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A portable RGB color sensor for detecting free fatty acid (FFA) in palm oil samples

Vakin Nunumvong[1], Kosin Teeparuksapun[2,*], Nicha Prasongchan[2] and Apichai Phonchai[3,4]

[1]Mathematic Program, Department of General Education, Faculty of Liberal Arts, Rajamangala University of Technology Srivijaya, Songkhla, Thailand
[2]Science Program, Department of General Education, Faculty of Liberal Arts, Rajamangala University of Technology Srivijaya, Songkhla, Thailand
[3]Division of Health and Applied Sciences, Faculty of Science, Prince of Songkla University, Hat Yai, Songkhla, Thailand
[4]Forensic Science Innovation and Service Center, Prince of Songkla University, Hat Yai, Songkhla, Thailand
[*]Corresponding author: kosin.t@rmutsv.ac.th

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Abstract

A colorimetric sensor based on red, green, blue (RGB) measurement using an OV2640 camera module and ESP32 microcontroller was developed for measuring free fatty acid (FFA) in crude palm oil samples. The proposed method is based on measuring the color of liquid samples and convert it to RGB and Grayscale intensity. The RGB sensor's performance was evaluated for application in analysing FFA in crude palm oil samples. The FFA analysis was based on the application of the limiting reagent concept in an acid-base (palmitic acid-Na_2CO_3) reaction with phenolphthalein as an indicator. The RGB sensor could detect FFA with a linear relationship in the range of 0.0 - 0.1 % w/w and the linear regression equation was y = 1,125x - 2.8056, r = 0.9923, with limit of detection (LOD) and limit of quantification (LOQ) having values of 0.017 and 0.057 % w/w, respectively. The analysis of FFA in crude palm oil samples showed good agreement with results obtained from the proposed RGB sensor and the titration method (AOCS; Ca5a-40). This simple, rapid, and economical analysis method for assessing FFA holds promise for application in the quality control of crude palm oil samples.

Keyword: Colorimetric analysis, Portable sensor, Low-cost device, Free fatty acid, Crude palm oil

1. Introduction

Palm oil is a versatile edible vegetable oil extracted from the mesocarp, which is the reddish pulp found inside the palm fruit [1-3]. The palm oil's quality is determined by various factors, and one of the most commonly assessed quality throughout production, storage, and marketing of the palm oil is the free fatty acid (FFA) content. In Thailand and Malaysia, the standard specification for FFA content in crude palm oil (CPO) is a maximum of 5% w/w [2]. Elevated FFA levels observed in crude palm oil can often be ascribed to improper palm fruit harvesting, improper transportation, and prolonged storage. It is essential to measure the percentage of FFA and control its content in crude palm oil so that it does not exceed the prescribed standard, thus, ensuring a higher selling price when it is sold to the refinery. The standard method used for analysing FFA content in crude palm oil follows a routine procedure based on a conventional wet chemical method adopted from the American Oil Chemists Society (AOCS; Ca5a-40) as well as other techniques. Man *et al.* (1999) introduced and detailed the implementation of a rapid direct Fourier transform infrared (FTIR) spectroscopic technique utilizing a 100 μ BaF_2 transmission cell for assessing FFA content in both CPO and refined-bleached-deodorized (RBD) palm olein. Their innovative FTIR approach demonstrated results on par with traditional chemical methods in terms of reproducibility and accuracy. The FTIR method's appeal lies in its streamlined analysis, which takes less than 2 minutes per sample, and its reduced reliance on solvents and labour compared to conventional wet chemical techniques [2]. An analytical method based on spectra that uses portable Near-infrared (NIR) equipment and chemometric tools was also used for detecting the substitution of authentic materials with non-dairy fat (vegetable

