GRADING OF FRESH FRUIT BUNCHES USING NIR SPECTROSCOPY TECHNOLOGIES

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Introduction

Oil palm in Malaysia: Facts and Figures (2019)

- **Palm oil is one of Malaysia's primary industries (Golden crop).**
- **Malaysia is one of the world's leading producers of palm oil, and the palm oil industry is a significant contributor to the Malaysian agricultural sector.**
- **Malaysia is the second-largest producer after Indonesia.**
- **The production volume of crude palm oil in Malaysia was approximately 19.86 million MT.**
- **5.9 million ha of land was used to plant oil palm in Malaysia.**
- **Total manpower about 491,000 workers.**
- **452 palm oil mills in operation in Malaysia.**
- **The average yield of FFB in Malaysia was 17.19 MT/ha.**
- **Total Malaysian exports of oil palm products in 2019 amounted to 18.471 million tons.**
- **Gross domestic Product (GDP) from palm oil was around 2.7%, equivalent to USD 8.54 billion.**

Oil palm: Background

Product

Oil palm tree start bearing fruits after 30 months of field planting and will continue to be productive for the next 20 to 30 years.

Fresh fruit bunch (FFB)

- Harvested and crushed to extract the oil from kernel and the flesh.
- The oil from kernel is used mostly for soap and industrial purposes as well as for processed foods.
- The oil from the fruit goes into food production.
- The quality of palm oil depends on the maturity level of the FFB

Problem Statement

2

Oil content in each fruitlet is maximized during the ripening process. The quality of the oil starts to deteriorate in the abscised fruit with increase in the level of free fatty acids (FFA) in the oil.

1

Traditional classification of FFB were using human eyes. However, the term ‘ripe’ is subjective, and can be interpreted from the view of oil content, surface color changes and number of loose fruits.

3

The overripe and unripe FFB at the mills has caused the low quality of oil extraction. Due to these weakness, optimum crude oil production cannot be achieved; hence, some operation costs become a loss and burden to manufacturers

Table 1. MPOB Manual of Grading Oil Palm Fresh Fruit Bunches Third Edition (2015) [9].

Bunch Classifications	Description
Ripe	Reddish orange color fruits, has at least 10 sockets of detached fruitlets and more than fifty percent (50%) of the fruit still attached to the bunch at the time of inspection at the mill.
Underripe	Reddish orange color fruits and has at least 10 sockets of detached fruitlets at the time of inspection at the mill.
Unripe	Purplish black color fruits and without any socket of detached fruitlets at the time of inspection at the mill.
Overripe	Darkish red color fruits and has more than fifty percent (50%) of detached fruitlets but with at least ten percent (10%) of the fruits still attached to the bunch at the time of inspection at the mill.
Empty	Bunch which has more than ninety percent (90%) of detached fruitlets at the time of inspection at the mill.
Rotten	Bunch partly or wholly, including its loose fruits, has turned blackish in color, as well as rotten and moldy.

Bunch Classifications	Description
Long stalk	Bunch which has s stalk of more than 5 cm in length (measured from the lowest level of the bunch stalk).
Unfresh	Bunch which has been harvested and left in the field for more than 48 h before being sent to the mill. The whole fruit, or part of it, together with its stalk, has dried out. Normally, this type of bunch is dry and blackish in color.
Old	Bunches that have been harvested and left long on the farm before being shipped to the factory. The fruit still attached on this bunch has been wrinkled and is colored brownish or black. The stalk has also been wrinkled and is soft and fibrous, with a blackish color. Many relay seeds fall out of the outer layer of the bunch.
Dirty	Bunch with more than half of its surface covered with mud, sand, or other dirt particles and mixed with stone or foreign matter.
Small	Bunch which has small fruits and weighs less than 2.3 kg.
Pest damaged	Bunch with more than thirty percent (30%) of its fruits damaged by pest attacks, such as rats, etc.
Diseased	Bunch which has more than fifty percent (50%) parthenocarpic fruits and is not normal in terms of its size or its density.
Dura	Shell thickness 2–8 mm; ratio of shell to fruit 25–50%; ratio of mesocarp to fruit 20–60%; ratio of kernel to fruit 4–20%.
Loose fruit	Fruit detached from a fresh bunch because of ripeness and reddish orange in color.
Stored	Unripe bunch that was stored or left long after harvest.
Wet	Consignment of FFB which has excessive free water.

