Agriculture and Natural Resources 51 (2017) 383–389

Contents lists available at ScienceDirect

Agriculture and Natural Resources

journal homepage: http://www.journals.elsevier.com/agriculture-and-natural-resources/

Original Article

Image analysis based on color, shape and texture for rice seed (*Oryza sativa L.*) germination evaluation

Benjamaporn Lurstwut, Chomtip Pornpanomchai*

Faculty of Information and Communication Technology, Mahidol University, 999 Phuttamonthon 4 Road, Salaya, Nakhon Pathom 73170, Thailand

ARTICLE INFO

Article history:
Received 6 April 2016
Accepted 3 June 2017
Available online 27 December 2017

Keywords:
Artificial neural network
Digital image processing
Germination evaluation
Germination verification
Rice seeds

ABSTRACT

Computer software—the Rice Seed Germination Evaluation System (RSGES)—was developed which can evaluate a rice seed image for germination prediction by using digital image processing and an artificial neural networks technique. The digital images are taken with a normal digital camera or mobile phone camera, which is very easy for farmers to process. RSGES consists of six main processing modules: 1) image acquisition, 2) image preprocessing, 3) feature extraction, 4) germination evaluation, 5) results presentation and 6) germination verification. The experiment was conducted on seed of the Thai rice species CP-111 in Bangkok and Chiang Mai, Thailand. RSGES extracted 18 features: 3 color features, 7 morphological features and 8 textural features. The system applied artificial neural network techniques to perform germination prediction. The system precision rate was 7.66% false accepted and 5.42% false rejected, with a processing speed of 8.31 s per image.

Introduction

Rice (*Oryza sativa L.*) is an extremely important food for people, feeding two-thirds of the world's population and providing 55–80% of total calories for people in Asia, Africa and Latin America (Correa et al., 2006). Thailand is a small country, which is located in Southeast Asia, but it is the largest rice trader, and has a market share of approximately 30 per cent of the world (Punthumast et al., 2012). The total cultivated area of Thailand is around 20.9 million ha and around half of this is devoted to rice farming and in 2007, Thailand produced around 18.4 million t of milled rice, and around 9 million t were exported (Forssell, 2009).

Normally, Thai farmers harvest the rice from their farm and keep some rice seed as rice stock for the next cropping round. They select the good rice seed by using the specific gravity method, which puts all the seed in a water solution made with salt or ethanol (Kobata et al., 2010). Only seed that sinks is selected for planting and floating seed is defective, which cannot germinate. Farmers need to clean all the sunk seed with pure water to dilute the salt or ethanol, then soak all the selected seed in water for priming before sowing on their farm (Farooq et al., 2009). The specific gravity technique is a labor- and time-consuming method and destroys the rice seed, which cannot be kept as rice stock because of potential fungal contamination (Hong et al., 2015).

In the present decade, many researchers have tried to present non-destructive methods for quality control, identification and cultivation of rice seeds, some of which are detailed here briefly. Wu and Shi, (2004) applied near-infrared reflectance spectroscopy to estimate the weight of rice seed for rice grain quality and breeding control. Basnet et al. (2014) applied laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) to determine the Sb, As, Pb, Cd and Zn levels in rice seed tissue to measure the levels of toxic metals and substances needed in rice seed cultivation. Abe et al. (2002) introduced using X-rays to detect heavy ions (C or Ne ions) in rice seed. The methods studied not only the mutation of rice seed but also rice seed cultivation. Nevertheless, all these non-destructive methods mentioned required very high technology equipment, which is very difficult for the farmers to manipulate. Due to the popularity and simplicity of mobile phones with a high precision camera, machine vision techniques may be a non-destructive and powerful method for processing rice seed images.

Many researchers have presented digital image processing for non-destructive rice seed manipulation with most of the rice seed images being processed using three important features: color features, morphological features and textural features, which are discussed below.

* Corresponding author.
E-mail address: chomtip.por@mahidol.ac.th (C. Pornpanomchai).

https://doi.org/10.1016/j.anres.2017.12.002

Color features

Color has been recognized as an important feature in a rice seed image. There are many color features which can be applied to an image processing method, namely: RGB (red-green-blue) features (OuYang et al., 2010), HIS (hue-saturation-intensity) features (Golpour et al., 2014) and CIE L × a × b × features (Deden et al., 2011). The rice seed color feature can identify two defective states of rice seed: the aging of rice seeds (Faruq et al., 2003) and fungal contamination (Singh et al., 2014). Old rice seeds are a gray-yellow color and mature rice seeds are a golden-yellow color. Fungus-contaminated rice seeds have some area of the seed that is black-yellow or gray-yellow in color (Yadav and Jindal, 2011). All old rice and fungus-contaminated rice seed was classified as non-germinative.

