. Considering the possibility of practical application, the sample port size of 19.6cm^2 (50mm diameter) was adopted, and both parts of injured and uninjured surfaces were contained in the illuminated area on the sample port.

The spectral intensity of a painted white ball as a standard was deremined before and after measuring of the spectral intensity of Satsuma mandarin. The spectral reflectance of each Satsuma mandarin was computed as a ratio of the spectral intensity of the sample to that of the white standard.

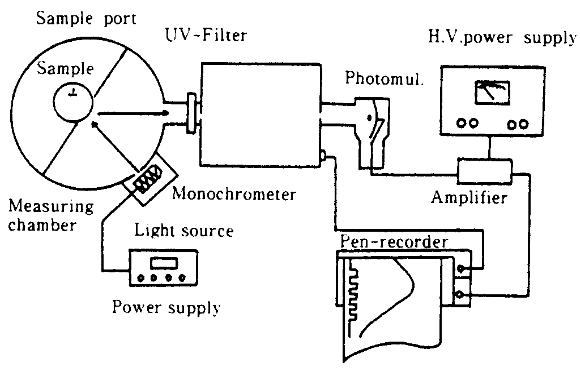

Fig. 1. Schematic diagram of the experimental apparatus.

Results and Discussion

1. Spectral reflectance properties of injured Satsuma mandarin

Spectral reflectance curves, over the wavelength region of 400 to 800nm, for different defects of Satsuma mandarin are shown Fig. 2. Tests made on all samples indicated that the spectral reflectance was virtually level in the wavelength region of 400 to 450nm. Therefore, the subsequent curves presented in this paper do not show any values for wavelengths below 450nm. In regard to sound Satsuma mandarin their spectral reflectances determined by the average values of four fully colored Satsuma mandarin showed the normal range in reflectance for Satsuma mandarin which would be acceptable on the basis of color level. Although the spectral reflectance curves for the six kinds of defects, such as sooty mold, melanose, scales, wind scar, puncture and water rot, tended to be similar in shape to the curve for sound Satsuma mandarin, there was reflectance drop over the wavelength region of 550 to 800nm. This tendency is different from the peculiar change of spectral reflectance curve at such a special wavelength as chlorophyll absorption band, and exhibited the existence of no absorption band characteristic of each defect. However, in these injured Satsuma mandarin, the lowering of spectral reflectance was markedly affected by the locations and degrees of the defect occuring on the surface, and was not constant depending on the difference of kinds of defects. For example, defect such as sooty mold, which was black in color and occurred concentratedly from one point of the surface, influenced very sensitively on its spectral reflectance curve, whereas in the case of scale that was brown and distributed over the surface its effect was weak and small. On the other hand, the spectral reflectance curves for such defects as scabs, plug and green rot showed somewhat different changes from that of sound Satsuma mandarin. The spectral reflectance for these defects was higher than that of sound Satsuma mandarin in the wavelength region of 450 to 550nm, while the mutual relationship was reversed over the region of about 550 to 800nm. The spectral reflectance of these injured Satsuma mandarin increased in the wavelength region of 450 to 550nm and decreased in the wavelength region of 550 to 800nm together with increasing of the injured area. According to the color of defects, injured Satsuma mandarin can be separated into two groups. The former is brown or black and the latter is white. This difference of reflectance in the wide wavelength region between injured and sound Satsuma mandarin was influenced by discoloration and darkness in color of the injured surface.

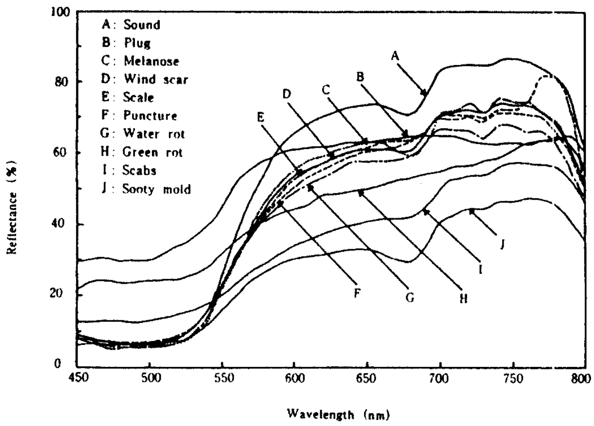

Fig. 2. Spectral reflectance curves for injured Satsuma mandarin.