Table 1. Oil palm ripeness classification criteria

Total number of empty fruitlet sockets	Mesocarp color		
	Yellow	Yellowish/orange	Orange
0	Unripe	Unripe	Ripe
0-10	Unripe	Unripe	Ripe
>10	Overripe	Overripe	Overripe

Research Gap / Goal

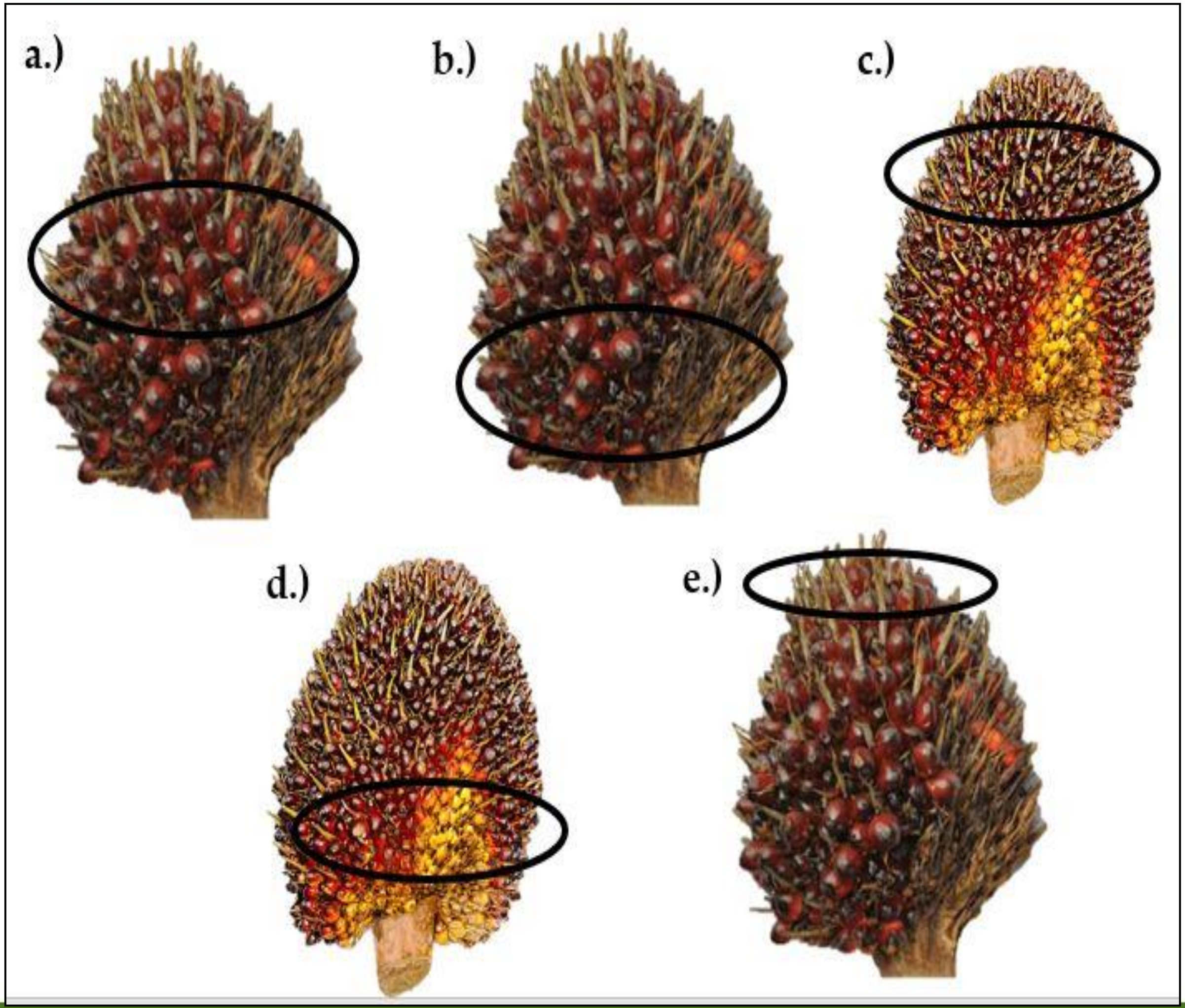
01 The fruit starts to ripe from outer and top of the bunch.

02 Different parts received different exposure of sunlight. This situation caused the different parts of FFB to have different colors.

