Engineering Innovations
ISSN: 2813-1002, Vol. 15, pp 9-20
doi:10.4028/p-jSMi1U

Submitted: 2024-12-12
Revised: 2025-05-15
Accepted: 2025-05-16
Online: 2025-11-18

Portable VIS-NIR Spectrophotometer for Detecting Adulteration of Minced Beef and Chicken Using AS7341 Sensor with PCA Method

Humaidillah Kurniadi Wardana[1,3,a*], Endarko[1,b] and Agus Muhamad Hatta[2,c]

[1]Department of Physics, Faculty of Science and Data Analytics, Institut Teknologi Sepuluh Nopember (ITS), Kampus ITS, Sukolilo, Surabaya 60111, Indonesia

[2]Department of Physics Engineering, Faculty of Industrial Technology and System Engineering, Institut Teknologi Sepuluh Nopember (ITS), Kampus ITS, Sukolilo, Surabaya 60111, Indonesia

[3]Electrical Engineering Study Program, Faculty of Engineering, Universitas Hasyim Asy'ari, Tebuireng, Cukir-Diwek, Jombang 61471, Indonesia

[a*]humaidillahwardana@unhasy.ac.id (corresponding author), [b]endarko@phys.its.ac.id, [c]emhatta@ep.its.ac.id

Keywords: AS7341 Sensor, Beef, Chicken, Pork, PCA, Spectrophotometer.

Abstract. The most vulnerable food products related to halal issues are in the form of mixing beef and chicken meat with pork, which has a physical resemblance if not carefully considered. The rise of meat adulteration is often found due to high demand and high prices. For this reason, a fast, effective, and low-cost meat adulteration detection tool is needed. Detection of beef and chicken adulteration in this study was carried out using a VIS-NIR spectrophotometer from an AS7341 multispectral sensor equipped with an LED light source and 11 channels to read the reflection of meat light in the near light and near infrared ranges, raspberry pi as a microcontroller, data displayed on an LCD stored in CSV form. The results of sensor response patterns formed in beef, chicken, pork, mixed beef-pork, and minced chicken-pork mixed meat show different characteristics. Then to clarify the characteristics of each meat, the results of the sensor response were analyzed using the Principle Componen Analysis (PCA) method. The results of data reduction from PCA projections through Principle Component 1 and Principle Component 2 regions are able to detect the presence of pork mixture in beef and chicken. The results of the PCA score plot on beef, pork and cow-pig mixture the percentage of PC1 is 100% and PC2 is 0% while on chicken, pork and chicken-pig mixture the percentage of PC1 is 100% and PC2 is 0%. The results of this study show the great potential of using a portable spectrophotometer using the AS7341 sensor whose results are analyzed using the PCA method to detect adulteration of minced beef and chicken.

Introduction

Meat is a very nutritious food ingredient and has high nutrients such as protein, vitamins, minerals, essential amino acids, and fatty acids [1–2]. The most vulnerable food product related to halal issues is beef adulteration by mixing beef with pork which has a physical resemblance if not carefully observed [3]. The rise of meat adulteration is usually found before major holidays due to high demand and prices. For this reason, a fast, effective, and flexible meat counterfeiting detection tool is needed.

Usually detecting the authenticity and halalness of food products with meat-based ingredients using protein-based methods, namely Enzyme Linked Immunosorbent Assay (ELISA) [4–7], with gas chromotography techniques [8–10], mass spectrometer for fatty acid analysis [11–13], DNA-based methods using real time Polymerase Chane Reaction (PCR) and multiplex PCR [14]. However, these methods require expensive reagents, complicated sample preparation, cumbersome, cannot be used in various places, and require a long time.

The presence of pig elements can also be detected physically using spectroscopic testing methods. The type of testing with spectroscopy that is developing at this time is FTIR (Fourier Transform Infrared) spectroscopy. FTIR spectroscopy was chosen because it is based on the interaction of analytes with electromagnetic radiation in the infrared region, is fingerprinted, that is, no two different compounds have the same IR spectrum [15], non-destructive analysis techniques, little sample used, easy and sensitive sample preparation [16], and there is no need for special treatment of samples [17]. FTIR spectroscopy with multivariate analysis and M-SVM classification successfully detected lard adulteration in beef, lamb, and chicken blends [18]. FTIR spectroscopy with chemometric combination identified beef meatballs from pork [19], wild boar meat [15], rat meat [20], dog meat [21], beef sausage from wild boar meat [22], beef jerky from pork meat [23], skin crackers from pork skin [24].