Morphological features

Many researchers have applied rice seed morphological features to identify and inspect rice seed quality using: 1) seed size, 2) seed shape, 3) seed area, 4) seed perimeter, 5) seed length, 6) seed width, 7) seed radicle length and 8) roundness factor (Dell'Aquila, 2004). Rice seed morphological features reveal two important defective problems: broken seed (Yadav and Jindal, 2011) and irregular seed shape (Maheshwari, 2013), both of which are key factors in predicting seed germination.

Textural features

Texture of the seed surface is an important feature for rice seed image evaluation. The gray-level co-occurrence matrix (GLCM) is one of the most practicable texture features, and is frequently used by researchers. The GLCM considers the spatial distribution of the gray levels in the neighborhood and calculates texture feature values including: entropy, energy, homogeneity, contrast and correlation (MousaviRad et al., 2012). Rice seed texture can be indicative of cracking (Yao et al., 2010) or tearing of the rice seed (Fang and Bin, 2004). A small crack in the rice seed is very difficult to see with the naked eye but it is very easy to find using computer vision by applying textural extraction features. Tears in rice seeds indicate where the rice seed has been separated into two parts that are still stuck together. Both cracking and tearing in rice seeds were considered non-germinative.

While the above brief literature review indicates there are many researchers who have proposed computer vision methods for rice seed quality management and identifying rice seed, little research has been conducted to predict rice seed germination using image processing methods. Therefore, the objective of this research was to develop a computer system using both software and hardware to predict the germination of rice seeds using image processing techniques.

Materials and methods

RSGES was developed on a computer with an Intel Core i5-2400 central processing unit using the Windows 7 software system (Microsoft Corp.; Redmond, WA, USA). The digital camera used in this research was a Nikon Coolpix-S3500 (Nikon Corp.; Tokyo, Japan).

System concept description

The system starts with laying the rice seeds down on paper towel on a stainless steel tray. Then, images of all the rice seeds are taken using the digital camera or a smart phone camera and stored on the computer where RSGES is installed (Fig. 1). The system evaluates all the rice seeds and marks a rectangle around the seeds predicted to not germinate. The farmer or user can return all the germination seeds to the rice stock because RSGES is a non-destructive rice seed method. The precision of the RGSES system is verified by planting all the tested seeds and observing seed germination.

System structure

For increased understanding, the conceptual diagram in Fig. 1 can be transformed to the chart shown in Fig. 2. The system consists of six main modules: 1) image acquisition, 2) image preprocessing, 3) feature extraction, 4) germination evaluation, 5) results presentation and 6) germination verification.

Image acquisition module

In the first module, all rice seed images are recorded using an overhead shot camera angle with the Nikon digital camera. The seeds are placed on a white towel sheet, with a distance between seeds and camera of 43 cm in an open environment. A sample of an input image is shown in Fig. 3A.

Image preprocessing module

This image preprocessing module consists of two submodules: 1) image segmentation and 2) image binarization. The process of image segmentation starts with RSGES changing a true color RGB image to a gray scale image. Then the system converts the gray-scale image to a binary image. Finally, a binary image is converted to a black-and-white image using a binarization technique (Fig. 3B). For image segmentation, RSGES labels the eight connected components of a whole rice seed binarization image. Then RSGES builds the rectangle which covers and fits each seed, as shown in Fig. 3C.

Features extraction module

The feature extraction module consists of 18 features: 3 color features, 7 morphological features and 8 textural features.

Color features. The color features are: 1) average red color (R), 2) average green color (G) and 3) average blue color (B). All the average RGB features use the mean of each color in the whole rice seed image.

