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In situ quality assessment of intact oil palm fresh fruit bunches using rapid portable non-contact and non-destructive approach

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ABSTRACT

The oil palm (*Elaeis guineensis* Jacq.) fresh fruits bunch (FFB) quality can be determined by its ripeness, oil content (OC) and free fatty acid (FFA) level. The change in fruit's color upon ripening due to biochemical reactions can be observed through VIS/NIR spectroscopy. In this study, portable VIS/NIR spectrometer was employed to rapidly measure quality of oil palm FFB on-site, by means of non-contact and non-destructive approach. A mean-normalized method was used in pre-processing the bunch's spectral reflectance data within 400–1000 nm range using 10 nm intervals. Two statistical analyses are performed to models FFB quality. First, a forward-stepwise method is employed to establish multiple linear regressions (FS-MLR), and second, a combination between principal component analyses with multilayer perceptron neural network (PCA–MLP). These statistical analyses are employed for predicting the FFB ripeness, OC and FFA. Performances of best models were demonstrated by coefficient of determination (R^2), standard error of calibration (SEC) and standard error of prediction (SEP), which were respectively 0.9688, 0.1782, 0.4258 for ripeness prediction, 0.984, 0.25085, 0.4366 for OC prediction, and 0.9909, 0.0917, 0.2367 for FFA prediction model. The application of FS-MLR method for modeling the FFB quality delivered better performances, since it introduced more predictor variables.

1. Introduction

The oil palm industry in Indonesia significantly contributes to its economy by employing millions of people. Indonesia supplies more than 45% of the global demand. With 7.8 million hectares of plantations and production surpassing 23 million tons of palm oil annually (Makky and Soni, 2013a, 2013b), Indonesia becomes the largest palm oil producer. Indonesian oil palm industry needs to increase their high quality palm oil production while keeping the production costs low in order to maintain its competitive advantages (Makky et al., 2004). This edible oil is extracted from its fleshy mesocarp by means of mechanical extraction (Makky et al., 2012). The fruit's quality can be determined by its ripeness, oil content (OC) and free fatty acid (FFA) level, that eventually determine the quality of the palm oil produced. In practice, manual ripeness assessment is carried out by visual inspection, while fruit's oil content and oil's free fatty acid level are determined through laboratory chemical analysis. These methods are time consuming, labor intensive and prone to human error. In addition to being costly, laboratory chemical analysis is usually performed to only a few samples and requires destructive sampling. Furthermore, it takes time to obtain the results and therefore poses challenge to the industries. It is necessary to replace these methods with rapid and non-destructive as well as cost-efficient techniques.

As the fruits ripe, its surface color gradually changes due to biochemical reactions in the fruits. The color changes due to variation in carotenoids and chlorophyll pigments ratios in its skin (Ikemefuna and Adamson, 1984), and can be correlated to fruit ripeness level. The chlorophyll is known to be highest in raw fruits, and gradually decreases along with ripening fruit. In contrast, the carotenoid is low in raw fruits and gradually increases during ripening process (Ikemefuna and Adamson, 1984). Therefore, it is possible to measure the ripeness of oil palm fruits or bunches by measuring the ratio of chlorophyll to carotenoids, or vice versa, in fruit skin. This condition is observable through spectral reflectance analysis, and hence the spectroscopy suits the assessment requirements. The advantage of VIS/NIR spectroscopy has been described as being low cost, low maintenance and chemical-free process while providing short measuring time with limited sample preparation (Valous et al., 2010). Another advantage of the technique is that it facilitates a continuous quality evaluation of the object. Using visible and near infrared spectrum, spectroscopy analysis can obtain internal properties of fruits and produces result in rapid and non-destructive manner.

The use of VIS/NIR spectral analysis to assess agricultural products' quality as a rapid and non-destructive technique has

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increased recently (Magwaza et al., 2012; Bertone et al., 2012). Spectroscopy analysis both in visible and near infrared range, has been widely used for classification as well as assessing quality and internal properties of fruits such as apple (Bertone et al., 2012), blueberries (Sinelli et al., 2008), jujubes (Wang et al., 2010), mandarin (Magwaza et al., 2012), mango (Subedi et al., 2007), tomato (Shao et al., 2007; Sirisomboon et al., 2012), pear (Fu et al., 2007), and plum (Louw and Theron, 2010; Pérez-Marín et al., 2010). This method is well known as a rapid and non-destructive analysis for assessing fruit quality. Nevertheless, among these researches, oil palm fruits receive lack of attention. No research has been reported for studying physical appearance of FFB and its internal properties using VIS/NIR spectroscopy under actual field operation.