In general, spectroscopic devices used to detect pig content in food products use laboratory-scale spectroscopy. Where this device has a very expensive price, its operation requires special skills, the size of the device is usually large, and it is not practical if used outside the laboratory [25]. One of the spectroscopy-based sensors that is cheap, easy to use, easy to find on the market, and easy to apply in the field is the AS7341 sensor. The AS3741 sensor is a reflectance-based sensor that has 11 channels consisting of 8 UV channels, 1 NIR channel, 1 non-filtered channel, and 1 flicker detection channel [26]. The AS7341 sensor is widely applied in the health sector as a non-invasive blood sugar level measurement tool [27–28]. The agricultural field as a photosynthesis measuring instrument for horticultural lighting [29], photosynthetically active radiation (PAR) measuring instrument [30]. In the field of water as a remote sensing measuring instrument in monitoring the aquatic environment (optical properties of water) [31]. Land field as a soil test tool to predict the level of NH4+ and NO3- in soil [32]. Measuring air pollution and air radiation [33,34].

Based on previous research to date, there is still no research on the use of the AS7341 sensor to detect counterfeiting and the safety of meat. For this reason, in this study, the manufacture of a portable VIS-NIR spectrophotometer was made by utilizing the AS7341 spectroscopic sensor as a detector equipped with a white LED as a light source, raspberry pi 4B as a microcontroller, the display results of spectra measurements and classification are displayed on an HDMI LCD. This tool uses Principel Componen Analysis (PCA) to classify meat sample data so that it can be known which samples are pure beef, chicken, pork and beef, chicken mixed with pork.

Experiments

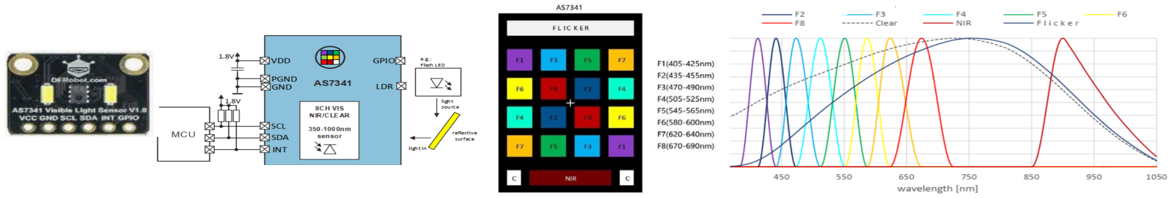
Tools and Materials

The ingredients used in this study were beef top side, fresh pork top side, and chicken breast. All fresh meat used in this study was obtained from Hokky Market in Surabaya.

Supporting tools used include: portable spectrophotometer with AS7341 sensor, knife, teleman, anallitic balance scale, coper cosmos CB 802 blender, gloves, tissue.

Design of Portable VIS-NIR Spectrophotometer with AS7341 Sensor

The main components used to make the spectrophotometer are AS7341 sensor, raspberry pi 4B as a microcontroller, 5 *inch* TFT hdmi lcd, jumper cable, hdmi usb cable, tab usb cable, and laptop. Figure 1 shows the AS7341 VIS-NIR sensor which consists of 11 channels: 8 visible channels, 1 NIR channel, 1 non-filtered channel, and 1 flicker detection channel [35–36]. It is used for color analysis and spectral analysis with spectral response determined in wavelengths of 410 to 940 nm [26,37,38]. Figure 2 shows the schematic circuit of the VIS-NIR spectrophotometer.



(b) (c)

Fig. 1. (a) The VIS-NIR spektrofotometer AS7341: breakout board and block diagram, (b) Layout of sensor array, (c) AS7341 typical characteristic (normalized intensity) [39].

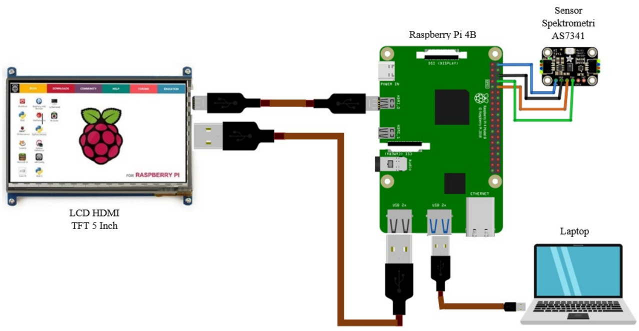


Fig. 2. Schematic of spectrophotometer with AS7341 sensor.

Figure 3 shows how to calibrate the AS7341 sensor [40].

