Postharvest Biology and Technology 138 (2018) 19–30

Contents lists available at ScienceDirect

Postharvest Biology and Technology

journal homepage: www.elsevier.com/locate/postharvbio

Cashews whole and splits classification using a novel machine vision approach

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ARTICLE INFO

Keywords:
Cashew
Grading
ImageJ
Image processing
Machine vision
Process system

ABSTRACT

Cashew is a high-value and the third largest edible tree nut that is universally consumed as a snack or included in food preparations. Classification of whole and split cashews in industries is carried out manually by visual inspection and hand-picking, which is time-consuming, tedious, challenging, and laborious. A machine vision methodology of capturing cashew shadows and associated image processing ImageJ plugin to classify cashews into whole and splits were developed and tested. The developed classification algorithm was based on a novel idea of using surface grayscale-intensity-profile for split-up cashews and object shadows for split-down and whole cashews. Out of several features derived from grayscale-intensity-profile values, the “length of curve” best classified the split-up cashews from others. The challenge of classifying the whole and split-down cashews was addressed by a new “shadow to total-area ratio.” An accuracy of 100 % was achieved by the algorithm. A process scale-up by increasing the height and power of light source was also proposed. The promising results suggest that the developed algorithm can be coupled with a suitable hardware system to perform accurate classification of the whole and split cashews.

1. Introduction

Cashew (*Anacardium occidentale* L.) is a high-value industrial crop and a popular tree nut worldwide, which is universally consumed as a snack or included in the confectioneries or food preparations for value addition. Cashew nut is the third largest edible tree nut after almonds and Brazilian nuts. The world production of cashew nut kernels was 754 700 Mg for 2016–17 and this was an increase of 31 % over the last decade; and Côte d’Ivoire has become the leading producer as it supplied 22 % of this world production (INC, 2017). Vietnam and India are the leading exporters with their contributions of 62 % and 21 %, respectively. Cashew is generally considered as a high-value and export-oriented commodity that earns foreign currency to the exporting country. The nutritive value of cashew nut is superior to some of the commonly consumed snack foods (e.g., pop corn, pasta), and it offers health benefits of fighting against major health concerns, such as cardiovascular disease and diabetes. However, about 1.1 % of the US population is allergic to cashew. The allergic effects include skin irritation, breathing trouble, and possible fatalities (Bock et al., 2001).

Cashew processing flow involves roasting, shell cracking and removal, peeling of kernel skin, grading, and the packaging (Berry and Sargent, 2011). All the processes are manual except for packaging operation. Cashew grades are based on kernel size, shape, and color. Common grades are white wholes, scorched wholes, splits, butts, and pieces. Among these grades, white wholes 180 (WW-180) is the premium grade and called “King of cashew.” Scorched wholes are another grade of cashew kernels with brown color and rough texture, where the prolonged roasting produces this grade and also makes the cashew crispier. However, both of these grades have all other characteristics similar including nutritional quality. Splits, butts, and pieces are low priced and are ideally used for garnishing, decorating ice creams and chocolates (CEPCI, 2017).

Generally, cashew grading is carried out through visual inspection by skilled laborers based on physical attributes, such as size, shape, and color. These skilled laborers while grading the cashews based on size (e.g., wholes, splits, pieces) also grade kernels based on color (white wholes and scorched wholes) using a reference color card. Even though some level of automation in cashew grading using mechanical grading equipment is followed, the available mechanical grading equipment grade cashews only based on overall size (wholes *vs* pieces) and are not capable of separating the whole and split cashews. Hence, so far, there are no effective means of separating whole and split cashews other than the manual inspection and hand-picking. Such a method by manual inspection is time-consuming, tedious, laborious, and less productive.

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https://doi.org/10.1016/j.postharvbio.2017.12.006
Received 5 October 2017; Received in revised form 11 December 2017; Accepted 15 December 2017
0925-5214/ Published by Elsevier B.V.

Therefore, machine vision, a modern method of image processing that has been successfully applied to several grading applications, would be a better an alternative that effectively classifies whole and split cashews.

Several researchers have reported the application of machine vision in classification, defect detection, quality inspection, and grading of fruits (Munera et al., 2017; Rady et al., 2017), vegetables (Lunadei et al., 2012; Pan et al., 2017), grains (Igathinathane et al., 2009), and many other food products as discussed by Zheng et al. (2006). Only a few machine vision methods have been developed for classifying cashews into different size grades. For example, Narendra and Hareesha (2011a) used MATLAB and trained an artificial neural network (ANN) model with 15 color features as input to classify six grades of cashews based on size. A similar study by Thakkar et al. (2011) on classifying based on size by training five machine learning models (multilayer perceptron, decision tree, *k*-nearest neighbors, naive Bayes, and support vector machine) and reported multilayer perceptron was found suitable with an accuracy of 86 %. Color based classification of whole cashews into white, scorched (light brown), and dessert (dark brown) types using multilayer perceptron in LabVIEW achieved an accuracy of 86 % (Thota et al., 2012). Including morphological features of cashews along with color features improved the accuracy to 88.93 % in classifying different size grades of cashew (Ganganagowdar and Siddaramappa, 2016). Including textural features in training ANN model in classifying different size grades of cashew was reported to improve the accuracy to 90 % (Narendra and Hareesha, 2011b).