Morphological features. The seven morphological features describe image regions based on an ellipse and consist of: 1) major axis length, 2) minor axis length, 3) orientation, 4) eccentricity, 5) area, 6) roundness and 7) aspect ratio. Each morphological feature has the following details.

a) The major axis length is the length (in pixels) of the major axis of the ellipse that is the same as the rice seed shape.
b) The minor axis length is the length (in pixels) of the minor axis of the ellipse that is the same as the rice seed shape.
c) The orientation is the angle between the *x*-axis and the major axis of the ellipse that has the same rice seed shape. The value ranges from −90 to 90°.
d) The eccentricity is the ratio of the distance between the foci of the ellipse and its major axis length. The value is between 0 and 1.
e) The area is the actual number of pixels in the region.
f) Roundness is measured as the similarity of the seed to a circular shape which can be determined using Equation (1):

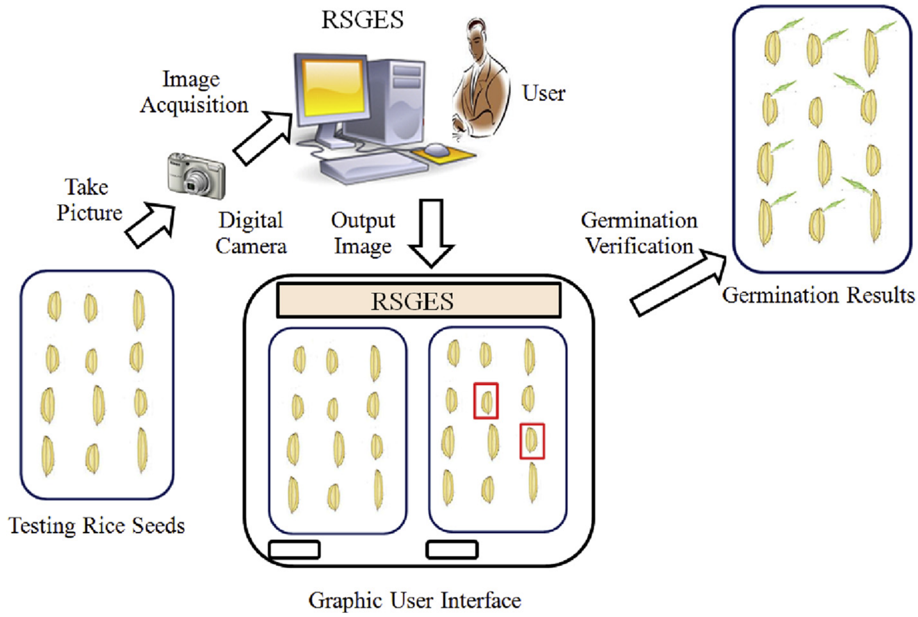

Fig. 1. Rice Seed Germination Evaluation System (RSGES) conceptual diagram.

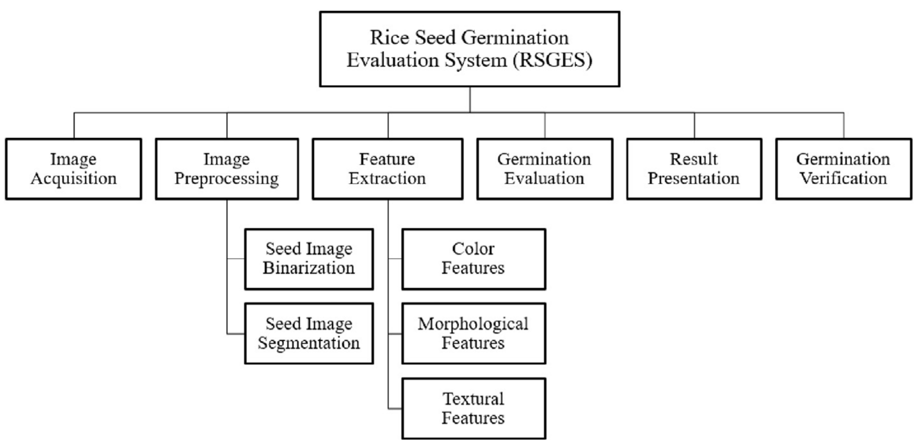

Fig. 2. Rice Seed Germination Evaluation System (RSGES) structure chart.

