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A novel image-analysis based approach to evaluate some physicochemical and cooking properties of rice kernels

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ABSTRACT

Prior to being edible, paddy needs to undergo several processing steps, which inevitably affect the kernel quality, both in terms of the physical, physicochemical and cooking characteristics. Unfortunately, many of the kernel quality parameters are time-consuming and not straightforward to evaluate, rendering the control of the paddy processing quite ineffective. An alternative means, which allows rapid determination of various properties of the kernels are therefore desirable. This study represents the first attempt to correlate image-analysis based apparent characteristics of rice kernels to physicochemical as well as cooking properties of the kernels for effective monitoring of rice processing and cooking processes. Parboiled rice production process was selected as a test process. Image-analysis based results, in terms of the changes of the kernel dimensions (i.e., elongation ratio, width ratio, and swelling) and translucency as well as the fractal dimension of the kernel images, were noted to adequately correlate with the tested physicochemical (i.e., amylose content, water uptake, degree of parboiling, which is closely related to the degree of starch gelatinization) as well as cooking (i.e., texture and cooked level of rice kernels) properties of the rice kernels of two varieties of Thai rice. This represents an attractive evaluation technique that can be adopted by an industry for various properties measurement and quality control.

1. Introduction

In order to obtain edible kernels, paddy needs to undergo several processing steps such as drying, milling and cooking. These processes naturally affect the kernel quality, both in terms of physical, physicochemical as well as cooking characteristics, which are time-consuming and not straightforward to evaluate. These difficulties partly prevent an effective control of paddy processing; alternative means that allows rapid and reasonably accurate determination of the various properties of the kernels is clearly desirable.

Recently, image analysis has been utilized as a tool to evaluate various properties of a wide array of foods (Brosnan and Sun, 2004; Jinorose et al., 2009). Nevertheless, for grain products, most studies focused only on the use of kernel dimensions, shape and color (or whiteness) for apparent quality evaluation (Jinorose et al., 2010; Moreda et al., 2012; Fıratlıgil-Durmus et al., 2010). Few attempts have been made on cooking or other properties evaluation (Zheng et al., 2007; Yadav and Jindal, 2007c). Although it has been noted that the cooking quality (e.g., texture of cooked rice kernels) is correlated in a significant fashion to the physicochemical changes (Jinorose et al., 2010; Yadav and Jindal, 2007a), no attempts have so far been made to correlate the image-analysis based results to the physicochemical properties of rice kernels, including the degree of parboiling, which closely related to degree of starch gelatinization, which are of great importance for effective monitoring of a paddy processing, especially parboiled rice production process, but is normally more difficult to evaluate.

In the present study, a parboiled rice production process was selected as a test process. This is because the process leads to many changes of paddy and hence the rice kernels; the process therefore requires careful monitoring and control (Bello et al., 2006; Jaisut et al., 2008; Luangmalawat et al., 2008; Soponronnarit et al., 2008). In a typical parboiled rice production process, paddy is first soaked in warm water and then parboiled (steamed) before being dried either in a mechanical dryer or under the sun or in shade (Juliano, 1993). Parboiled rice has significantly higher yield compared to its non-parboiled counterpart and takes longer time to cook due to starch gelatinization during the steaming process; gelatinization also leads to other physicochemical and microstructural changes of paddy as well (Naivikul, 2007). It is therefore of great importance to evaluate the degree of starch gelatinization during the parboiling process. A number of studies have been

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conducted to investigate the degree of gelatinization of rice starch via the use of such complicated techniques as differential scanning calorimetry and enzymatic analysis (Zhou et al., 2010). These techniques are, however, time-consuming and may not be suitable for real-time (or near real-time) process control. An alternative means, preferably the one that requires no complicated and time-consuming analysis, which allows rapid evaluation of the degree of parboiling, which is closely related to the degree of starch gelatinization is desired. It is noted that parboiled rice takes longer time than raw rice to cook if comparable texture is to be obtained (Juliano, 1993). The cooking time therefore depends on the palatability of the consumers. Parboiled rice would take longer to cook if soft and fluffy rice is preferred (as in most Asian countries); however, parboiled rice would take shorter time to cook if hard and firm rice is preferred.

Since visual characteristics of rice kernels could easily be obtained via image analysis, the present study aimed to develop, via the use of effective but simple and inexpensive image-analysis set-up and algorithms, the relationships between visual (i.e., kernel contour and translucency as well as fractal dimension of the kernel images) and physicochemical (i.e., amylose content, water uptake and degree of parboiling) as well as cooking (i.e., texture and cooked level of rice kernels) properties of Thai paddy and rice kernels; two rice varieties were used to investigate the effect of amylose content on the observed properties. The study was performed with the hypothesis that implicit physicochemical and cooking characteristics of rice kernels could be evaluated through some other more apparent characteristics, which can be obtained easily by image analysis and the technique should be easy enough to implement in an industry.

