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Analysis of Rough Rice Moisture Content through Infrared Thermography (IRT)

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ABSTRACT: Rough rice's moisture content should be measured in order to ensure its quality, preservation, and proper handling all through storage and processing. When assessing and monitoring the quality of agricultural products, such as rough rice, moisture content is an important consideration. For measuring the moisture content of various agricultural products, infrared thermography (IRT) is a quick and easy non-destructive technique that has shown effectiveness. Traditional methods for determining moisture content require a long time and require sample destruction. Images of the sample were captured with a FLIR ONE thermal camera. The average value of the pixels in the thermal image was applied to create a thermal index that represented each sample. This study aims to investigate the feasibility and accuracy of IRT as a method for analysing the moisture content of rough rice. The results of the study showed that 87.30% accuracy when measuring moisture content was achieved with infrared thermography. Based to the results, rough rice's moisture content may be accurately identified through infrared thermography evaluation using wavelengths analysis. The use of non-contact, non- destructive methods to measure the moisture content of rough rice can be highly beneficial to farmers, rice millers, and other relevant governmental organizations. The results demonstrate the potential of infrared thermography as a rapid and non-destructive tool for moisture content evaluation in rough rice, offering significant advantages in terms of time efficiency and sample preservation.

KEYWORDS: Infrared Thermography, Moisture Content, Image Processing, Rough Rice, FLIR Thermal Studio, Matlab, non-destructive evaluation, quality control.

I. INTRODUCTION

An essential sector that supports both the economy on a whole and our supply of food is rice farming. Although there are several of challenges with rice production in the Philippines, including limited access to modern farming technologies, managing pests and diseases, and the effects of natural catastrophes. To overcome these challenges and increase rice production, the government and agricultural organizations are working aggressively.

The moisture content of rough rice is an important aspect to consider when analyzing its quality and shelf life because it has a direct impact on how well it stores, mills, and produces the finished product. Rice is one of the agricultural crops grown in the Philippines, which has an extensive background of being referred to as an agricultural country. Most Filipinos depend on agriculture to provide for their families and everyday needs. Farming combines food production and income generation, offering food security, self-sustainability. It provides a source of income through selling agricultural products [1].

A fresh paradigm of technology that will reduce costs, increase efficiency, and offer insights for development will be brought about by precision farming combined with the use of ICT especially in rural farm areas. The actual adoption of this technology is yet somewhat limited, but it is captivating interest, particularly among young farmers who have learned that rice farming is more than just tedious work and can be made smarter through the application of cutting-edge technology [2]. Aspects like shape, color, and grain moisture content all determine rice quality. These characteristics determine the properties, physical appearance, and marketability of the rice. Additional factors include cultural preferences, aroma, texture, and size [3]. It's important for assessing rough rice's moisture content (MC) in the farming industry. The need for a non-destructive method for assessing MC has been brought on by the increasing price of agricultural goods made from rice.

Furthermore, we are able to accurately determine the moisture content (MC) distribution of the rice samples by measuring an individual rice kernel.

When rice has a high moisture content (MC), frequently between 25 and 40% dry basis (db) or 25 and 32% wet basis (wb), it is frequently harvested. Rice has a high respiration rate and is especially vulnerable to attack from microorganisms' insects, and pests at this moisture level. In marketing, it's important to know the grain bulk's average MC. For example, a cargo of 10,000 tons with 15% MC (w.b. is used herein unless otherwise specified) can equal 1,500 tons of water. At a price of USD 0.10 per kg, that is worth USD 10,000. Both the buyer and the seller must be informed of the amount of this costly water that is utilized [4].

Several mechanical properties of wood are significantly affected by moisture content (MC). The amount of water mass present in the material divided by oven-dry mass is the definition of oven-dry base MC, a term frequently used in the lumber industry. The most common way to represent MC is as an amount of oven-dry mass. However, measuring MC is not just done using the oven-dry method. Using the relative humidity and temperature of the environment, we may calculate the MC of the specimen. Depending on the temperature and relative humidity of the surroundings, wood specimens will eventually attain a moisture equilibrium. Equilibrium moisture content (EMC) at this moment can be calculated using temperature and relative humidity [5].

The relationship between the rough rice's moisture content and heat index can be determined using Pearson's correlation coefficient. The researcher additionally emphasizes that each set of variables must have a bivariate normal distribution in order for Pearson's correlation coefficient to be applicable to it. The strength and direction of the relationship between two variables can be determined by a correlation coefficient. A complete positive correlation is denoted by a coefficient of 1, whereas a perfect negative correlation is denoted by a coefficient of -1. The variables are more tightly related to one another in the correct manner as the coefficient gets closer to these extremes. There is no linear relationship between the variables, as indicated by a coefficient of 0 [6].