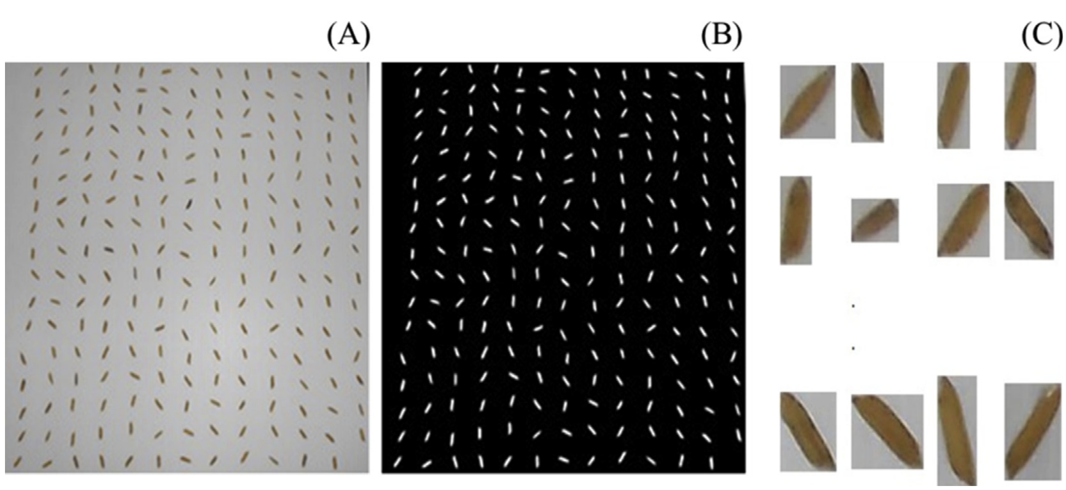

Fig. 3. Rice seeds image segmentation and binarization: (A) seed photographed on paper towel; (B) black-and-white image; (C) rectangular image produced for each seed.

$$R = \frac{(4\pi \times A)}{P} \tag{1}$$

where R is the roundness, A is the seed area and P is the approximate length of the seed boundary.

g) The aspect ratio is calculated from the major axis length divided by the minor axis length using Equation (2):

$$AP = \frac{Ma}{Mi} \tag{2}$$

where AP is the aspect-ratio; Ma is the major axis length of the seed and Mi is the minor axis length of seed.

Textural features

The GLCM in this research applies four texture features: 1) contrast, 2) correlation, 3) entropy and 4) homogeneity. Each texture feature is calculated based on Equations (3)–(6) (Zareiforoush et al., 2015). The system employs eight textural features using GLCM in two directions—horizontally and vertically. The eight texture features are: 1) contrast horizontal, 2) correlation horizontal, 3) entropy horizontal, 4) homogeneity horizontal, 5) contrast vertical, 6) correlation vertical, 7) entropy vertical and 8) homogeneity vertical. All the GLCM textural values are defined below using terms where $P_{i,j}$ is the entry in a normalized gray-tone spatial-dependence matrix and N is the number of distinct gray levels in the quantized image.

a) The contrast texture feature measures the local variations in the GLCM. The contrast texture can be calculated using Equation (3):

$$\sum_{i,j=0}^{N-1} Pi,j(i-j)^2 \tag{3}$$

b) The correlation texture feature measures the linear dependency of the gray levels on those of neighboring pixels. The correlation texture can be calculated using Equation (4):

$$\sum_{i,j=0}^{N-1} Pi,j\left(\frac{(i-\mu_i)\left(j-\mu_j\right)}{\sigma_i\sigma_j}\right) \tag{4}$$

where μ_i, μ_j, σ_i and σ_j = the mean and standard deviations of $p_{j,\,j}$

c) The entropy texture feature is a statistical measure of randomness that is used to characterize the texture of the input image. The entropy texture can be calculated using Equation (5):

$$\sum_{i,j=0}^{N-1} Pi,j(-\ln Pi,j) \tag{5}$$

d) The homogeneity texture feature measures the closeness of the distribution of elements in the GLCM to the GLCM diagonal. The homogeneity texture can be calculated using Equation (6):

$$\sum_{i,j=0}^{N-1} \frac{Pi,j}{1+(i-j)^2} \tag{6}$$

Germination evaluation module

In the fourth module, RSGES applies the neural network technique to predict which rice seed image represent seeds that will germinate. The artificial neural network (ANN) classifies the rice images by using the neural network structure: 18-13-2. The 18 input nodes are equal to the 18 features of each seed image and the two output nodes are equal to two kinds of seed—seed that will germinate and seed that will not. The hidden nodes are two-thirds of the average between input nodes and output nodes, which is the accepted rule of thumb (Karsoliya, 2012).

Result presentation module

This module shows the rice seed germinating prediction results. The graphic user interface of the system is shown in Fig. 4, which has the following details.

Image box: There are two image boxes: the input unknown rice image (Fig. 4, label 1) and the germination analysis image box (Fig. 4, label 2). The germination analysis results contain the boxes that represent non-germination rice seed results.

Text box: There is one textbox, namely the browse image file location text box (Fig. 4, label 3).