oil) in butter cheese [3]. The cheese was verified as authentic or adulterated through an analysis of its fatty acid profile. Classification models using Partial Least Squares Discriminant Analysis (PLS-DA) achieved an impressive 94.44% accuracy in detecting adulteration. PLS prediction models also showed excellent performance (RPD > 3.0) in estimating the degree of adulteration. These results underscore the effectiveness of NIR spectra in uncovering soybean oil substitution in butter cheese and demonstrate the robustness of the developed models that help identify adulteration in external samples. A surface acoustic wave (SAW) sensor-based electronic nose was also used for monitoring the storage stability of RBD palm olein [4]. This study analyzed fatty acid composition, iodine value (IV), peroxide value (PV), and FFA content in order to determine the quality of the oils and compliment the electronic nose data. A strong correlation emerged between electronic nose responses, chemical test data and sensory evaluation scores, as indicated by the Pearson's correlation coefficient. These findings suggest that the SAW sensor-based electronic nose could serve as a valuable analytical tool for monitoring the oxidation and degradation of vegetable oil over time. However, several techniques for FFA analysis are labour intensive and require skilled operators [5].

Currently, colorimetric sensors based on visible color change reaction of target analytes and reagents have been developed and used for the analysis of various analytes [6-9]. Colorimetric sensors are generally simpler and more cost-effective to fabricate, which makes them more accessible to a wider range of users. They do not require specialized training to operate, and their results can be interpreted visually, making them easy to use for non-experts [6,10-11]. The color change occurs as a result of a chemical reaction between the target analyte and reagents, which can be observed visually, or the sample can be analyzed using a spectrophotometer to measure the intensity of the color change [7,10].

Another approach is to detect the color change by taking a digital image with a smartphone camera. The digital image is then analyzed using an application or software that extracts the color information from the image and converts it into a quantitative measurement. The advantage of smartphone colorimetry is that it eliminates the need for expensive or specialized equipment typically used in traditional colorimetry. It also enables real-time, on-site analysis of samples, making it a valuable tool for a range of applications [11-13]. However, smartphone colorimetry has some limitations, including significant analytical variation among different smartphone models. Furthermore, image processing may require a computer or mobile application, making real-time monitoring more cumbersome [14-15].

The RGB sensor has recently gained widespread popularity and is widely utilized as an analytical tool for detecting various analytes with accurate color reproduction in electronic devices. It is a type of sensor designed to detect the intensity of red (R), green (G), and blue (B) light [16-18]. RGB sensors measure the intensity of each color channel and then combine them to create a full-color image. These sensors can detect a wide range of colors and shades, and they are typically very accurate and reliable. Oliveira *et al*. (2022) pioneered and reported the work on RGB sensors for the colorimetric analysis of liquid samples [18]. This novel sensor eliminates the need for a computer or mobile application to collect RGB values. In addition, the sensor is remarkably cost-effective, being approximately 100 times less expensive than a mid-range smartphone.

This current study focused on the design and fabrication of an RGB sensor using a camera module. The sensor architecture is described in detail. The feasibility of the RGB sensor was demonstrated for the detection of FFA in palm oil samples.

2. Materials and methods

2.1 Chemicals

Palmitic acid was purchased from ACROS (Belgium) and sodium carbonate (Na_2CO_3) was obtained from KEMAUS (Australia). All chemicals were utilized as received without additional purification and double distilled de-ionized water was used. Palm oil samples were sourced from Trang, Songkhla and Surat Thani provinces located in Southern Thailand.

2.2 Apparatus

An OV2640 color CMOS UXGA (2.0 Mega Pixel) Camera Chip (array size 1600 × 1200 (UXGA), with a sensitivity of 0.6 V/Lux-s, S/N ratio 40 dB and lens size 1/4 inches), was produced by OmniVision, USA. ESP32 microcontroller (Espressif Systems, China), lithium polymer battery (Li-Po, 2,000 mAh), and light-emitting diode (LED) (2.6-2.9 v, 1.8 mA) were purchased from a commercial online store (www.analogread.com).

2.3 Architecture of the RGB sensor and data acquisition

A block diagram of the RGB sensor design is presented in Figure 1.