Fig. 3. AS7341 Sensor calibration.

Tristumulus spectral power distribution (xyz):

$$X = \int P(\lambda) \,.\, x\ (\lambda) \tag{1}$$

$$Y = \int P(\lambda) \,.\, y\ (\lambda) \tag{2}$$

$$Z = \int P(\lambda) \,.\, z\ (\lambda) \tag{3}$$

With the conversion to tristumulus color coordinates (xyz), the color of light can be expressed in terms of two chromaticity coordinate indices:

$$x = \frac{X}{X+Y+Z} \tag{4}$$

$$y = \frac{Y}{X+Y+Z} \tag{5}$$

$$z = \frac{Z}{X+Y+Z} \tag{6}$$

Data Collection Procedure

Figure 4 shows the step-by-step meat testing process: Whole meat ingredients that have been cleaned are cut into small pieces and then mashed by chopping and grinding one by one alternately using a blender for 10 minutes. The materials used were measured using analytical balance scales with the same weight, namely 10 grams of beef, 10 grams of pork, 10 grams of chicken, a mixture of beef and pork with concentrations (7:3, 5:5, 1:9), and a mixture of chicken and pork with concentrations (7:3, 5:5, 1:9). Materials that were ready to be tested were placed on a cup. The spectrophotometer was turned on for 5 minutes before taking measurements. The material was then brought closer to the AS7341 sensor with a distance of 3 cm and ready for spectra detection.

Figure 4 shows how the developed tool works, namely the flash led sensor will light up on the meat sample and be reflected and received back by the photodiode. The reflected light will be received by the photodiode as a wavelength that represents a certain color spectrum. The color spectrum is converted by the photodiode into an analog signal and forwarded to the ADC into a digital signal. The digital signal is then processed by the raspberry pi 4B through various programming procedures which are finally translated into measurement results in the form of numbers in the form of wavelengths. The numbers of measurement results are displayed on the LCD and recorded and stored in csv format. The meat spectra measurement process is carried out for 3 minutes.

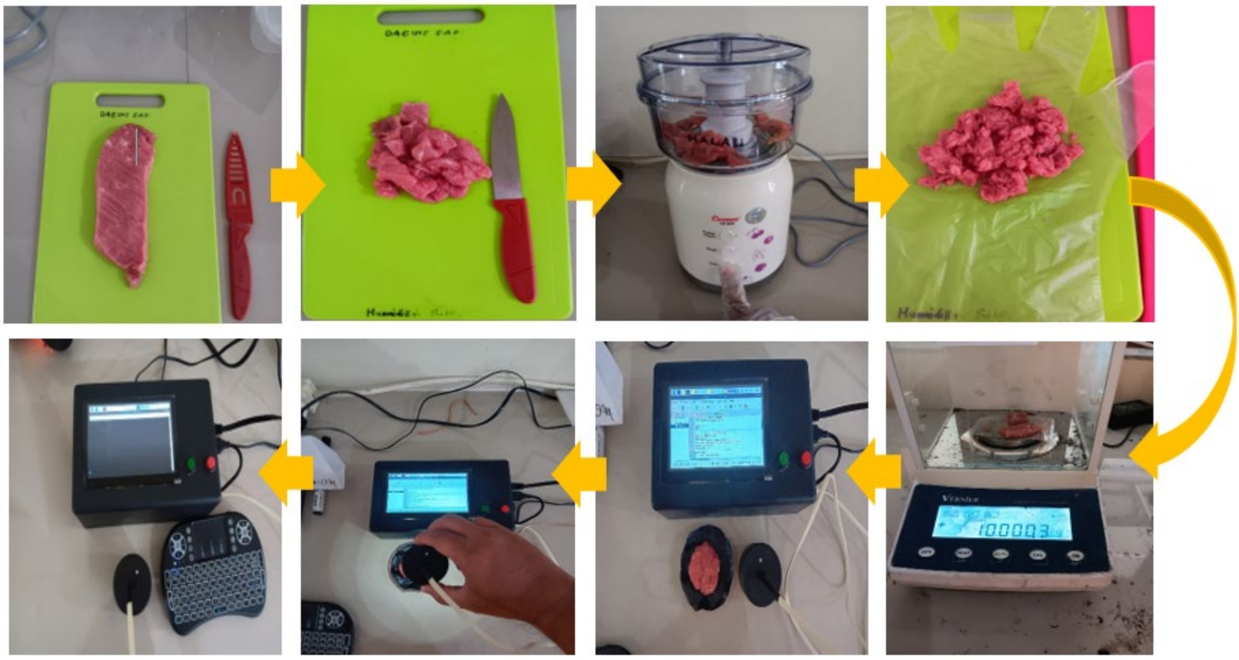


Fig. 4. Meat testing process.