Command button: There are two command buttons: the browse image button (Fig. 4, label 4) and the result button (Fig. 4, label 5).

Germination verification

RSGES verifies the seed germination prediction by laying all the tested seeds on paper towel on a stainless tray (Fig. 5B), with the seeds arranged the same as for the input image (Fig. 5A). The rice seed will germinate around 1 mth after planting (Fig. 5B). A magnified image of the germinated rice seed is shown in Fig. 5C.

Results and discussion

Experimental results

RSGES employed the ANN with 18 input nodes, 13 hidden nodes and 2 output nodes. The testing dataset was made up of 600 rice seeds with 360 seeds for germination prediction and 240 seeds for non-germination prediction. RSGES produced 0% of both false positives and false negatives when the training dataset was used to test the system.

The untrained dataset was conducted on seed of the Thai rice species CP-111 using 34,835 images and testing took place in two locations (Bangkok with 20,901 seed images and Chiang Mai City with 13,934 images), as shown in Table 1. For the experiment in Bangkok, the system predicted 16,578 seeds for germination and 4323 seeds for non-germination. The experimental results showed a false positive rate of 4.74% (786/16,578 × 100) and a false negative rate of 3.15% (136/4323 × 100), as shown in Table 2. For the experiment in Chiang Mai, the system predicted 11,148 seeds for germination and 2786 seeds for non-germination. The experimental results showed that 9809 from 11,148 germinated and 2537 from 2786 did not germinate. These experimental results showed a false positive rate of 12.01% (1339/11,148 × 100) and false negative rate of 8.94% (249/2786 × 100), as shown in Table 2. The total tested rice seed using RSGES involved 34,835 images. The experimental results showed that 25,601 from 27,726 germinated and 6724 from 7109 were non-germinants. The experimental results showed a false positive rate of 7.66% (2125/27,726 × 100) and false negative rate of 5.42% (385/7109 × 100), as shown in Table 2.

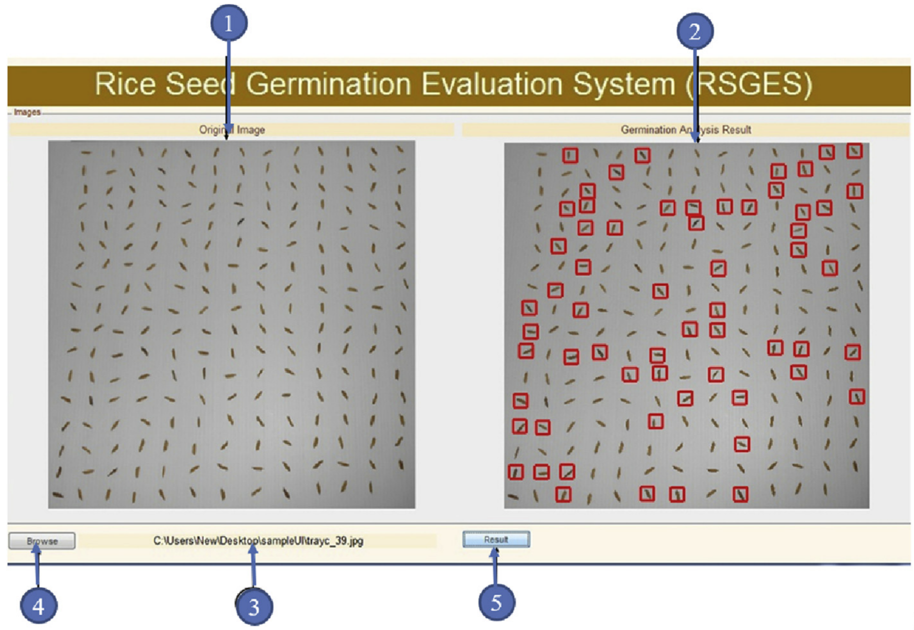

Fig. 4. Rice Seed Germination Evaluation System (RSGES) graphic user interface (1 = input unknown rice image; 2 = germination analysis image box; 3 = image file location; 4 = image file name; 5 = result button).