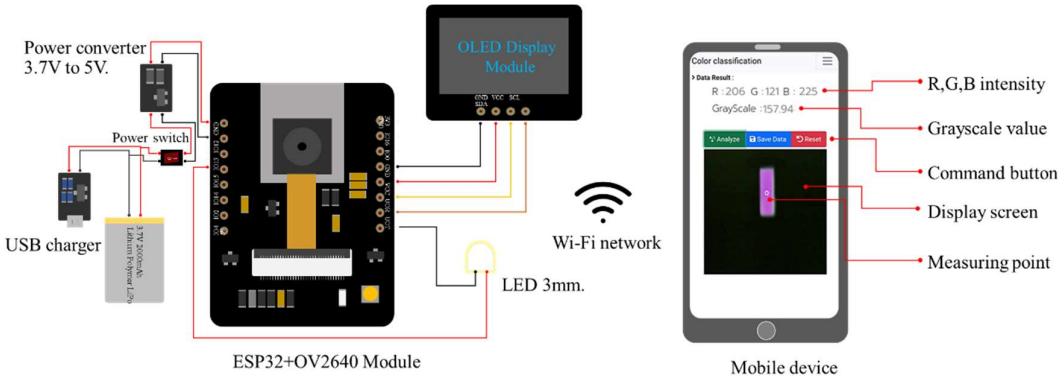

Figure 1 A block-diagram illustrates the fabrication of the RGB sensor and circuit pin connection of ESP32 microcontroller, OV2640 and other electronic components.

An OV2640 camera module was utilized to capture the image of the samples. This device was connected to a single board ESP32 microcontroller by a I2C socket. A white high-brightness luminescent LED (LED 3 mm) was pointed towards the sample from a distance of 30 mm, and the sensor emitted light to illuminate the intended surface. A Li-Po rechargeable battery was connected with a power converter to increase the voltage from 3.7 v to 5.0 v and also to empower the electronic devices. In addition, the Li-Po battery charger module was placed between the Li-Po battery and converter with an external power supply that can simultaneously recharge the battery. The devices pin connection on the ESP32 board to the OV2640 camera module, power source, LED and an organic light-emitting diode (OLED) screen is summarized in Table 1.

Table 1 Circuit pin connection on the EPS32 microcontroller board to the OV2640 camera module, power source, Li-Po battery, LED and OLED screen.

ESP32 pin	OV2640	Power source	LED	OLED screen
32	PWDN GPIO			
0	XCLK GPIO			
26	SIOD GPIO			
27	SIOC GPIO			
35	Y9 GPIO			
34	Y8 GPIO			
39	Y7 GPIO			
36	Y6 GPIO			
21	Y5 GPIO			
19	Y4 GPIO			
18	Y3 GPIO			
5	Y2 GPIO			
25	VSYNC GPIO			
23	HREF GPIO			
22	PCLK GPIO			
5V		VDC in		
GND		Ground		
GPIO13			LED 3mm.	
UOR (GPIO1)				SCL (OLED display pin)
UOT (GPIO3)				SDA (OLED display pin)

The microcontroller unit was connected to the OLED display screen to indicate the status of the device. The OV2640 camera module configuration was set as follows - image size (SVGA, 800×600 pixel), Jpeg quality (12, 0 = low, 12 = high), white balance (auto adjust), brightness (0, -2 = low, 2 = high), contrast (0, -2 =low, 2 = high), saturation (0, -2 = low, 2 = high), threshold (120) and exposure (auto adjust). The RGB sensor works by sending a command from the web interface to ESP32. The ESP32 then generates a command to OV2640 to capture the image (800×600 pixel). In the image capturing step, the sensor's array of pixels detects light and then converts it into electrical signals. The signals are then processed by an analogue-to-digital converter, which converts them into digital values representing the pixel's intensities. These digital values are then organized and stored (as a

.Jpeg file) to create a complete image. The center of the image is then selected and sent to ESP32 to extract and calculate the RGB and Grayscale intensity, which is then sent back to the web-interface. The Grayscale intensity is calculated using Equation (1).

$$\text{Grayscale intensity} = (0.299 \times R) + (0.587 \times G) + (0.114 \times B) \quad (1)$$

Here, R, G, and B represent the red, green, and blue intensities, respectively.