03 Previous research have focused on comparison between parts that were covered by leaves and not covered by leaves.

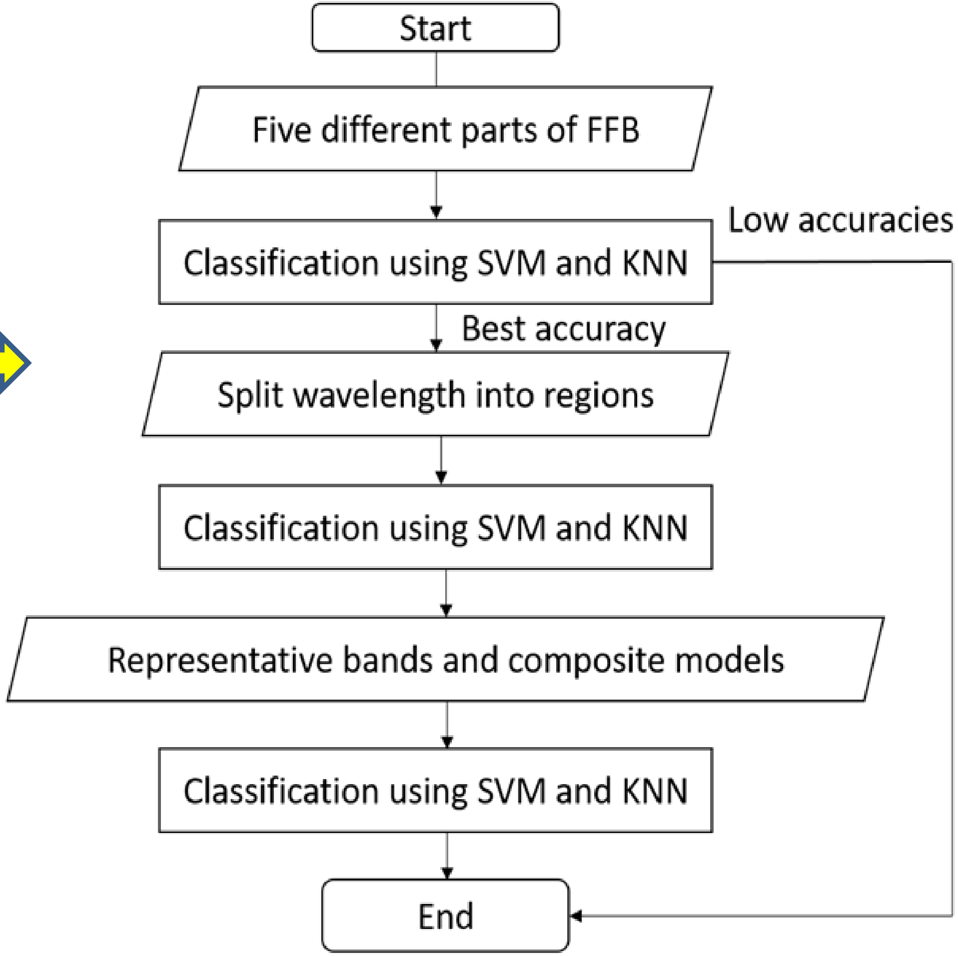
04 In this research, the research gap is further filled by dividing FFB into five different parts which were apical, front equatorial, front basil, back equatorial and back basil for analysis.

Five different parts of FFB:
(a) front equatorial;
(b) front basil;
(c) back equatorial;
(d) back basil;
(e) apical.