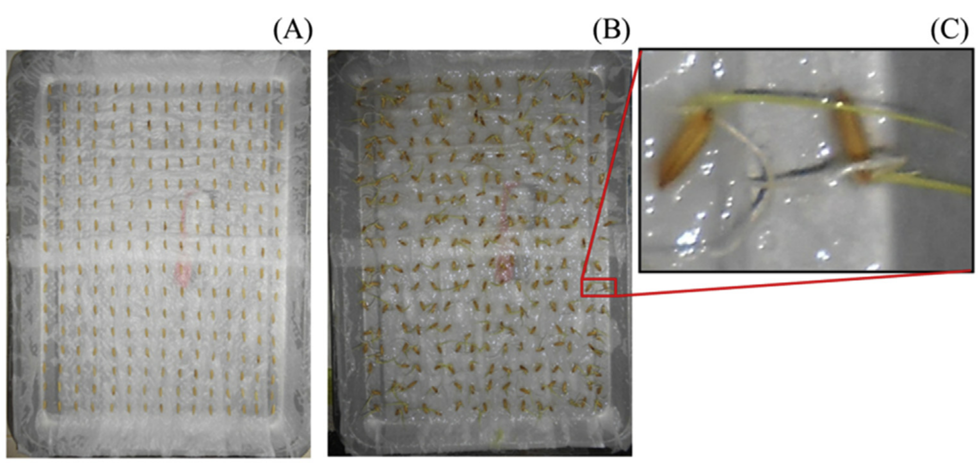

Fig. 5. Rice Seed Germination Evaluation System verification of the system by planting the rice seed: (A) before moistening, (B) 1 mth after moistening, (C) magnified image (× 115) of rice seed germination.

Table 1
Experimental results based on samples in Bangkok and Chiang Mai.

Location	Number of seeds	Germination prediction		Non-germination prediction	
		Germinated	Non-germinated	Germinated	Non-germinated
Bangkok	20,901	15,792	786	136	4187
Chiang Mai	13,934	9809	1339	249	2537
Total	34,835	25,601	2125	385	6724

Table 2
False positive and false negative rates for Bangkok and Chiang Mai datasets.

City	False positive rate (%)	False negative rate (%)
Bangkok	4.74	3.15
Chiang Mai	12.01	8.94
Overall	7.66	5.42

The experiment controlled all nutritional effects by planting the rice seeds on paper towel to avoid toxic contaminants and nutrients in the soil and all watering used tap water. The experiment was conducted in an open environment in Bangkok and Chiang Mai between September 2013 and October 2014 at a temperature of 30 °C and humidity of 67% in Bangkok, and during the same period in Chiang Mai city at a temperature of 27 °C and humidity of 62%. Both the false positives and false negatives in Bangkok were lower than in

Chiang Mai because Bangkok was warmer and had higher humidity during the testing period. Therefore, the temperature and humidity are rice seeds germination factors. Based on the experimental results in Tables 1 and 2, RSGES can predict rice seed germination in both Bangkok and Chiang Mai, Thailand with an average false positive rate of 7.66 and false negative rate of 5.42. RSGES will generate different evaluation results depending on the location of the test.

Discussion

As noted earlier, nowadays, many researchers have applied image processing techniques to process rice seeds for two important reasons. First, a digital camera and mobile phone camera are easy to manage and are reasonably priced. Second, the image processing technique is non-destructive, which does not change the structure of the rice seeds. Based on these two reasons, researchers and scientists are sure to employ an image processing method for the rice seeds applications because there is no negative side effect to the rice from this method.

Normally, researchers have conducted the rice seed experiment using three main features: color, morphological and texture, from which researchers can detect many defects occurring in rice seed. The color feature enables the system to detect rice seed aging or a seed contaminated with fungus. The morphological feature of the system can detect broken rice seed or an irregular seed shape, while the textural feature can detect cracked rice seeds or fungus contamination. Moreover, if RSGES can detect more features, such as smell, taste and weight, this would increase the precision rate.

Generally, researchers have employed an image processing technique to conduct rice seed experiments for three purposes: identification, quality control and germination evaluation.

Rice seed species identification

There are many rice species, planted around the world. A major problem for cooks, famers and traders is how to identify the different rice seed species. Only experts can recognize or identify many kinds of rice species (Sun et al., 2015). Therefore, many researchers have employed image processing techniques to solve this problem because this method is a non-destructive technique. The average precision rates of developed systems are around 85–100% (Liu et al., 2016). The cooks need different utensils to cook different rice species (Mohapatra and Bal, 2006). For example, jasmine rice can be cooked in a normal rice cooker but sticky rice needs to be cooked in a sticky rice steaming pot. The farmers need to know what kind of rice species they will plant on their farm because different rice species can be sold at different prices. Also the traders need to know the rice species for the same reason, because different rice species can be traded at different prices too (Dalen, 2004).