The RGB sensor device was connected to the mobile device via a Wi-Fi network to display the measurement and the calculated RGB and Grayscale intensity data were recorded in a Google sheet. All electronic components were packed in a box fabricated by 3D printing (ET4, Anet, Shenzhen, China) using a gray plastic filament (PLA+, 1.75 mm). The dimensions of the sensor box were 70 mm in width, 130 mm in length, and 60 mm in height, with a thickness of 3 mm. A photograph of the RGB device box is shown in Figure 2(A). A 10 mm hole was used for placing the 1.5 mL microcentrifuge tube containing the liquid sample. The distance between the sample holder and color sensor module was 90 mm. Figure 2(B) shows the main electronic components of the sensor.

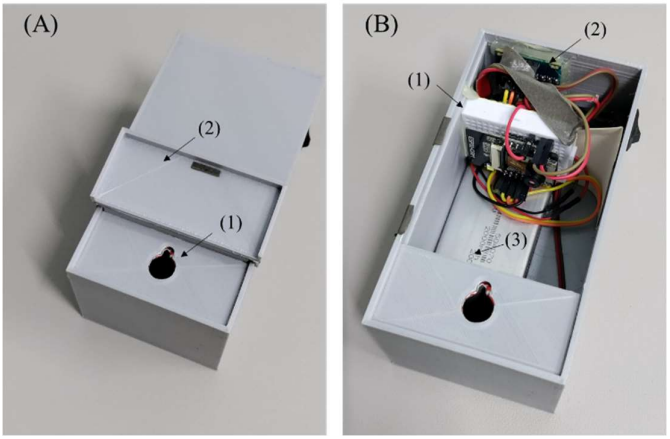

Figure 2 (A) A 3D-printed sensor box comprising a holder for a 1.5 mL microcentrifuge tube (1) and a lid (2) to regulate external light (B). The sensor setup included (1) a color sensor module (OV2640), (2) an ESP32 microcontroller, and (3) a Li-Po battery.

2.4 Colorimetric detection of FFA by an acid-base reaction

Colorimetric detection of FFA is based on the color reaction of an acid-base in the presence of phenolphthalein, as an indicator. This study used palmitic acid to represent FFA. For each assay, 250 µL of palmitic acid was added to a 1.5 mL microcentrifuge tube. A phenolphthalein indicator (0.5 % w/v in ethanol) measuring 50 µL was then added to the mixture and subsequently mixed with a vortex mixture. Following this, 500 µL of 0.01 M Na_2CO_3 was added, and the mixture was allowed to sit for 2 minutes. Finally, a digital image was captured and processed for RGB and Gray intensity. In order to evaluate the performance of the RGB sensor, the linear dynamic range, limit of detection (LOD), and limit of quantification (LOQ) were investigated.

2.5 Analysis of FFA in crude palm oil samples

2.5.1 Crude palm oil sample

Three groups of crude palm oil totaling 10 samples were used in this study. These were crude palm oil from fresh fruit bunches (CPO-FFB; S1-S4), crude palm oil from oil palm loose fruits (CPO-LF; S5-S7) and crude palm oil from a palm oil mill (CPO-POM; S8-S10). Oil palm fresh fruit bunches (FFB) were harvested from oil palm trees in Trang province. The preparation of palm oil samples was adapted from procedures outlined by Nizam *et al* [19]. Since the oil palm fruits in the FFB vary in ripeness, the FFB was initially divided into three parts, namely distal, central and proximal, as illustrated in Figure 3(A), and the fruits were then collected from these regions to obtain an average ripeness level.