2. Materials and methods

2.1. Materials

Two Thai paddy varieties, i.e., *Oryza sativa* L. var. Khao Dawk Mali 105 (KDML 105) and var. Suphan Buri 1 (SPR1), which is a popular variety for parboiled rice production, with the amylose contents of 15% and 26%, respectively, were used in the experiments. Both paddy varieties were provided by the Rice Research Center, Pathum Thani, Thailand.

2.2. Preparation of rice samples

The parboiling process started by soaking paddy in water at a constant temperature of 70 °C in excess water at a water-to-rice ratio of more than 10:1 (Juliano, 1985; Naivikul, 2007). The water temperature was maintained by the use of an electric hot plate (Rommelsbacher, THL 100172, Berlin, Germany). Soaking was continued until the moisture content of the paddy reached 40% dry basis (d.b.) (Juliano, 1985). Soaked paddy was then drained and spread evenly as a thin layer in a steamer and steamed at atmospheric pressure for either 0, 10, 20 or 30 min to study the effect of different degrees of rice starch gelatinization. After steaming paddy was cooled by being spread on a tray and placed under ventilated ambient air; ventilation was performed until the moisture content of the paddy reached 16% (d.b.). The sample was then shade dried at ambient temperature until the moisture content reached 14% (d.b.). Finally, the parboiled paddy was dehusked and polished to obtain parboiled rice kernels. For comparison a control sample with similar moisture content was prepared from paddy with no soaking and steaming.

The above-mentioned rice kernels were cooked in excess boiling water, at a water-to-rice ratio of more than 20:1; excess water was used since this amount of water could be used for any rice variety, irrespective of its amylose content. Since the cooking rate is dependent on water absorption of the kernels, different water-rice ratios naturally affect differently the cooking behavior of the kernels. In order to avoid such an effect, excess water was used.

Cooking was performed for either 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55 or 60 min in order to vary the cooked level of the rice kernels (or, in other words, the level of kernel deformation).

2.3. Image acquisition

The utilized computer vision system consists of a lighting system, digital video camera and personal computer to acquire RGB (Red, Green and Blue) images with 24-bit color depth (Jinorose et al., 2010). The lighting system includes a circular fluorescent lamp (Osram, L32 W/765, Tangerang, Indonesia) with a color temperature of 6500 K, placing on the top cover of a light box. The angle between the lamp and a camera was 45° in order to capture the reflection of the light that scattered from a sample (ASTM, 2003; Jinorose et al., 2009). The whole lighting system is contained in a wooden box (Fig. 1); the interior of the box is painted in matte black in order to reduce the reflection of thelight. A single-CCD camera (Creative NX Ultra WebCam, Milpitas, CA) was positioned on a stand at 2 cm above the sample; the camera was connected to a PC. An image was acquired automatically by an algorithm written in MATLAB™, 2010a (MathWorks, Inc., Natick, MA). Calibration of the system with standard white paper was performed prior to each image acquisition to ensure lightness consistency.

After either soaking or cooking, rice kernels were first drained to get rid of excess water. Ten kernels were individually placed on a 9-cm diameter Petri dish (Pyrex, Germany); the whole content was then directly placed under the camera for image acquisition.

2.4. Image processing and data analysis

All algorithms for image processing were written in MATLAB™. Each image was cropped to 360 × 360 pixel (without any change of the sample dimension and color depth). A background was removed from the image using Otsu thresholding algorithm in combination with the boundary detection technique (Otsu, 1979). A grey-scale image was obtained using "rgb2grey" function of MATLAB™. A binary image was then obtained using an appropriate threshold, which was automatically calculated from the algorithm. The interested region was finally extracted from an original RGB color image.

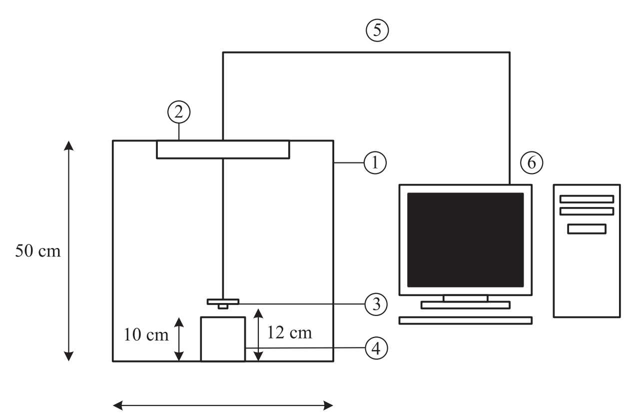

Fig. 1. Computer vision system. (1) light box; (2) circular fluorescent lamp; (3) CCD camera; (4) image-acquisition stage with black velvet background where a sample sit on; (5) USB cable; and (6) PC.