Rice seed quality control

Many researchers have employed image processing methods to determine the quality of the rice seeds because the quality of rice seed is one of the most important key factors for rice trading, cooking and cultivating. For traders, broken rice seed has a lower price than complete rice seed (Pabamalie and Premaratne, 2010). For farmers, complete rice seed can be cultivated and yield higher productivity than defective or cracked rice seed. For cooks, whole rice seed is more prefer than broken rice seed (Dalen, 2004).

Germination evaluation

Only a few researchers have conducted rice seed germination evaluation because it requires much labor and time to cultivate and observe the germination of the seed (Hong et al., 2015). Moreover, there are many key factors affecting cultivation of the rice seeds in a laboratory, including: the temperature, humidity, soil minerals, water and moisture. A few researchers have conducted plant seed germination evaluation using on seed other than rice. Dell'Aquila, (2004) germinated and evaluated the seed of five vegetable species (broccoli, radish, lentil, lettuce and carrot). However, no evidence is available that a researcher has conducted rice seed germination evaluation. Therefore, this research tried to evaluate rice seed germination by using an image processing method. The experiment controlled some seed germination factors such as soil minerals by using an artificial environment on a rolled paper towel. The experimental results showed a high precision rate of germination prediction. This research will contribute to the development of a computer system that can help traders and farmers select good germination rice seed to serve their purposes. Moreover, RSGES can retrain the system database for germination evaluation of other rice species, for example Japanese rice seed. Japanese rice seed (*Oryza sativa japonica*) is shorter than the seed used in the current research (*Oryza sativa L.*). The *Oryza sativa japonica* length is 4.94 ± 0.24 mm (Tanabata et al., 2012) and the *Oryza sativa L.* length is 7.20 ± 0.8 mm (Dalen, 2004). Therefore, RSGES needs to include additional training feature values for evaluating other rice seed germination.

RSGES fulfilled the research objective of developing a non-destructive rice seed germination evaluation system using an image processing method.

In Thailand, there are many tropical fruits and vegetables such as mango, orange, papaya, lemon, grape, rambutan, longan and chili that are also important export products and some of them are cultivated using their seeds (Lurstwut, and Pornpanomchai, 2011). Therefore, the developed system can be applied not only to Thai rice seeds but also to Thai fruit and vegetable seeds. The image processing technique developed is the best currently available, non-destructive technique, which can be applied to evaluate the germination of many plant seeds.

Conflict of interest

The authors declare there is no conflict of interest.

Acknowledgments

The authors thank the Bureau of Rice Seed, Ministry of Agriculture and Cooperatives; Rice Department of Thailand for supplying the rice seeds and the Faculty of ICT, Mahidol University, Bangkok, Thailand for supporting the research.

References

Abe, T., Matsuyama, T., Sekido, S., Yamaguchi, I., Yoshida, S., Kameya, T., 2002. Chlorophyll-deficient mutants of rice demonstrated the detection of a DNA fragment by heavy-ion irradiation. Radiat. Res. 43, S157–S161.

Basnet, P., Amarasiriwardena, D., Wu, F., Fu, Z., 2014. Elemental bioimaging of tissue level trace metal distributions in rice seeds (*Oryza sativa L.*) from a mining area in China. Environ. Pollut. 195, 148–156.

Correa, F.C., Silva, F.S.D., Jaren, C., Junior, P.C.A., Arana, I., 2006. Physical and mechanical properties in rice processing. J. Food Eng. 79, 137–142.

Dalen, G.V., 2004. Determination of the size distribution and percentage of broken kernel of rice using flatbed scanning and image analysis. Food Res. Int. 37, 51–58.

Deden, M.F., Nazaruddin, Y.Y., Raharja, S., 2011. Estimation of rice milling degree using image processing and adaptive network based fuzzy inference system (ANFIS). In: Proceeding of International Conference in Instrumentation Control and Automation. Bandung, Indonesia, pp. 98–103.

Dell'Aquila, A., 2004. Application of a computer-aided image analysis system to evaluate seed germination under different environmental conditions. Ital. J. Agron. 8, 51–62.

Fang, C., Bin, Y.Y., 2004. Machine vision inspection of rice seed based on Hough transform. J. Zhejiang Univ. Sci. 5, 663–667.

Farooq, M., Basra, S.M.A., Wahid, A., Khaliq, A., Kobayashi, N., 2009. Rice seed invigoration: a review. J. Sustain. Agric. 1, 137–175.