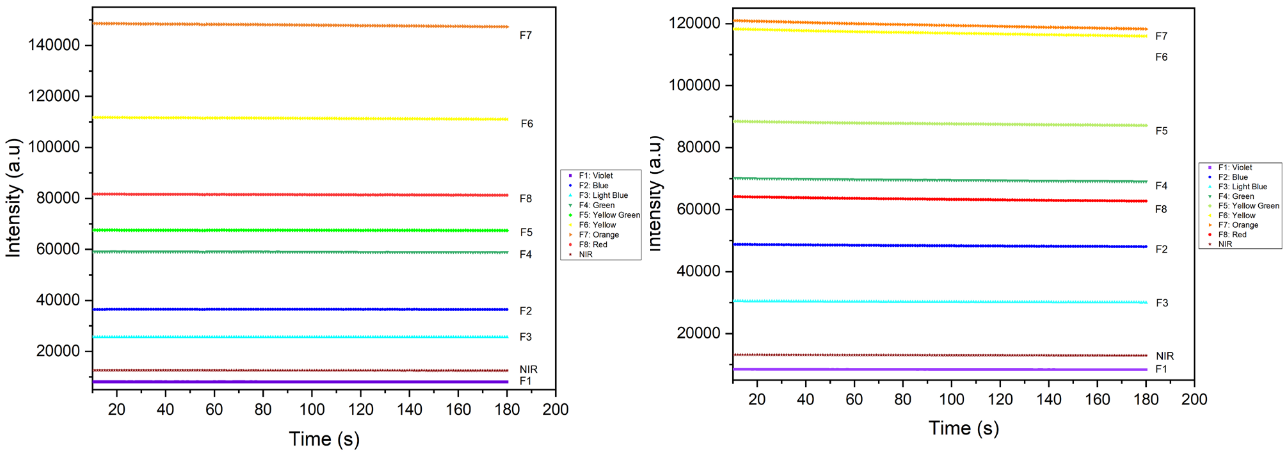
Data Analysis with Principal Componen Analysis (PCA)

Data analysis was carried out on the spectra measurement results of each meat. Measurement data stored in CSV form is analyzed using the PCA method by looking at the results of reduction and projection through PC1 and PC2 regions that are able to explain the percentage of classification of each beef, pork, chicken, mixed beef-pork, and mixed chicken-pork.