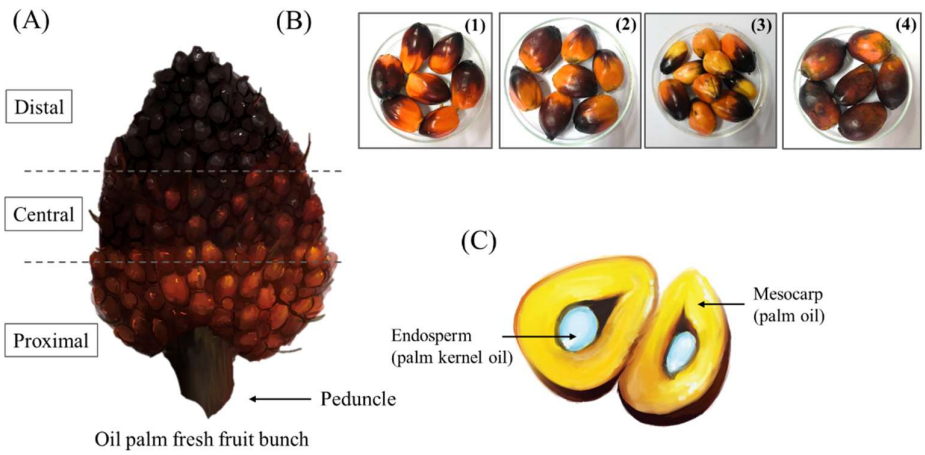

Figure 3 Illustration of an oil palm fruit: (A) an oil palm fresh fruit bunch; (B) oil palm fruits harvested from the distal (1), central (2), proximal (3) part of the oil palm fresh fruit bunch, and loose fruits (4); (C) a cross-section of an oil palm fruit revealing the mesocarp and kernel.

As depicted in Figure 3(A), the distal region matures first, followed by the central and proximal regions. Fruits from the proximal region exhibit variations in size, leading to differences in oil yield, whereas those from the central and distal regions show no discernible differences [20]. The palm oil in palm oil mills is typically extracted from fruits on the entire FFB. Hence, fruits for in this study were manually harvested from each of the three regions (Figure 3(B) - (1-3)) and combined to achieve an average ripeness level and then divided into four samples (S1-S4).

In order to extract the oil from palm fruits, each batch of mixed fruits underwent initial washing with tap water to eliminate any dirt. Subsequently, the fruits were autoclaved at 121 °C for 25 min to simulate the sterilization process. This step serves to soften the palm mesocarp and suppress lipolytic activities, thereby preventing a further increase in the FFA content [19, 21]. The oil palm fruits consist of mesocarp and kernel, as depicted in Figure 3(C), which were then manually separated. The mesocarp underwent preheating in an 80 °C water bath for 2 hours prior to extraction to facilitate the breakdown of oil cells [21]. Subsequently, CPO was extracted by squeezing the mesocarp with a squeezer. The collected CPO underwent additional processing where it was heated in an 80 °C water bath and then subjected to centrifugation at 4,000 rpm for 20 min to separate the oil from solid particles. The resulting oil, forming the top layer, was carefully collected using a plastic dropper and stored in plastic bottles for subsequent analysis.

Oil palm loose fruits (LF), as shown in Figure 3(B) - (4) were gathered from the oil palm bunch collection center in Songkhla province. They underwent the same extraction procedures outlined earlier for the CPO-FFB samples. Three samples of CPO-LF were obtained (S5-S7).

Three crude palm oil samples from a palm oil factory (CPO-POM) were included in this study (S8-S10). These samples were generously provided by a palm oil factory in Surat Thani province and had been stored at room temperature for 10 months.

2.5.2 RGB sensor analysis

The CPO samples underwent analysis for % FFA using the RGB sensor. The CPO samples were initially filtered in each analysis by passing it through a nylon membrane filter with a pore size of 0.22 µm. Subsequently, they were appropriately diluted to ensure that the analytical value fell within the linear range of the calibration graph before being analyzed for their total % FFA using a linear equation.

2.5.3 Titration method

The method of analysing FFA through titration was adapted from the American Oil Chemists' Society (AOCS; Ca 5a-40) (1989) standard procedure [22,23]. Initially, 5 g of the CPO sample was placed into a dried conical flask. Subsequently, 50 mL of isopropanol was added and the mixture was thoroughly mixed. Following this, 10 drops (500 µL) of 1% phenolphthalein indicator were introduced into the mixture. The flask was then positioned on a hot plate and heated until a temperature of approximately 40 °C was reached. The mixture underwent titration with 0.1 N sodium hydroxide (NaOH) until a pink color persisted for at least 30 seconds. The percentage of FFA was determined using Equation 2.

$$\%\text{FFA as palmitic acid} = \frac{N \times V \times 25.6}{m} \quad (2)$$

Here, N represents the normality of sodium hydroxide, V denotes the volume of titrant (0.1 N NaOH) utilized during titration, 25.6 refers to the equivalence factor attributed to palmitic acid, which is the predominant fatty acid in palm oil, and m represents the weight of the CPO sample in grams (g).