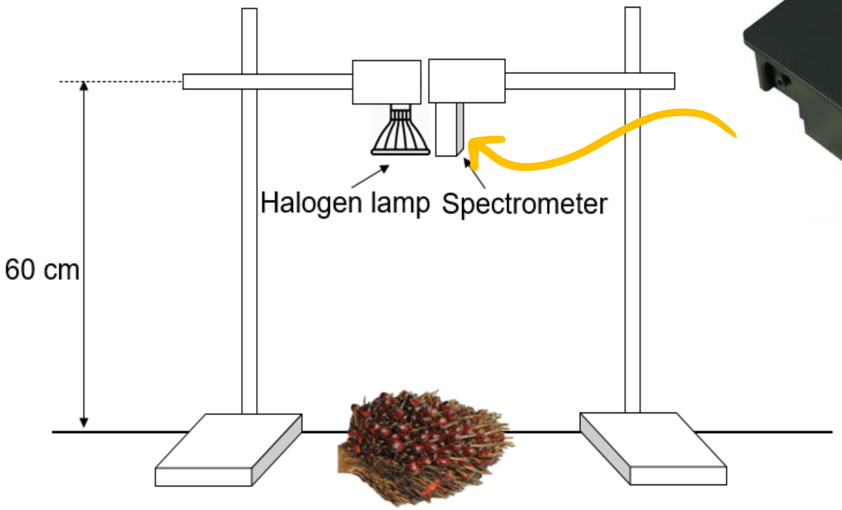
Methodology

Research Workflow



KNN - K-Nearest Neighbor
SVM - Support Vector Machine

Experimental Setup



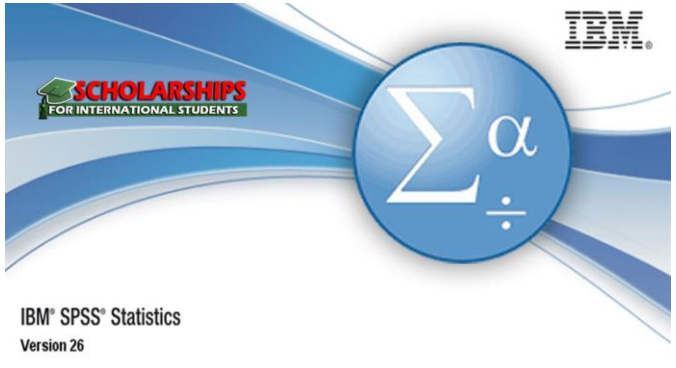
Sample Preparations

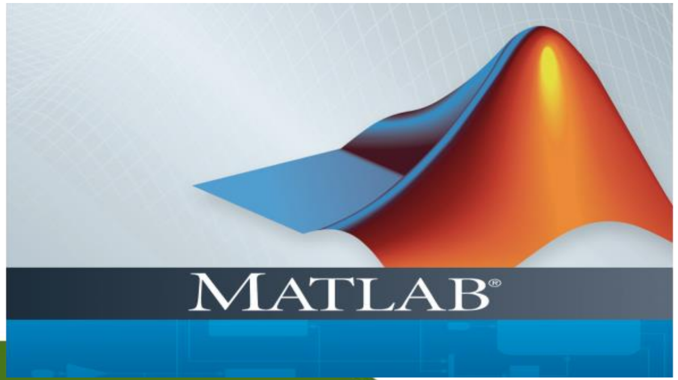
- FFBs were prepared by trained graders and classified into the three highly critical maturity categories of oil palm fresh fruit bunches, that is, unripe, ripe, and overripe.
- Each category contained 30 FFB samples.
- The FFBs were cleaned by a brush to remove dirt and dried leaves from them.

Optical sensor

- The device used was a SE Series spectrometer (OtO Photonics, Inc., Hsinchu City, Taiwan).
- The SE Series spectrometer is built with a linear CCD-type sensor and a high performance 32-bit RISC controller.
- The spectrometer has the ability to capture reflectance intensity at a wavelength range of 180 to 1100 nm.

Analysis Method





Statistical analysis using SPSS

Principal component analysis, ANOVA

Prediction

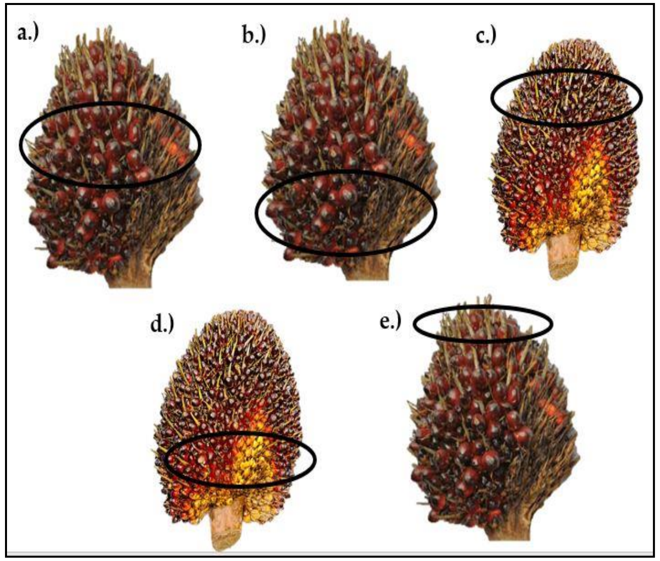
Receiver operating characteristics (ROC) curve and area under the curve (AUC)

Classification using MATLAB R2020a

Classifiers： Support Vector Machine (SVM) and K-Nearest Neighbors (KNN)

Results and discussion

Principal Component Analysis



Parts	No. of PC extracted	Percentage of variance explained
Front equatorial	1	92.4%
Front basil	5	90.6%
Back equatorial	5	90.3%
Back basil	5	89.8%
Apical	5	90.2%

PCA was used to reduce the dimensionality of a data set without losing too much information.

At the end of PCA, data set was transformed into a new set of variables or the principal components (PCs) that are uncorrelated and retain most of the variation in the original variables.