2. Selection of wavelength fit for detection of defects

This measurement was excuted on the spectral reflectance properties of the surface containing both the parts belonging to the injured and uninjured areas. On account of this, concerning the effect of the injured area, the difference of the spectral reflectance between injured and sound Satsuma mandarin was examined at each wavelength, and this difference was shown in Fig. 3. The difference more than at least 10% was recognized in the wavelength region of 590 to 660nm and 690 to 760nm about almost all samples, and especially the difference more than 15% was concentrated at the wavelength region of 700 to 760nm. Some variability in the reflectance from different samples of same type of defect is to be expected. Taking this variability into account, it is assumed that, in addition to the possible variations in the sensitivity of the detection system, the spectral reflectance at the wavelength showing, between acceptable Satsuma mandarin and defects, the difference more than 15% would be adequate as the standard for sorting certainly. However, according to the previous paper[1] in the wavelength region of 550 to 700nm the spectral reflectance changed remarkably depending on the degree of coloring, hence it was assumed that the spectral reflectance in this region would not be used for detection of defects. Therefore, the spectral reflectance in the wavelength region of 700 to 760nm, which was little affected by the degree of coloring and was largest difference between injured and sound Satsuma mandarin, was considered as the effective index for sorting out injured Satsuma mandarin.

The difference in reflectance of about 5% between sound Satsuma mandarin and white colored defects was obtained over the wavelength region of 460 to 540nm. Basing on the fact that the reflectance in this region is quite stable (See Fig. 2), this difference was assumed to be available for detection of defects.

Therefore, in order to accomplish separation between sound and injured Satsuma mandarin, it would be desired to be used a combination of wavelengths selected from that of 700 to 760nm and 460 to 540nm.

3. Effect of injured area

The effect of the extent of damage, which was quite important for sorting injured Satsuma mandarin on the spectral reflectance was investigated. Fig. 4 (left) shows the changes of spectral reflectance over all the visible regions when attached the circular black tape simulated black defect to sound Satsuma mandarin and increased the circular area by increasing its radius at the central

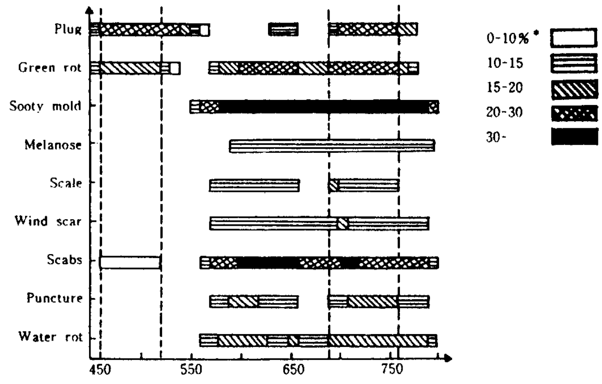

Fig. 3. Selection of wavelength for detection of defects.
*Difference in percent between injured and sound Satsuma mandarin.

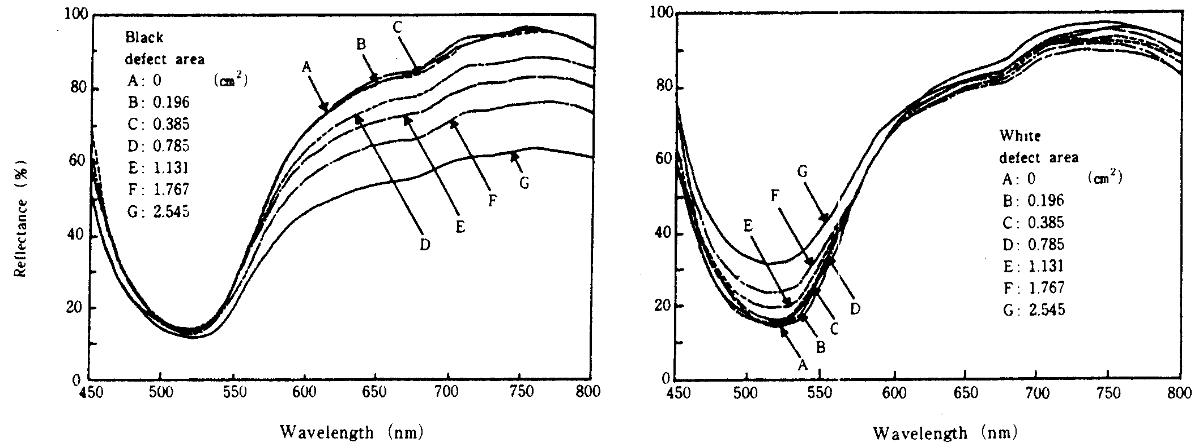

Fig. 4. Spectral reflectance curves for different simulated defects on Satsuma mandarin surface. (Left: black defect, Right: white defect)