The results obtained via the RGB sensor were then compared to those obtained through the titration method using an independent t-test.

3. Results and discussion

3.1 Fabrication of the RGB sensor

The sensor was developed for measuring RGB and Grayscale intensity of the target samples using a camera module. The sensor works by measuring light intensity in three separate color channels (red, green, and blue) using the OV2640 camera module. The OV2640 contains a built-in color filter array (CFA) that divides the incoming light into its three primary colors. The sensor has a 24-bit RGB data output and when integrated with an ESP32 microcontroller, it provides a digital signal representing the intensity of light in each of the three-color channels (RGB). Figure 4 shows some part of the microcontroller's programming language used for RGB and Grayscale intensity processing.

```
R = src.data[row * src.cols * src.channels() + col *
src.channels()];
G = src.data[row * src.cols * src.channels() + col *
src.channels() + 1];
B = src.data[row * src.cols * src.channels() + col *
src.channels() + 2];
A = src.data[row * src.cols * src.channels() + col *
src.channels() + 3];
Gray = ((R*0.299)+(G*0.587)+(B*0.114)); //Gray
drawRGB_PROBE_Text();
```

Figure 4 A microcontroller's programming language used for data acquisition by RGB and Grayscale intensity.

The RGB sensor was designed to run on a Li-Po battery, which has a capacity of 3.7 V (2,000 mAh), while the capacity was increased to 5V when connected to power converter. The ESP32 equipped with an OV2640 camera module and other electronic devices has a power consumption of 310 mA, which enables the sensor to run continuously for approximately 6.5 hours. Once the power is decreased, the sensor would be charged by a DC adapter. However, operating conditions, such as environment temperature, humidity and other environmental factors, can also affect the performance and efficiency of the battery, potentially reducing its lifespan. Thus, calibration is required prior to the analysis.

3.2 Colorimetric detection of palmitic acid-Na_2CO_3 reaction

The colorimetric detection of FFA operates on the principle of "limiting reagent" in a chemical reaction [19]. In the presence of the phenolphthalein indicator, a neutralization reaction between acid and base occurs when palmitic acid is mixed with Na_2CO_3. Once the base becomes excessive, the color of the mixture changes from colorless to pink. The intensity of this color shift corresponds to the concentration of the acid, which in this case is the FFA. The reaction of palmitic acid and Na_2CO_3 is shown in Equation 3 [24].

$$Na_2CO_3(aq) + 2CH_3(CH_2)_{14}COOH(aq) \longrightarrow 2CH_3(CH_2)_{14}COONa(aq) + H_2CO_3(aq) \quad (3)$$

When sodium carbonate (Na_2CO_3) reacts with palmitic acid ($CH_3(CH_2)_{14}COOH$), it produces 2 moles of sodium palmitate ($CH_3(CH_2)_{14}COONa$) and carbonic acid (H_2CO_3) in a complete and precise manner. However, H_2CO_3 is unstable, so it decomposes quickly into water and gaseous carbon dioxide (CO_2), as illustrated in Equation (4).

$$H_2CO_3(aq) \longrightarrow H_2O(l) + CO_2(g) \quad (4)$$

Thus, by applying the limiting reagent concept, the color shades of the reaction mixture containing palmitic acid at concentrations ranging from 0 to 0.1% w/w were evaluated using a fixed concentration of Na_2CO_3 at 0.01 M with phenolphthalein as indicator. A digital image of the resulting reaction between Na_2CO_3 and palmitic acid was captured and the color intensities of R, G, B and Grayscale were then analyzed. Grayscale intensity was used as an analytical signal in this study since it provides good linearity. This result is consistent to the previous report [24].