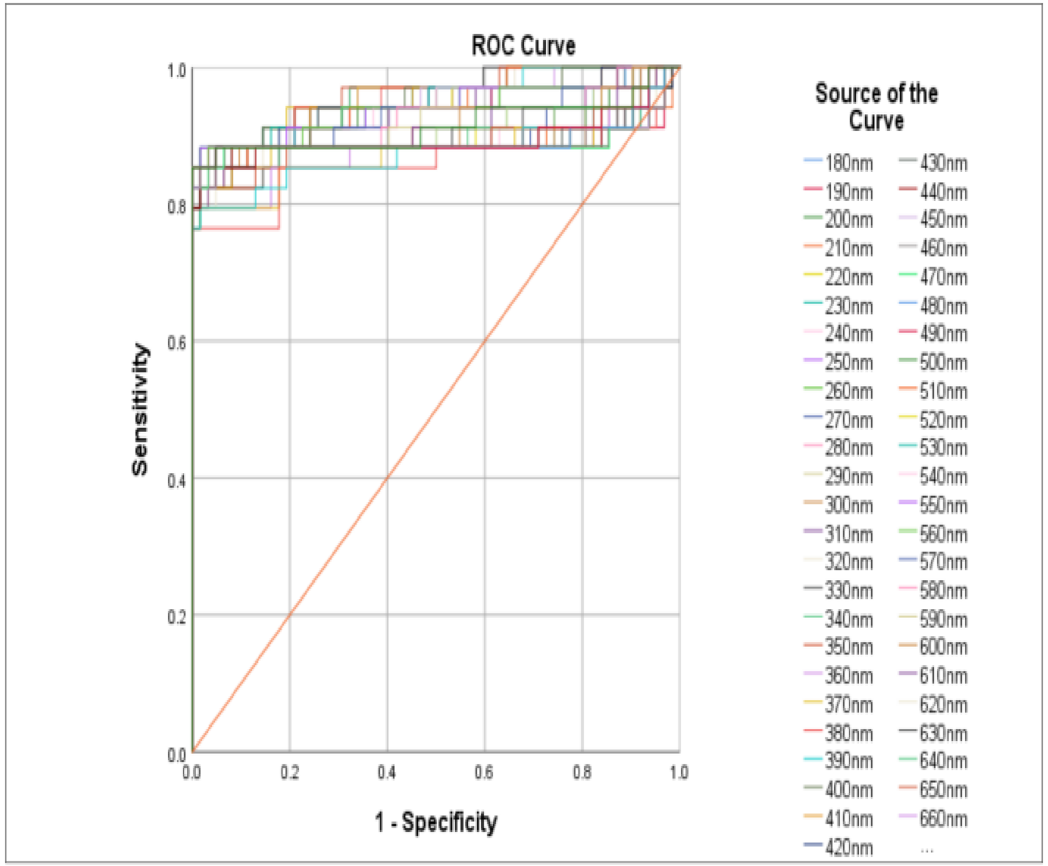
Classification using all bands from 180 to 1100 nm

	Classification accuracy (%)	
	Classifiers	
Parts	KNN	SVM
Apical	68.4	74.5
Front equatorial	87.5*	90.6*
Front basil	69.1	71.3
Back equatorial	60.2	69.4
Back basil	65.6	66.4