position of illuminated area. The reflectance drop occurring with the increase of the simulated black defect was obserbed over the wavelength region of 550 to 800nm. The difference in reflectance between injured and sound Satsuma mandarin began to appear starting at about 0.785cm^2 area, and reached about 15% at the area above 1.13cm^2. Therefore, it was concluded that the change of spectral reflectance was not caused by kinds of defect, but remarkably depended on its color and size.

Fig. 4 (right) is the result of measurement using similarly white tape simulated white defect. Compared with sound Satsuma mandarin, the spectral reflectance showed higher value with increasing of simulated white defect in the wavelenght region of 480 to 550nm. The difference of reflectance between injured and sound Satsuma mandarin began to appear starting at about 1.13cm^2 area, and reached about 10% at 1.77cm^2 area. The wavelengths of 740nm and 520nm indicated maximum difference in reflectance between injured and sound Satsuma mandarin and would be considered to be suitable for sorting defects.

Fig. 5 shows the relationship between the ratio of defect area to illuminated area and the reflectance using simulated defect, and the numbers on the abscissa indicate the ratio of defect area to the sample port area of 19.63cm^2. The reflectances at the wavelength of 740nm and 520nm were linearly related to the area ratio. It was fixed to be necessary for detecting the defects that the difference in reflectance between injured and sound Satsuma mandarin was 15% at 740nm and 10% at 520nm, therefore Satsuma mandarin which had the defect area to the total area more than 6% (in black defects) or 5.5% (in white defects) were able to be sorted out from sound Satsuma mandarin.

4. Effect of location of defect

The effect of location of defect appeared on the surface at the spectral reflectance was investigated. The center of illuminated area was used as the standard, and rectangular axis on which the defect moved at interval of 5mm was set up on the surface. In order to detect the effect of defect more exactly, 2.54cm^2 (area ratio: 12.9%) of simulated black color was adopted as the sample A (Fig. 6).

Fig. 7 shows the change of spectral reflectance when the defect moved on sample port from the center of illuminated area. For the transfer of the defect toward X-axis (Fig. 7 left), the spectral reflectance increased as the defect moved out away from the center of illuminated area in the wavelength region of 550 to 800 nm. However, the curves for different location of defect tended to be similar in shape to the curve for sound Satsuma mandarin. For the transfer of the defect toward

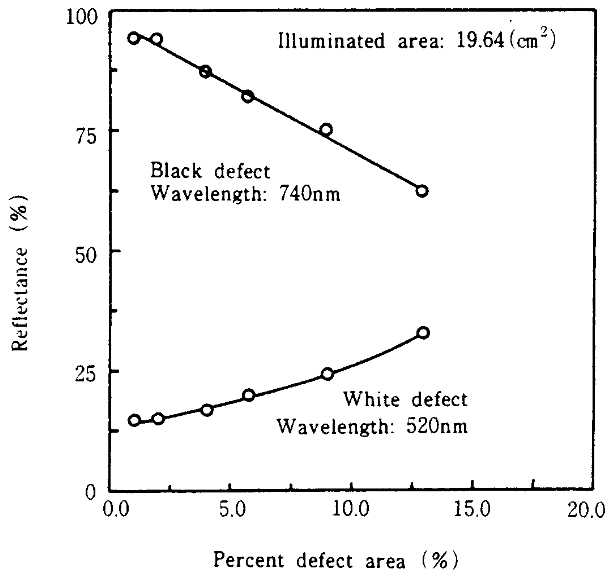

Fig. 5. Relation between reflectance and the area ratio of injured area to illuminated area.