The RGB sensor's performance in this study was investigated as a colorimetric sensor used for the detection of palmitic acid. In Figure 5(A), a digital image displays the reaction between palmitic acid and Na_2CO_3 with the color change observed using phenolphthalein as an indicator. As the concentration of palmitic acid increased from 0 to 0.1% w/w, the color of the reaction changed gradually from reddish to faint pink and turquoise. The Grayscale digital images processed from the RGB sensor is also shown and reveals a high degree of faint Gray color shades with increasing palmitic acid concentration. The analytical characteristics of the RGB sensor is shown in Figure 5(B). A linear relationship between the Grayscale intensity and palmitic acid concentrations was in the range of 0.0 - 0.1 % w/w. The linear regression equation is y = 1,125x - 2.8056, r = 0.9923. The LOD and LOQ were 0.017 and 0.057 % w/w, respectively.

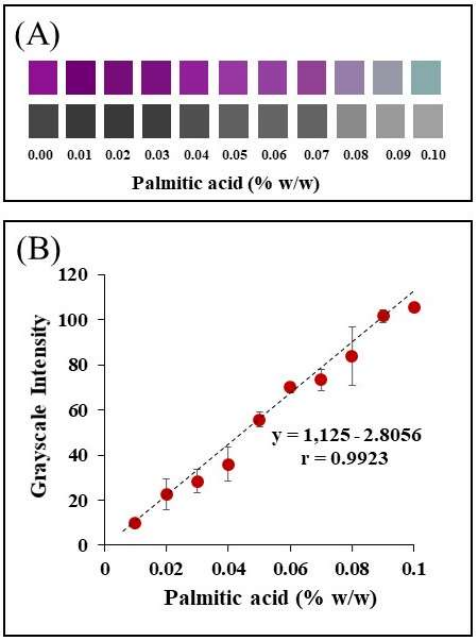

Figure 5 (A) Color change resulting from the reaction between palmitic acid and Na_2CO_3, and (B) linear dynamic range of palmitic detection using the RGB sensor.

3.3 Analysis of FFA in palm oil samples

FFA content serves as a critical parameter when evaluating the quality of palm oil. In this study, 10 crude palm oil samples were analyzed for % FFA using the RGB sensor, which were then compared to results obtained using the titration method (AOCS; Ca 5a-40). The FFA content in the palm oil samples analyzed by the two methods is presented in Figure 6. As for CPO-FFB samples (S1-S4), FFA concentrations ranged from 0.58±0.04 to 0.95±0.09% w/w. These findings align consistently with previous reports where FFA concentrations in CPO-FFB were found to be 0.65 [22] and 0.919% w/w [19]. Notably, there was a significant increase in FFA concentration for CPO-LF samples (S6-S8). As illustrated in Figure 6, the %FFA were 2.56±0.11, 2.64±0.05, and 2.55±0.16% w/w, respectively, which surpasses that of CPO-FFB samples. This could be attributed to the higher degree of ripeness of oil palm loose fruits (LF), resulting in pericarp softening and bruising [25]. This observation is supported by previous findings indicating that heavily bruised fruits exhibit markedly higher FFA content compared to less bruised fruits [26]. The soft pericarp is also more susceptible to microbial attacks, leading to increased microbial lipolytic activity and subsequent FFA release due to the disruption of oil-bearing cells and the induction of hydrolysis reactions [27].

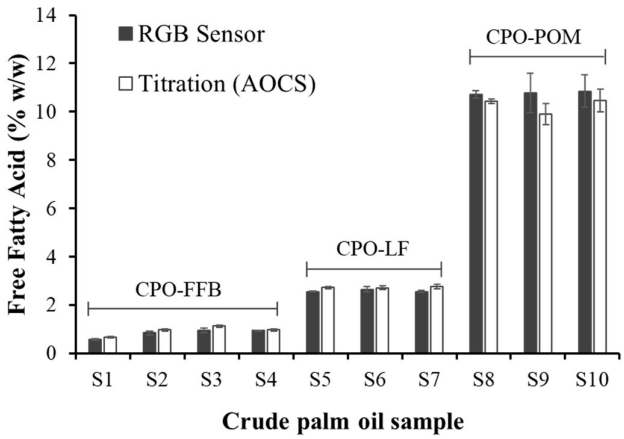

Figure 6 FFA concentration (% w/w) of 10 crude palm oils samples measured by the RGB sensor compared to the titration method (AOCS; Ca 5a-40).