The objective of this study was to use VIS/NIR spectroscopy for measuring ripeness and internal quality of oil palm fruits. The specific objectives were to analyze relationships between VIS/NIR spectral reflectance characteristics and three important oil palm fruit quality indices (ripeness fraction, OC and FFA level) assessed through manual visual inspection and laboratory chemical analysis. The FFA level determines the quality of palm oil, because the presences of high FFA result in poor quality oil. Another advantage of low level FFA is less chemical processing, thus saving production cost and promoting green and more environmental friendly production in oil palm industries. These correspond to the requirements of palm oil industries where greater volume of quality production is desirable, through maximizing output from the oil content in the fruits, while minimizing its FFA level.

2. Material and methods

2.1. Samples preparation

The oil palm FFBs were harvested from 7 to 20 year-old trees during June–July, 2011 at National Plantation Company's Kertajaya plantations, Banten Province, Indonesia. All plants were of tenera variety, and the FFBs were harvested from eight different ripeness fraction conditions (Table 1), according to Indonesian Oil Palm Research Institute (IOPRI) standard (IOPRI, 1997). Every ripeness fraction has distinguished properties, including the fruit color and the number of detached fruitlets (Fig. 1). The FFBs' samples were classified by a panel of three experienced graders using visual assessment. In this research, 96 FFB samples, 12 from each ripeness fraction, were used to be analyzed by spectrophotometry. Infected, bruised or damaged bunches were discarded before these bunches with good appearance were selected. All containments on the bunch such as dirt, fiber and leaves were removed before measurement performed.

Table 1
FFB ripeness fraction classification (IOPRI, 1997).

Ripeness fraction	Quality	Detached fruitlets
F00	Bad	None
F0	Low	Up to 12.5% of outer fruits
F1	**Preferable**	**12.5–25% outer fruits**
F2	**Preferable**	**25–50% outer fruits**
F3	**Preferable**	**50–75% outer fruits**
F4	Low	75–100% outer fruits
F5	Bad	Inner fruits start to detached
F6	Worst	Most fruits detached

Since changes in color of oil palm fruits can be distinguished during fruit ripening process, due to the change of chlorophyll and carotenoids pigment concentrations in the fruits, measurement of spectral reflectance were performed in order to determine the change in these two pigments' ratio. Within a bunch, the color of the fruitlets is usually not uniform, and there exists gradation of fruitlets color from the top part of the bunch (apical) to the bottom part of the bunch (basal). Therefore, the measurements were performed at the three parts of each bunch, i.e. apical, middle and basal part. Subsequently, measurements were replicated thrice for each part, located around the equator, with the distance of about 120° apart (Fig. 2a).

In this study, the nigrescens fruit type was selected being the major fruit type popularly grown in Indonesia. As described by Corley and Tinker (2003), these fruits can be distinguished by its purplish black color at the apex and pale greenish yellow color at the base during raw or unripe state. Bunches were inspected on site. For each bunch, measurement and data acquisition took less than one minute, and then the bunch was immediately sent to the laboratory for chemical analysis.

2.2. VIS/NIR reflectance spectra measurements

The spectroscopy measurements were performed using Ocean Optic USB2000+VIS–NIR series spectrometer (Ocean optics, USA). The device provided spectral information between 350 and 1000 nm with resolution of 1.5 nm. For the light source, HL-2000 tungsten halogen light sources (Ocean optics, USA) were used. For measuring the reflectance of oil palm fruits surface, optical fiber reflection Probes (QR600-7-VIS–NIR, Ocean optics, USA) were employed to record diffuse or specular reflectance. The reflection probes were coupled to the spectrometer and light source to measure reflection. To calibrate the spectrometer, a white reflec-

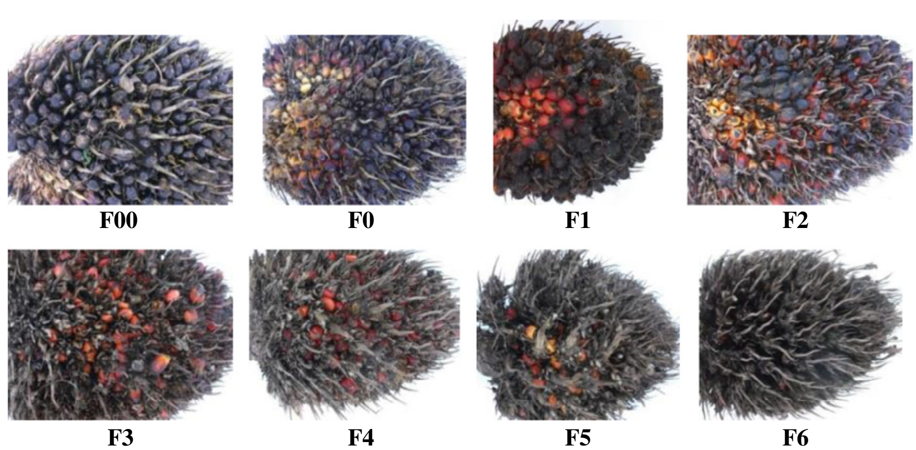

Fig. 1. FFB appearance of different ripeness conditions.