Result and Discussion

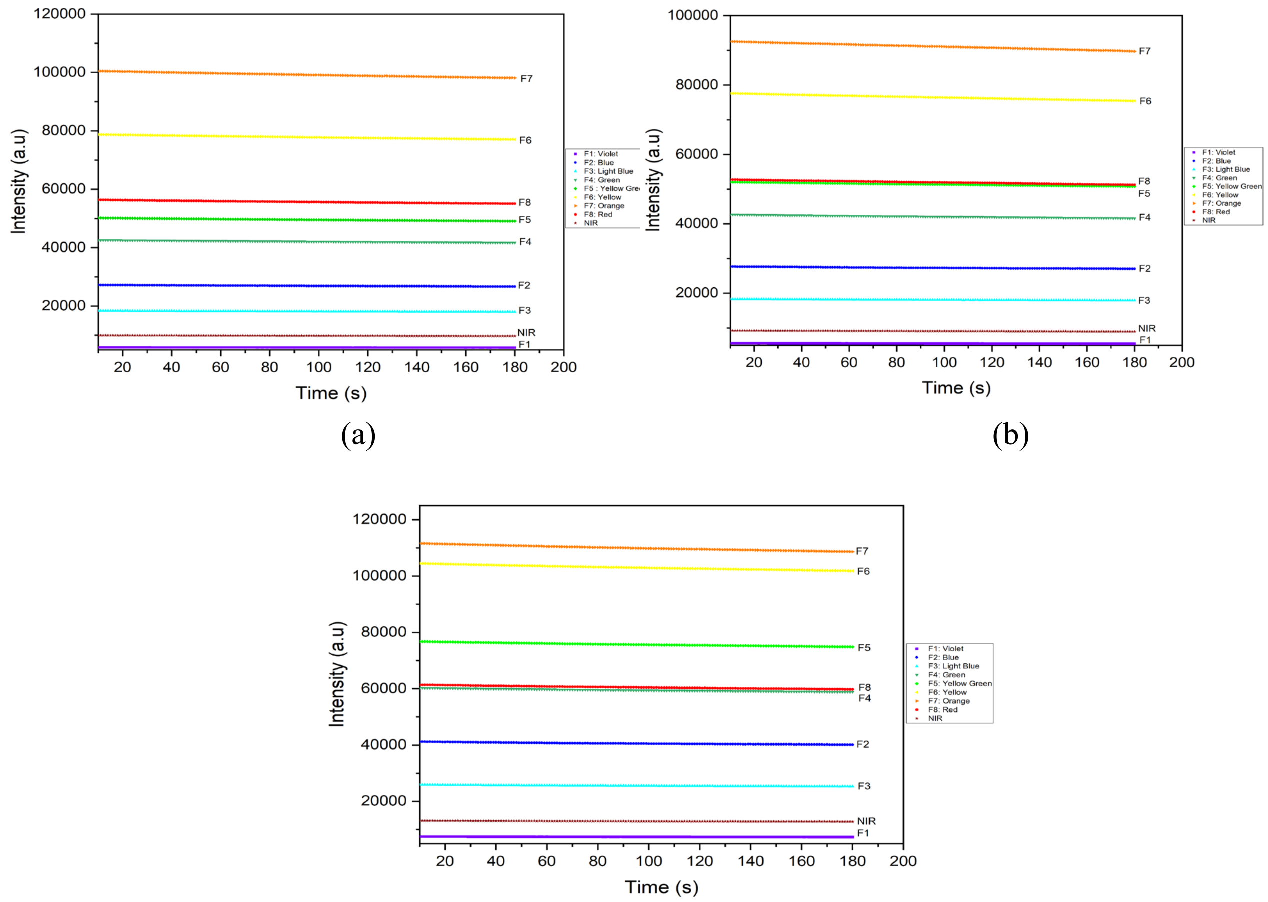
Test Response of AS7341 Sensor to Beef-Pork and Mixed Beef-Pork Samples

Figure 5 and Figure 6 show the sensor response graphs for pure beef, pure pork, and mixed beef-pork samples, respectively.



(a) (b)

Fig. 5. AS7341 Sensor response chart to meat samples (a) beef, (b) pork.



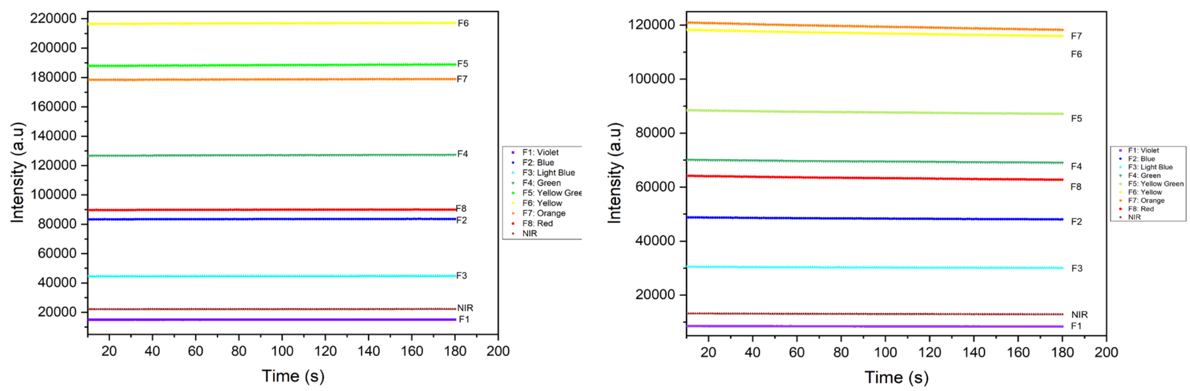
(a) (b)

(c)

Fig. 6. Response graph of AS7341 sensor to samples of (a) 7:3 beef-pork mixed meat, (b) 5:5 beef-pork mixed meat, (c) 1:9 beef-pork mixed meat.

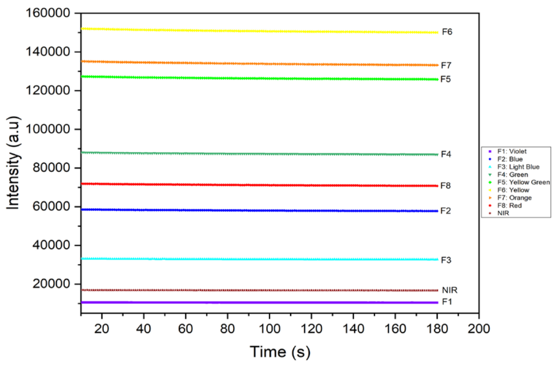
Test Response of AS7341 Sensor to Chicken, Pork and Mixed Chicken-Pork Meat Samples

Figure 7 and Figure 8 show the sensor response graphs for pure chicken, pure pork, and chicken-pig mixed meat samples, respectively.