Faruq, G., Mohamad, O., Hadzim, M., Meisner, C.A., 2003. Optimization of aging time and temperature for four Malaysian rice cultivars. Pak. J. Nutr. 2, 125–131.
Forssell, S., 2009. Rice Price Policy in Thailand Policy Making and Recent Development. Minor Field Study Series (M.Sc. thesis). Department of Economics, the University of Lund, Lund, Sweden.
Golpour, I., Parian, J.M., Chayjan, R.A., 2014. Identification and classification of bulk paddy, brown, and white cultivars with color features extraction using image analysis and neural network. Czech J. Food Sci. 32, 280–287.
Hong, P.T.T., Hai, T.T.T., Lan, L.T., Hoang, V.T., Hai, V., Nguyen, T.T., 2015. Comparative study on vision based rice seed variety identification. In: Proceedings of International Conference in Knowledge and Systems Engineering. Ho Chi Minh City, Vietnam, pp. 377–382.
Karsoliya, S., 2012. Approximation number of hidden layer neurons in multiple hidden layer BPNN architecture. Int. J. Eng. Trends Technol. 3, 714–717.
Kobata, T., Akiyama, Y., Kawaoka, T., 2010. Convenient estimation of unfertilized grains in rice. Plant Prod. Sci. 13, 289–296.
Liu, W., Liu, C., Ma, F., Lu, X., Yang, J., Zheng, L., 2016. Online variety discrimination of rice seeds using multispectral image and chemometric methods. J. Appl. Spectrosc. 82, 993–999.
Lurstwut, B., Pornpanomchai, C., 2011. Plant seed image recognition system. Int. J. Eng. Technol. 3, 600–605.
Maheshwari, C.V., 2013. Quality assessment of *Oryza sativa* ssp. *indica* (rice) using computer vision. Int. J. Innovat. Res. Comput. Commun. Eng. IJIRCCE 1, 1107–1115.
Mohapatra, D., Bal, S., 2006. Cooking quality and instrumental textural attributes of cooked rice for different milling fractions. J. Food Eng. 73, 253–259.
MousaviRad, S.J., Tab, F.A., Mollazade, K., 2012. Application of imperialist competitive algorithm for feature selection: a case study on bulk rice classification. Int. J. Comp. Appl. 40, 41–47.
OuYang, A.G., Gao, R.J., Liu, Y.D., Dong, X.L., 2010. An automatic method for identifying different variety of rice seeds using machine vision technology. In: Proceedings of International Conference in Natural Computation. Chandong, China, pp. 84–88.
Pabamalie, L.A.I., Premaratne, H.L., 2010. A grain quality classification system. In: Proceeding of International Conference in Information Society (I-Society). London, UK, pp. 56–61.
Punthumast, P., Auttawaikul, Y., Chiracharit, W., Chamnongthai, K., 2012. Non-destructive identification of unmilled rice using digital image analysis. In: Proceedings of International Conference in Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON). Phetchaburi, Thailand, pp. 1–4.
Singh, S., Sinha, A., Kumar, S., Yadav, S.M., 2014. Determination of seed germination percent and effect of *Trichoderma harzianum* Rifai on fresh and stored seed by different methods. In: Proceeding of National Conference in Harmony with Nature in Context of Environmental Issue and Challenges of the 21st Century. Rajasthan, India, pp. 181–185.
Sun, J., Lu, X., Mao, H., Jin, X., Wu, X., 2015. A method for rapid identification of rice origin by hyperspectral image technology. J. Food Process Eng. 2015, 1–9.
Tanabata, T., Shibaya, T., Hori, K., Ebana, K., Yano, M., 2012. SmartGrain: high-throughput phenotyping software for measuring seed shape through image analysis. Plant Physiol. 160, 1871–1880.
Wu, J.G., Shi, C.H., 2004. Prediction of grain weight, brown rice weight and amylase content in single rice grains using near-infrared reflectance spectroscopy. Field Crop. Res. 87, 13–21.
Yadav, B.K., Jindal, V.K., 2011. Monitoring milling quality of rice by image analysis. Comput. Electron. Agric. 33, 19–33.
Yao, M., Liu, M., Zheng, H., 2010. Exterior quality inspection of rice based on computer vision. In: Proceedings of World Automation Congress (WAC). Kobe, Japan, pp. 369–374.
Zareiforoush, H., Minaei, S., Alizadeh, M.R., Banakar, A., 2015. Potential Applications of Computer vision in quality inspection of rice: a review. Food Ethics Rev. 7, 321–345.