The development of a nondestructive testing method to differentiate the overripe fruit from the optimal ripened of balsam pear (*Momordica charantia* L.) fruit for the machine grading system

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Introduction

Balsam pear (*Momordica charantia* L.) fruit is cultivated in the warm region of Japan such as Okinawa Prefecture. Recently, the consumption of the fruit has increased sharply because of the interest of consumers in its high vitamin C content, leading to a bitter taste that gives an extra flavor, and a unique surface that is covered with a lot of protrusions. While the fruits are distributed to retailers after harvesting, they are likely to undergo changes in pigment and pulp as the process of ripening progresses. Although the color of the fruit's aril changes from white to red and that of the seeds changes from white to brown during the early stages of ripening, it is difficult to judge this change based on appearance. This difficulty in judgment allows the fruit to ripen before it reaches the market, and it may be sold to a consumer without recognizing the overripe fruit, which can cause discomfort to the consumer. The maturity of the balsam pear fruit is being judged experimentally by observing the shapes of the protrusions on the surface (Okinawa Prefecture, 2001). However, the technique for the discriminant of maturity based on the protrusions requires expert skill, and frequent mistakes occur during the operation to eliminate overripe fruits. Further, the operational speed of this technique cannot much the increase in production. Thus, a machine grading system prossessing an automatic discriminant of maturity for balsam pear is necessary to increase the production. In this study, the discriminant method for the selection of overripe balsam pear fruits by using the image processing technique, which is suitable for the machine grading system, was developed.

Methodology

The cultivar Murubushi was grown under the normal growth conditions under which balsam pear is usually cultivated, and 44 fruits were harvested on different days in order to make two groups according to maturity levels. The number of samples in the optimal ripened group was 28 and that in the overripe group was 16. The fruit was placed on a white sheet on a photography table in a dark room. A digital camera (Power Shot S45, Canon) with 4 million pixels was placed on a plane perpendicular to the white sheet. Light was emitted by two lighting bulbs placed 40 cm above the sheet. Image processing was executed using an image analysis software (Image-Pro Plus Ver4.0, Media Cybernetics) in order to obtain several types of image characteristic variables that determine the fruit ripeness. Two color specification formats were used to analyze the sampled pixels of the color digital image: RGB format and HIS format.

Results and Discussion

The discriminant analysis was carried out by the following procedure. The balsam pear fruit was classified into two groups: optimal ripened and overripe fruit. In this study, the fruit whose aril turned red from white was defined as overripe considering consumer preference at the time of purchase. A maturity variable was created with values of +1 for optimal ripened fruits and -1 for overripe fruits, and a multiple linear regression of the maturity variable was perfomed on some of the image characteristic variables. The regression equation was given as follows: $z = a_0 + a_1x_1 + a_2x_2 + \ldots + a_nx_n$. The coefficients a_i were decided to obtain z that was greater than zero when the variables, $x_1, x_2,\ldots,x_n$ for the optimal ripened fruits were substituted

into the regression equation, and to obtain z that was less than zero when the variables, x_1, $x_2, \ldots, x_n$, for the overripe fruit were substituted. Based on the contribution ratio of the image characteristic variables, some image characteristic variables that gave an accurate result for the discriminant were chosen to decide a discriminant function. In this study, two image characteristic variables, standard deviation of B value and "white ratio" were selected. The white ratio was defined as follows. As the distance between the tops of two protrusions on the surface expands and the color of the surface of the fruit changes from dark green to yellow with an advance in maturity. Therefore, the boundary of each protrusion appears as a thin black shaded line for optimal ripened fruits, but the appearance of the boundary changes to vivid green broad line for the overripe fruits. The saturation value was expressed by the 8 bits gray-level value and the proportion of the number of pixels that is over 200 to all pixels was defined as the white ratio. The white ratio was high for the overripe fruits.
The result of the discriminant function and the discrimination between optimal ripened and overripe fruits for all samples is shown in Figure 1. The error rate was calculated by the leave-one-out cross-validation method and the result is shown in Table1. Although this method is the practically sufficient, however, from the viewpoint of its practical utilization, it is necessary to avoid the misjudgment overripening as optimal ripened fruit.

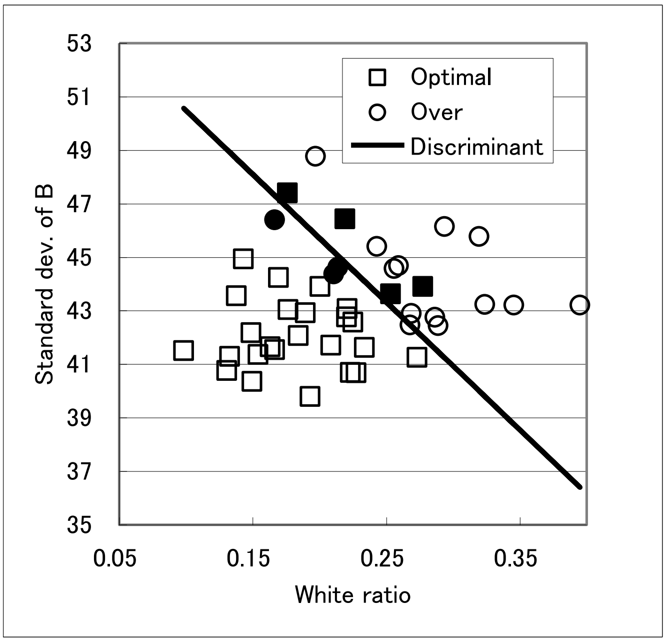

Figure 1: Result of the discriminant function and the discrimination between optimal ripening and overripe fruits. (The errors are expressed by filling symbols.)

Table 1: Error rate discriminant of analysis

	Number of error	Ratio of error (%)
Misjudgment optimal ripened as overripe fruits	4	14
Misjudgment overripe as optimal ripened fruits	4	25
Total	8	18

References

Okinawa Prefecture. 2001. Manual for discriminant of maturity for Balsam pear (in Japanese).

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