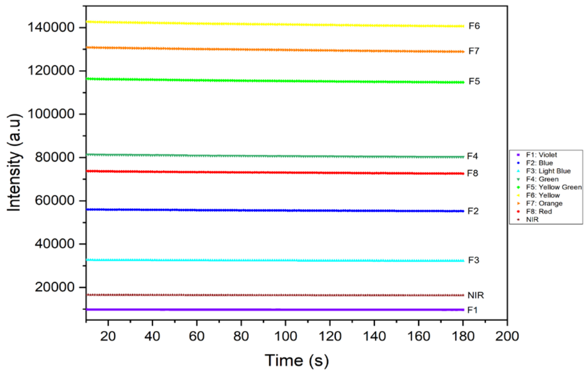


(a) (b)

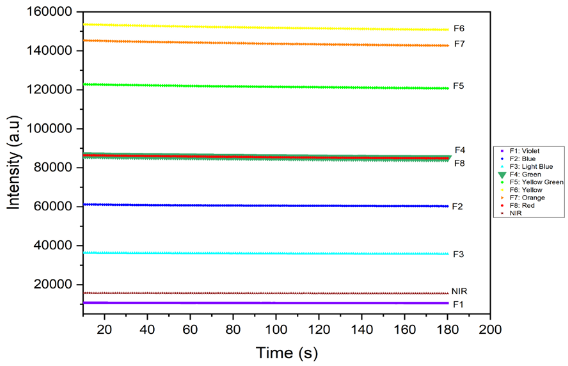
Fig. 7. AS7341 Sensor response chart to meat samples (a) chicken, (b) pork.



(b)



(c)



(d)

Fig. 8. Response graph of AS7341 sensor to samples of (a) 7:3 chicken-pork mixed meat, (b) 5:5 chicken-pork mixed meat, (c) 1:9 chicken-pork mixed meat.

Figure 5 and Figure 8 are the response results of a portable spectrophotometer using the AS7341 sensor capable of measuring the spectral response to light reflected on each meat surface so as to provide information about the intensity of light in each spectral channel F1, F2, F3, F4, F5, F6, F7, F8, and NIR measured by the sensor. In the sample testing results, it can be seen that the AS7341 sensor response produces different characteristics in each type of beef, pork, chicken, mixed beef-pork, and mixed chicken-pork samples.

The spectra characteristics of each meat are:

a) Figure 5a shows pure beef has the highest to lowest intensity values in spectral channels: F7, F6, F8, F5, F4, F2, F3, NIR and F1.

b) Figure 5b shows pure pork has the highest to lowest intensity values on spectral channels: F7, F6, F5, F4, F8, F2, F3, NIR, F1.

c) Figure 6a and Figure 6b show mixed beef-pork (7:3), (5:5) has the highest to lowest intensity values in the spectral channels: F7, F6, F8, F5, F4, F2, F3, NIR, F1

d) Figure 6c shows the beef-pork mix (1:9) has the highest to lowest intensity values in the spectral channels: F7, F6, F5, F8, F4, F2, F3, NIR, F1.

e) Figure 7a shows chicken meat has the highest to lowest intensity values in the spectral channels: F6, F5, F7, F4, F8, F2, F3, NIR, F1.

f) Figure 7b shows pure pork has the highest to lowest intensity values on spectral channels: F7, F6, F5, F4, F8, F2, F3, NIR, F1.

g) Figure 81, 8b, 8c shows chicken-pork mixed meat (7:3), (5:5), (1:9) has the highest to lowest intensity values in the spectral channels: F6, F7, F5, F4, F8, F2, F3, NIR, F1.

The difference between pure beef, pure pork, pure chicken, mixed beef-pork, and mixed chicken-pork lies in the spectral channels: pure beef: F8, F5, F4, pure pork: F5, F4, F8, pure chicken: F6, F5, F7, mixed beef-pork (7:3), (5:5): F6, F8, F5, beef-pork mix (1:9): F6, F5, F8, chicken-pig mix (7:3), (5:5), (1:9): F6, F7, F5.