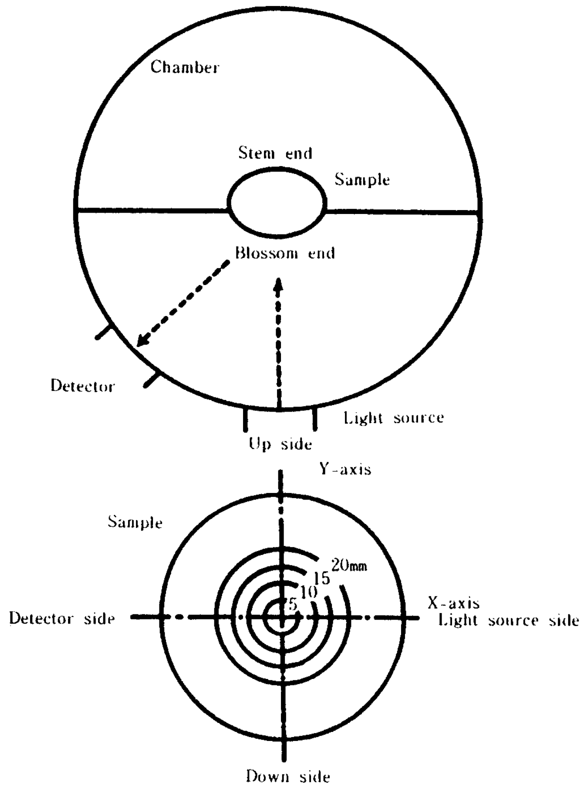

Fig. 6. Schematic diagram of movement of injured area on illuminated area.

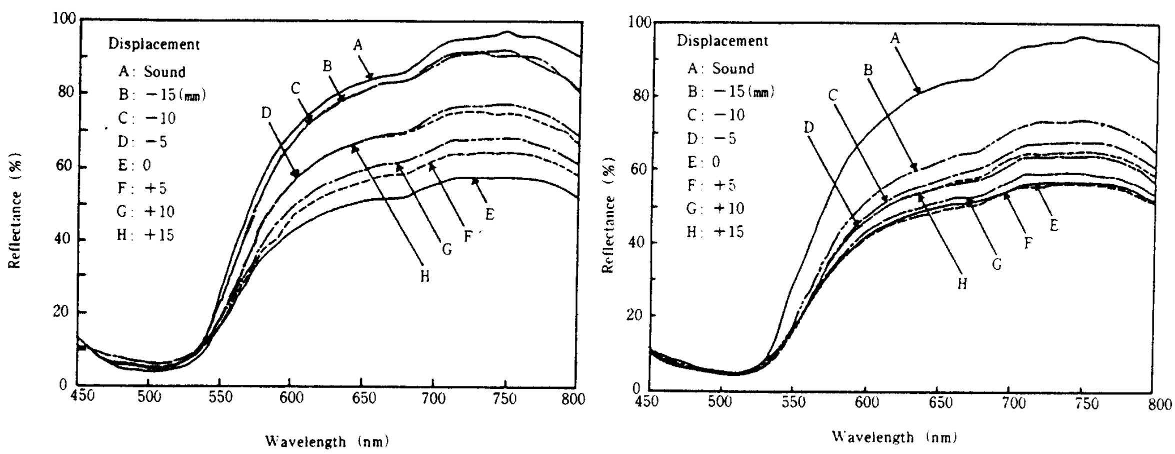

Fig. 7. Spectral reflectance curves for different location of defects on Satsuma mandarin surface. (Left: movement on X-axis, Right: movement on Y-axis)

Y-axis (Fig. 7 right), the change of spectral reflectance exhibited the same tendency as that of X-axis, but the increment was far less in comparison with X-axis and difference from the reflectance of sound Satsuma mandarin was also large.

Next, the effect of movement of the defect on the reflectance at 740nm that was effective in sorting out the black defect was investigated and the results in Table 1 were obtained. Sample A and B are the same simulated black defect whose injured area were $2.54cm^2$ (A) and $1.13cm^2$ (B) respectively, and the change of spectral reflectance for each transfer of defect was indicated by the difference from that of sound Satsuma mandarin. As to the direction of X-axis, in both sample A and B, the

Table 1. Difference of reflectance at 740nm between sound and injured Satsuma mandarin

		Displacement (mm)						
		−15	−10	−5	0	+5	+10	+15
Difference of Reflectance(%)	X−axis A	18.4	27.4	31.2	38.0	20.9	5.1	3.4
	B	12.0	15.4	17.5	18.4	10.3	7.3	5.6
	Y−axis A	21.8	27.4	29.9	38.0	38.9	35.9	31.2
	B	12.8	16.2	15.5	18.4	21.3	18.4	17.9