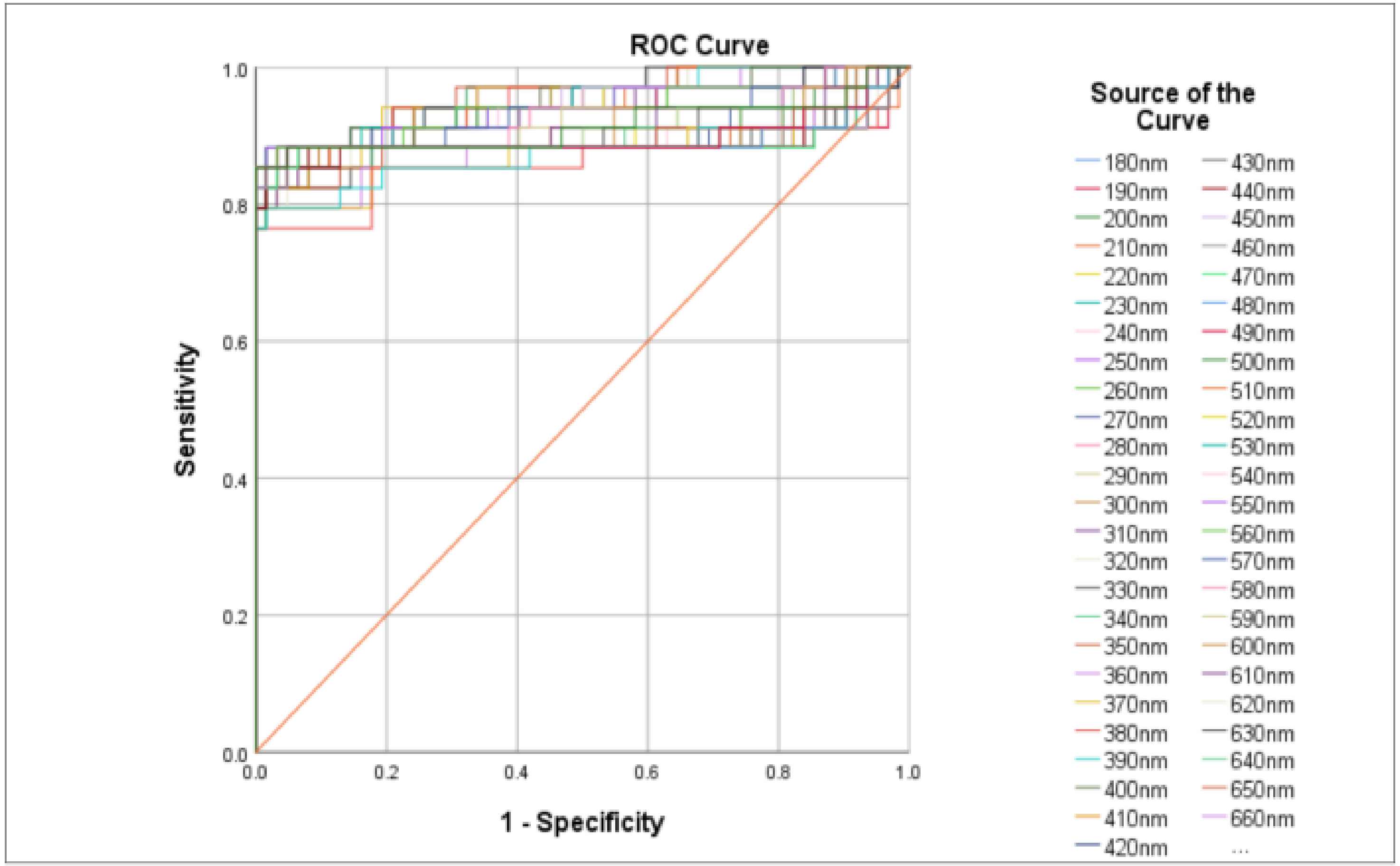
Note: The asterisks mark the highest accuracies of each column

Receiver operating characteristics (ROC) curve for front equatorial

- **Receiver operating characteristic (ROC) describes the accuracy performance of the classification.**
- **It is a graph of sensitivity against specificity.**
- **Curves that are closer to the top-left corner represent better performances.**
- **The diagonal line is drawn across the middle of the graph.**
- **The closer the curves to the diagonal line, the less accurate it is.**
- **To compare different curve performances, the area under the curve (AUC) can be utilized.**
- **AUC, a measure of a model's ability to discriminate between classes, is frequently used to summarize ROC curves.**
- **The higher the value of AUC, the better the performance of the model.**



Receiver operating characteristics (ROC) curve for front equatorial



The mean of area under curve (AUC) was 0.908, with a 95% confidence interval.

The highest AUC value was contributed by the 350 nm curve with a value of 0.959, whereas the lowest AUC value came from the 680 nm curve with a value of 0.865.

The mean lower bound was 0.824, while the upper bound is 0.992.

Classification using different wavelength bands for front equatorial parts

	Classification accuracy (%)	
	Classifiers	
Regions	KNN	SVM
UV (180- 400 nm)	87.5*	91.7*
Blue (450 – 490 nm)	87.5*	87.5
Green (500 – 570 nm)	82.3	69.8
Red (630 – 700 nm)	78.1	76.0
NIR (800 – 1100 nm)	84.4	78.1

Note: The asterisks mark the highest accuracies of each column

Classification using representative bands for front equatorial

Classification using representative bands	Classification accuracy (%)	
	Classifiers	
Bands (nm)	KNN	SVM
365	87.5	79.2*
460	84.4	74.0
523	75.0	65.6
590	80.2	68.8
623	82.3	60.4
660	89.6*	69.8
735	88.5	71.9
850	78.1	72.9