The rise in FFA levels in CPO resulting from lipase degradation is notable. Since FFA levels play a pivotal role as a quality indicator by influencing storage duration, marketability, production, and pricing of palm oil products, an investigation was conducted on CPO samples stored for 10 months. As demonstrated by the CPO-POM samples (S8-S10), the FFA contents were 10.72±0.82%, 10.77±0.68%, and 10.85±0.84% w/w, respectively. These values surpass the maximum acceptable FFA level for crude palm oil, which is 5% w/w. Hence, it can be inferred that the increase in FFA content is indeed correlated with the storage period.

The analysis of FFA in CPO-FFB, CPO-LF and CPO-POM samples was also performed using the titration method. FFA levels detected in these samples exhibited a similar trend to the results obtained using the RGB sensor. Hence, to ascertain the agreement between the two measurement methods, a comparison was made using an independent t-test. The mean, standard deviation (S.D.), t and P value are summarized in Table 2. Results of comparing the pairwise means using the independent t-test method indicated no significant difference in the % FFA values obtained from both the RGB sensor and titration tests across 10 samples, which was at a significance level of 0.05. This lack of a significant difference suggests that both the RGB sensor and the titration method are equally effective in quantifying FFA levels in CPO samples.

Table 2 Comparison of % FFA values between RGB sensor and titration methods in 10 crude palm oil samples using the independent t-test.

Sample	Method	N	Mean	S.D.	t	P value
S1	RGB sensor	3	0.580	0.040	2.279	0.085
	Titration	3	0.666	0.051		
S2	RGB sensor	3	0.839	0.078	2.475	0.069
	Titration	3	0.973	0.051		
S3	RGB sensor	3	0.951	0.102	2.668	0.056
	Titration	3	1.126	0.051		
S4	RGB sensor	3	0.937	0.017	1.141	0.318
	Titration	3	0.973	0.051		
S5	RGB sensor	3	2.557	0.123	2.072	0.107
	Titration	3	2.731	0.078		
S6	RGB sensor	3	2.643	0.057	1.049	0.353
	Titration	3	2.714	0.102		
S7	RGB sensor	3	2.549	0.178	1.813	0.144
	Titration	3	2.765	0.102		
S8	RGB sensor	3	10.723	0.915	-0.464	0.667
	Titration	3	10.445	0.488		
S9	RGB sensor	3	10.771	0.764	-1.632	0.178
	Titration	3	9.899	0.523		
S10	RGB sensor	3	10.851	0.941	-0.640	0.557
	Titration	3	10.462	0.476		

4. Conclusion

The RGB sensor was successfully developed using an OV2640 camera module and ESP32 microcontroller. The sensor analyses RGB and Grayscale intensity with color coordinates. The RGB and Grayscale intensity were used to select a suitable color intensity for the analytical purpose based on linearity. The performance of the developed RGB sensor was investigated, specifically its application for analysing FFA in palm oil samples, and it was found that the RGB sensor could detect FFA accurately. Results from the sensor were in agreement with the standard method used in FFA analysis, which is based on the titration method (AOCS; Ca 5a-40). While the RGB sensor might encounter limitations due to interference from suspended particles or cloudiness, particularly evident in turbid CPO samples, these challenges can obscure the true color reaction, leading to potentially inaccurate results. Nonetheless, it is noteworthy that despite turbidity presenting a hurdle for colorimetric assays, effective sample preparation methods, including centrifugation, filtration, and dilution, can mitigate this issue. Dilution of the CPO sample in this study serves to diminish the concentration of suspended particles, consequently reducing turbidity and enhancing the precision of colorimetric measurements. Therefore, although the RGB sensor may initially face obstacles in analysing turbid CPO samples, the strategic implementation of centrifugation, filtration, and dilution techniques can often render this method suitable for achieving accurate measurements.

5. Acknowledgements

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