A : Injured area of 2.54㎠
B : Injured area of 1.13㎠

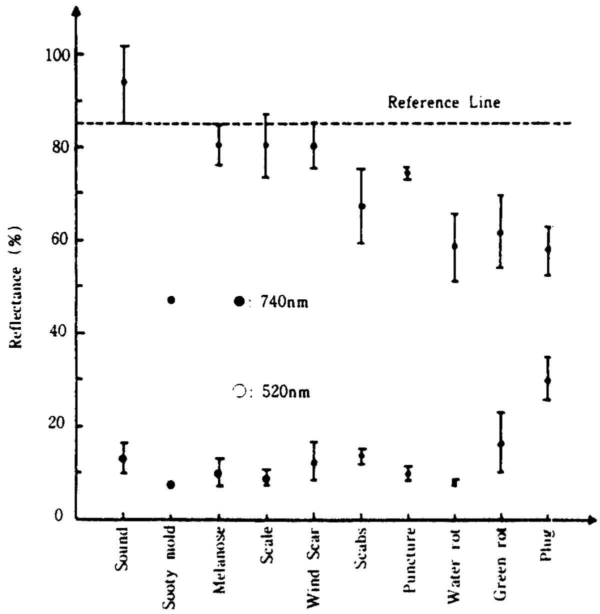

Fig. 8. Reflectance at 740 and 520nm for different defects.

difference in reflectance changed markedly depending on the location of defect. On the other hand, concerning the direction of Y-axis the variation of reflectance for the movement of the location of defect was noted to be less than that of X-axis.

The results indicated that almost all the defects appearing on different locations of the surface would be detected by using reflectance at the wavelength of 740nm, under the condition that the ratio of defect area to illuminated area was more than 6%.

Further investigation in the detecting system shows that a technique using a couple of symmetric detectors on X-axis was necessary for practical application of the method of sorting out injured Satsuma mandarin.

5. Separation of injured Satsuma mandarin at the effective wavelength fit for sorting

It was found that a combination of reflectance at 740nm (sensitive for black defect) and at 520nm (sensitive for white defect) was effective for the defect. Fig. 8 shows the mean and standard deviation of reflectance for each injured Satsuma mandarin category, together with reference line of 85% in reflectance at 740nm. The reflectance of each category was supposed to be normally distributed around their mean values, and reference value of 85% in reflectance at 740nm was adopted as an acceptance-rejection threshold value that was applicable for sorting out almost all injured Satsuma mandarin from sound ones. However, it was ascertained that the reflectance at

520nm was not so effective for sorting out Satsuma mandarin except for those afflicted with plug. It would be necessary for the promotion of usefullness of reference line in reflectance at 520nm to gather more intensive data for every category.

Consequently, it was assumed that successfull sorting might be accomplished by using the 85% in reflectance at 740nm as reference line. Lowering the reference value would lead to increasing the contamination of injured Satsuma mandarin into accepted ones, on the other hand, raising the reference value would lead to increasing of contamination of sound Satsuma mandarin into injured ones to be removed. It would be desirable to succeed in determining the optimum reference value minimizing the percentage of contamination of injured Satsuma mandarin into sound ones and maximizing the percentage of correct acceptance of sound Satsuma mandarin.

Summary

Spectral reflectance fitting for different defects of Satsuma mandarin was measured using a sample port of 19.6cm^2 area. The intensity of spectral reflectance was fixed to be a combination of those of injured and uninjured areas. The spectral reflectance was affected only by color difference of the defects, but not by the type of defect. The spectral reflectance at the wavelengths of 740nm and 520nm was found to be most suitable as a grading index. The spectral reflectance obtained as a grading index indicated that it depended on the area of defect. This grading index was further fixed to be more effective or applicable when the ratio of defect area to total area was more than 6% (in black defect) or 5.5% (in white defect) at simulated defect. The spectral reflectance varied with the defect position fixed through the sample port. By properly arranging the detector positions and adding detectors, injured Satsuma mandarin could be better sorted out from sound ones. However, for the samples with minute and / or scattered defects, further intensive collection of data was considered to be necessary before the establishment of accurate sorting out method. In this study, the standard value of 85% in reflectance at 740nm was fixed to be most suitable for sorting out almost all the kinds of defect. Even then considering grading efficiency, the reflectance at 520nm should be regarded as a secondary grading index.

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