All these studies predominantly classified whole cashews based on size in combination with color, morphology, and texture features into different size grades (e.g., WW-180, WW-210). Until now, there is no research reported on classification of whole and split cashews using machine vision approach. Developing a machine vision method to classify and grade the wholes and splits can be seen as a right step toward automation, and would also make economic sense as the cost of these two grades is significantly different. Therefore, the objective of this study was to develop a machine vision algorithm in ImageJ, an open source Java platform, which accurately classifies the whole and split cashews.

2. Materials and methods

2.1. Test materials — whole and split cashew nuts

The processed whole cashew samples were collected from “Alphonsa Cashew Industries,” Kollam, Kerala, India. The cashew samples were selected approximately of same size (length = 25(2) mm and width = 9(1) mm). This size selected was for the algorithm development and demonstration purpose, and the developed method was expected to work for cashews of any size. Broken cashews were not included as it was studied earlier and was easy to grade based on size or projected area, thus considered beyond the scope of this study. However, classifying whole cashews from split cashews can be challenging as the shape or projected area of whole and split cashews were similar. Furthermore, the splits get presented in two ways, such as split facing down (split-down), split facing up (split-up) creating distinct images (Fig. 1a), unlike wholes. For algorithm development and testing, the split samples were generated by manually splitting the whole cashews into two halves such that smooth edges were obtained.

2.2. Novel concept of classifying the whole and split cashews

It can be readily visualized that a segmented binary image (generally used for processing) derived from the color image of whole, split-down, and split-up (Fig. 1a) will be similar and a challenge to separate. In this study, a novel concept of using shadows of cashews as one of the features for identification and classification was proposed. It was hypothesized that the whole and split cashews will produce different amount of shadows, and this variation can be used for classification.

To produce the required well-defined, sharp-edged shadows, a point light source (LED light; 45 lm) was used (Fig. 1b). The light source was set at a horizontal distance (d) of 150 mm from the cashew, and at a height (h) 100 mm from the ground, which was finalized by varying the distance and height in preliminary trials. Different distances and heights alter the shadow length, which might encroach the adjacent samples too, therefore an optimum value was necessary. The finalized setting produced the light source start angle (α) of 56° and working angle (β) of 8°, which were derived using trigonometry principles. This setting produced a working zone width (w) of 60 mm and was found suitable for capturing the single column of three cashews (Fig. 1a) along with their shadows (Fig. 1c).

2.3. Image acquisition

Digital images of whole and split cashews were acquired using a digital single-lens reflex (DSLR) camera (Model: Nikon D5100, Nikon Corp., Japan) with the following camera settings: exposure mode = manual, shutter speed = 1/30 s, aperture = f/5.6, ISO = 400, and lens = 18–55 mm. Images were captured by placing the cashews on a pink (selected after tests) letter paper to provide good color contrast between the background and foreground. The camera was held on a tripod at 300 mm vertically above cashews to maintain uniform resolution. Each image consisted of three cashew samples representing whole, split-down, and split-up. An image captured at 90° orientation is shown in Fig. 1c, as an example. The orientation of cashews was varied by turning the cashews from 0° to 360° at ≈10° per image. As it is possible to present cashews in any random orientation practically, it is necessary to study the effect of orientation.

2.4. Image processing and analysis

The image analysis and plugin coding were developed using an open source image analysis software, Fiji (Ver. ImageJ 1.51p, Java 1.6 lifeline). The plugin coding was performed with Java language, and the several components and functions were derived from the basic methods available from various application programming interface (API) classes.

Generally, the morphology of objects is used in separation/grading analysis. However, in our present approach along with the object's morphology, the shadow dimensions were also used in developing the algorithm for classification of whole and split cashews. While considering shadow dimensions, the split-up cashew produces a bigger shadow (similar to the whole cashew but not quite large as the whole) at certain orientations due to the surface curvature placed below (Fig. 1c). This similarity in shadow dimensions between whole and split-up cashew poses an additional challenge during the classification process. However, with split-down cashews, the flat surface facing below caps the background closely and produced a smaller shadow.

2.4.1. Cashew classification strategy

As observed from Fig. 1c, the split-up cashew's surface exhibits a smooth texture, while whole and split-down cashew's surface exhibits rough texture. This textural difference (without shadows) can be used to classify the split-up cashew first, and then the comparison of shadow dimensions to classify the whole and split-down cashews as a clear difference exists between them. Therefore, the central idea of the developed algorithm consists of two phases: (i) classifying and digitally removing split-up cashew based on grayscale-intensity-profile, and (ii) classifying whole and split-down cashew based on the shadow dimension.

A clear difference in the surface texture between split-down and split-up cashew was visually observed (Fig. 1c). The split-down cashew gives a rough texture and it looks similar to the whole cashew, while the split-up gives a smooth texture. The rough texture, in a preprocessed grayscale image, was indicated by irregular patterns of darker spots,