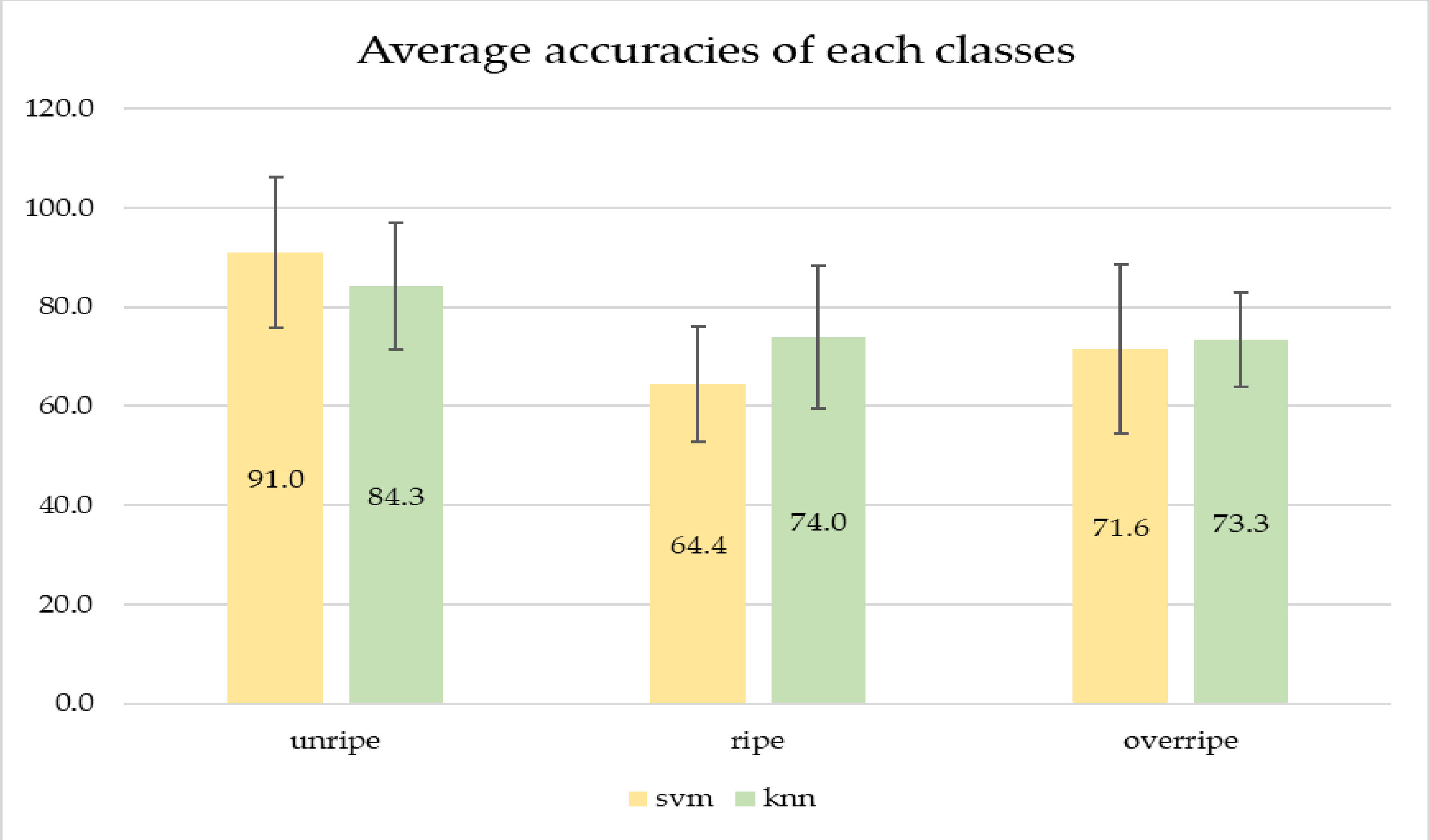
Note: The asterisks mark the highest accuracies of each column

Classification using composite bands

Classifiers	Combination of bands (nm)	Accuracies (%)
KNN	365, 460, 523, 590, 623, 660, 735, 850	92.7*
	365, 460, 590, 623, 660, 735, 850	91.7
	365, 460, 523, 590, 623, 660, 735	92.7*
	365, 460, 590, 623, 660, 735,	91.7
SVM	365, 460, 523, 590, 623, 660, 735, 850	92.7
	365, 523, 590, 623, 660, 735, 850	92.7
	365, 460, 523, 623, 660, 735, 850	92.7
	365, 460, 735, 850	93.8*

Note: The asterisks mark the highest accuracies of each column

Discussion


Average accuracies of each classes
120.0
100.0
80.0
60.0
40.0
20.0
0.0
91.0
84.3
64.4
74.0
71.6
73.3
unripe
ripe
overripe
svm
knn

Discussion

Front equatorial was identified as the best part to determine the FFB maturity level. It has the highest classification accuracies of 87.5% and 90.6% using KNN and SVM respectively.

This could be due to the growing condition of the FFB on the oil palm tree where front equatorial faces the direction of sunlight.