The difference in spectral values in each meat is influenced by myoglobin which is the main pigment that gives color to meat. Myoglobin consists of: oxymyoglobin (OxyMb) which is cherry red in fresh meat, deoxymyoglobin (DeoxyMb) which is purplish red in vacuum-packed meat, and metmyoglobin (MetMb) which is brownish red resulting from oxidation making the meat pale or not fresh [41–43]. In addition, meat is a translucent material. When light hits the surface of the meat, the light is not only absorbed by myoglobin but some is reflected to the surface to produce a red color in the meat and some also penetrates the surface and interacts with the microstructure below the surface so that in this case absorption affects the color and scattering affects the brightness or darkness of the meat [44–45]. Subsurface scattering depends on the wavelength of the incident light, the size of the scattering particles, and the directional inhomogeneity of the tissue [44].

It can be seen that the portable spectrophotometer using the AS7341 sensor is able to produce different pattern characteristics for pure meat samples and mixed meat samples, thus further analysis can be carried out to obtain more informative results for sample classification analysis.

Classification Analysis of Pure Meat and Mixed Meat with Principal Componen Analysis (PCA)

Figure 9 and Figure 10 show the results of PCA analysis of each meat. PCA analysis in this study was conducted to determine differences in the distribution of spectra data from beef, pork, chicken, mixed beef-pork, and mixed chicken-pork.

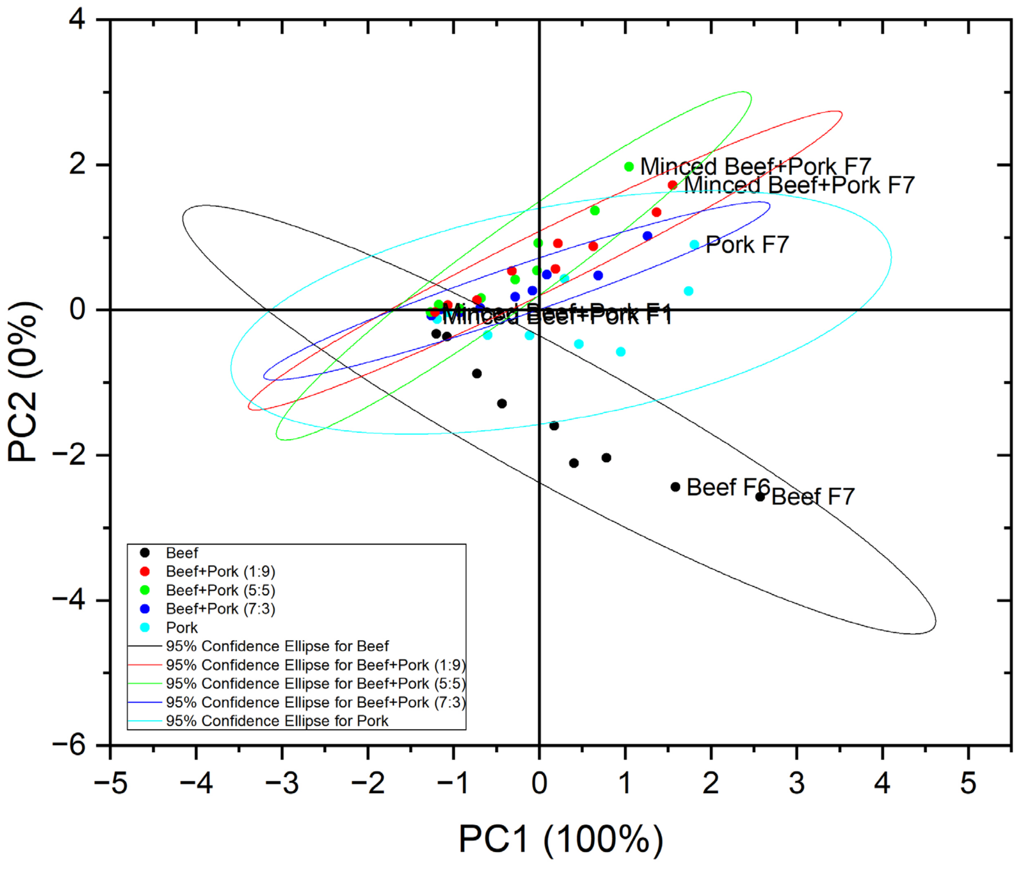


Fig. 9. Score plot of PCA spectra of beef, pork and beef-pork mixture.

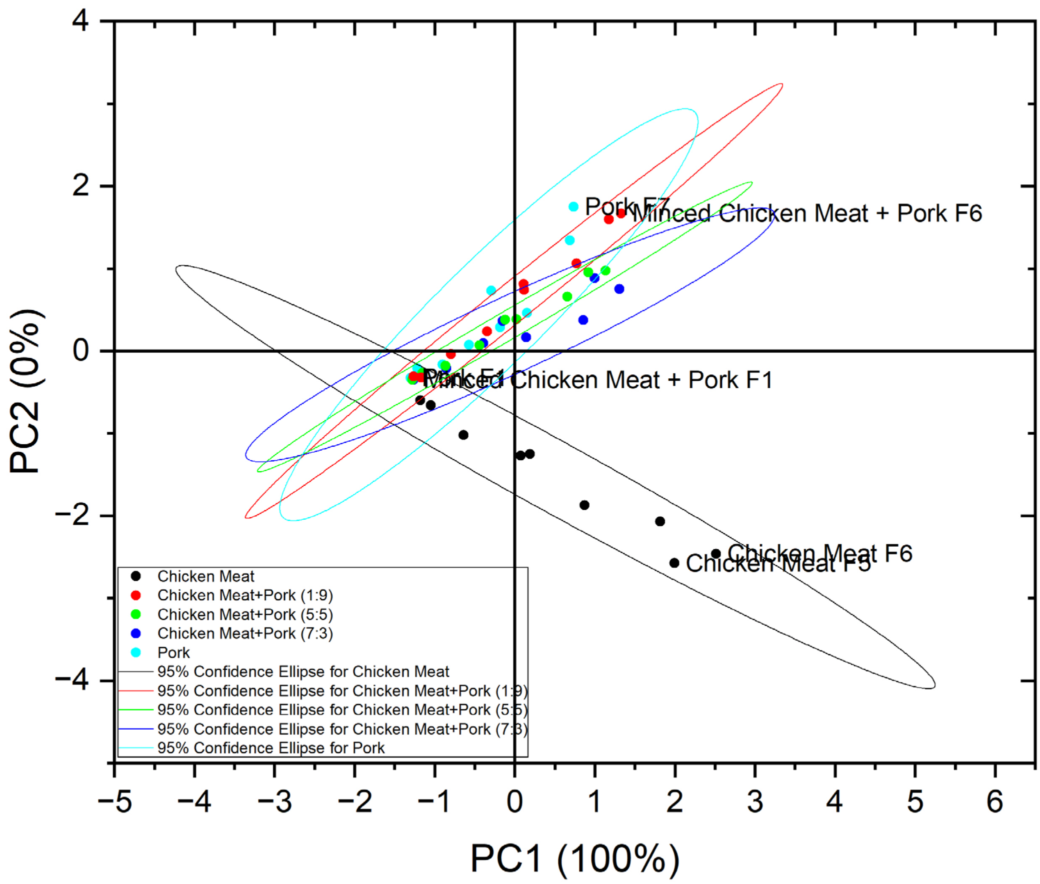


Fig. 10. Score plot of PCA spectra of chicken, pork and chicken-pork mixture.

Figure 9 shows the results of the PC1 percentage of 100% and PC2 of 0%, indicating that the points (clusters) of beef are separated from the points (clusters) of pork. Meanwhile, the mixed beef-pork meat gathers and overlaps with pork. Figure 10 shows the results of PC1 by 100% and PC2 by 0%, indicating that the points (clusters) of chicken and pork spectra are separated while the chicken-pork mixture gathers with pork. This explains that PCA can classify or distinguish between pure beef, pure pork, pure chicken and mixed meat, namely beef-pork, chicken-pork.

The limitation of this research is that until now it has only considered the value of the spectral response to light reflected on each meat surface. It is more interesting for further research to also add meat aroma detection with a gas sensor and meat color with a color sensor. Further research can also be carried out using more sample variations to determine the wider potential of the AS7341 spectrophotometer. Data analysis and comparison with several other methods can also be carried out to find out which method is the most effective.

Summary

In general, a *Portable* VIS-NIR spectrometer with AS7341 sensor combined with *Principle Componen Analysis* (PCA) has been successfully made to detect adulteration of beef, chicken meat mixed with pork. The response results from the sensor can identify differences in spectra on each meat shown in the PCA score plot on beef, pork and mixed beef-pork PC1 percentage of 100% and PC2 of 0% while in chicken, pork and mixed chicken-pork PC1 percentage of 100% and PC2 of 0%.

Acknowledgment

The authors would like to thank DRPM ITS for funding this research through a scientific research scheme sourced from ITS funds in 2023 with TM/DRPM-ITS/PN.02.003.

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