Compared to the back side of FFB where it faces the tree and does not receive enough sunlight, back basil and back equatorial both have the lowest accuracies in KNN and SVM classifications

Back basil part is always concealed by the fronds of the tree and is often yellowish or greenish in color

Discussion

This study attempted to reduce the number of bands for classification without losing accuracy and found that the UV region containing 23 bands, from 180 to 400 nm, improved the accuracy by 1%. 1

In the classification of each region, the UV region from 180 nm to 400 nm had the highest maturity classification accuracy, of 87.5% using KNN and 91.7% using SVM. 2

In the classification of each region, the UV region from 180 nm to 400 nm had the highest maturity classification accuracy, of 87.5% using KNN and 91.7% using SVM. 3

This finding agreed with the results of Cherie et al. (2015), where the UV lamp with 320–380 nm could determine the most suitable harvest decision for FFB on the tree. 4

Discussion

On the other hand, the composite model of 365, 460, 735, and 850 nm improved the accuracy to 93.8%, despite using only four bands.

Furthermore, this composite model also surpassed the accuracy of all band classifications with 90.6% for the front equatorial data set and 91.7% for the UV region. This was the highest accuracy in the three modes of classification in this study

Conclusion and Recommendation

This study investigated FFB reflectance data. It was proven that the optical spectrometer had the ability to determine oil palm FFB maturity levels.

The utilization of all bands, from 180 to 1100 nm, resulted in 90.6% accuracy by using SVM as a classifier for the front equatorial. The front equatorial was identified as the prime part of FFB for the maturity data acquisition of the oil palm FFB.

The next important contribution of this research was the findings that the UV region alone produced an accuracy of 91.7% by using SVM.

Finally, a composite model consisting of 365, 460, 735, and 850 nm produced the highest accuracy, at 93.8%. It can be concluded that, instead of all bands, we can reduce the number of bands to a specific region or specific bands for the classification of FFB maturity levels.

For future work, a simple sensor that consists of the above-selected regions or a composite model can be built to detect the maturity level of FFB to replace the existing human grading method.

Further reading/ reference

Goh, J. Q., Shariff, A. R. M., and Nawi, N. M. (2021). Application of optical spectrometer to determine maturity level of oil palm fresh fruit bunches based on analysis of the front equatorial, front basil, back equatorial, back basil and apical parts of the oil palm bunches, Agriculture, 11, 1179. https://doi.org/10.3390/agriculture11121179.

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Article

Application of Optical Spectrometer to Determine Maturity Level of Oil Palm Fresh Fruit Bunches Based on Analysis of the Front Equatorial, Front Basil, Back Equatorial, Back Basil and Apical Parts of the Oil Palm Bunches

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Abstract: The quality of palm oil depends on the maturity level of the oil palm fresh fruit bunch (FFB). This research applied an optical spectrometer to collect the reflectance data of 96 FFB from unripe, ripe, and overripe classes for the maturity level classification. The spectrometer scanned the FFB from different parts, including apical, front equatorial, front basil, back equatorial, and back basil. Principal component analysis was carried out to extract principal components from the reflectance data of each of the parts. The extracted principal components were used in an ANOVA test, which found that the reflectance data of the front equatorial showed statistically significant differences between the three maturity groups. Then, the collected reflectance data was subjected to machine learning training and testing by using the K-Nearest Neighbor (KNN) and Support Vector Machine (SVM). The front equatorial achieved the highest accuracy, of 90.6%, by using SVM as classifiers; thus, it was proven to be the most optimal part of FFB that can be utilized for maturity classification. Next, the front equatorial dataset was divided into UV (180–400 nm), blue (450–490 nm), green (500–570 nm), red (630–700 nm), and NIR (800–1100 nm) regions for classification testing. The UV bands showed a 91.7% accuracy. After this, representative bands of 365, 460, 523, 590, 623, 660, 735, and 850 nm were extracted from the front equatorial dataset for further classification testing. The 660 nm band achieved an 89.6% accuracy using KNN as a classifier. Composite models were built from the representative bands. The combination of 365, 460, 735, and 850 nm had the highest accuracy in this research, which was 93.8% with the use of SVM. In conclusion, these research findings showed that the front equatorial has the better ability for maturity classification, whereas the composite model with only four bands has the best accuracy. These findings are useful to the industry for future oil palm FFB classification research.

Keywords: oil palm; fresh fruit bunch; ripeness; optical spectrometer

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1. Introduction

The most productive oil crop, oil palm, can meet the enormous and growing global demand for vegetable oils—expected to reach 240 million tons by 2050 [1]. Oil palm trees produce three to eight times more oil than any other oil crop [1]. To achieve the same amount of soybean or coconut oil, four to ten times more land is needed [2]. According to Oil World, the world production of major vegetable oils in 2018 was 200.8 million tons, with palm oil accounting for 73% of it [3]. By 2025, the worldwide market for palm oil is expected to reach 25.3 billion USD. Palm oil is the main ingredient in many daily supplies, including soaps, cosmetics, detergents, candles, food shortening, cooking oil, margarine,

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