However, other research showed that traditional methods of measuring moisture content—such as oven drying and moisture meters—are time-consuming, require for sample destruction, and possibly have accuracy and representativeness limitations. Infrared thermography has come into its own as an alternative possibility in recent years for agricultural commodities' non-destructive moisture content analysis. Many different areas, including image classification, object identification, facial recognition, and medical imaging, use computer vision and neural networks. By applying visual data to solve a variety of problems, they revolutionize AI [7]. Many image processing techniques can be utilized to measure the vast majority of parameters suitable for quality analysis, including image gathering, preprocessing, feature extraction, segmentation, parameter measurement, calibration, and analysis. The selected algorithms depend on the data inputs and the objects under study. The purpose of expanding this work is to develop a system that can analyze rice grains based on each parameter that may be utilized to improve the quality of the grain.

A solution like this should be less expensive and require less time for quality analysis. [8]. Concentrating on various sampling procedures, sample sizes, sample preprocessing methods, various characteristics, and different models of neural networks in order to meet the needs of the rice industry [9]. To improve accuracy, components like color and texture can be extracted. Additionally, it is possible to examine the identification of different rice kernel flaws, such as fissures [10]. In the fields of agriculture, production, rice storage, trading, and processing, it is necessary to carry out quick, non-destructive moisture content measurements. It would be more beneficial for processing and pricing if the instrument could provide both the mean and the variation of moisture content samples. [4].

This study aims to explore the application of IRT for moisture content analysis in rough rice that benefits the farmers, rice millers, and consumers and compare its performance with conventional methods.

II. MATERIALS AND METHODS

A. Rough Rice Sample

The rough rice samples used in this study came from a Philippines rice granary. The samples were also obtained before to drying and throughout the harvest season in order to obtain samples of real rough rice. In this study, three (3) different cultivars of rough rice were used, all of which are widely farmed in the Philippines.

Rough rice is normally harvested when the moisture content is between 20% and 25%. The moisture content of the rough rice was determined using a Smart Sensor AR991 Grain Moisture Meter. A grain moisture meter can check rough rice with moisture levels between 11% and 55%. Three measurements of rough rice were taken, and an average moisture content was determined. The data was used to show how precisely the moisture content of the rough rice could be determined.

The samples' true moisture content was determined using a sun-drying method akin to that used by Filipino farmers. Samples of the rough rice were prepared for each of these two functions in order to assess the purity and moisture level of the rough rice. In this study, 2,238 samples were evaluated and categorized by analysis.

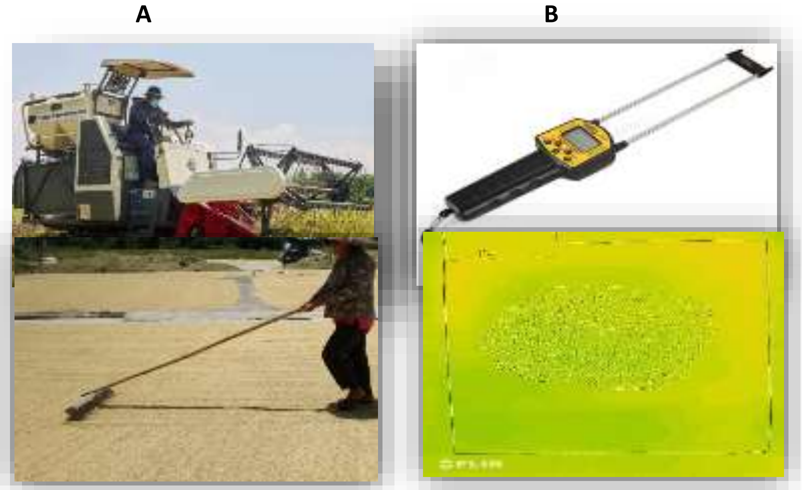


Figure 1. (A) Rough rice harvesting; (B) AR991 grain moisture meter; (C) Sun drying; (D) IR Image of rough rice.

The procedure for collecting samples, from harvesting to drying to classification, is shown in Figure. 1. Rice reapers are agricultural tools used to harvest rice crops. They are sometimes referred to as combination harvesters or rice harvesters. In the Philippines, they are used to mechanize the processes of harvesting rice, separating the grains from the chaff, and cutting and collecting rice stalks. To increase output, ease manpower shortages, and boost the effectiveness of the rice farming sector, the government and numerous organizations support the usage of rice reapers. Sun drying is a common and traditional method in the Philippines for drying raw rice. Depending on multiple circumstances, sun drying can take a few days to a week. To make sure the rice has the proper moisture content, farmers make use of moisture testing. Sun drying is cost-effective, but it has limitations such weather dependence and potential quality problems.

B. Thermal Camera

The selected spectrum of wavelengths will be represented by an infrared camera that can acquire thermal images. For accurate recording of changes in rice surface temperature, the camera's resolution and accuracy should be sufficient. as shown in figure 2. The FLIR ONE Gen 3 thermal camera, which had a visual resolution of 1440 x 1080 and a thermal resolution of 80 x 60, was attached to a mobile phone and stored in the FLIR Ignite cloud. FLIR ONE combines the conventional and thermal images using Multi Spectral Dynamic Technology (MSX) [11].

Figure 2. FLIR One Gen 3 Thermal Camera

C. Experimental Setup

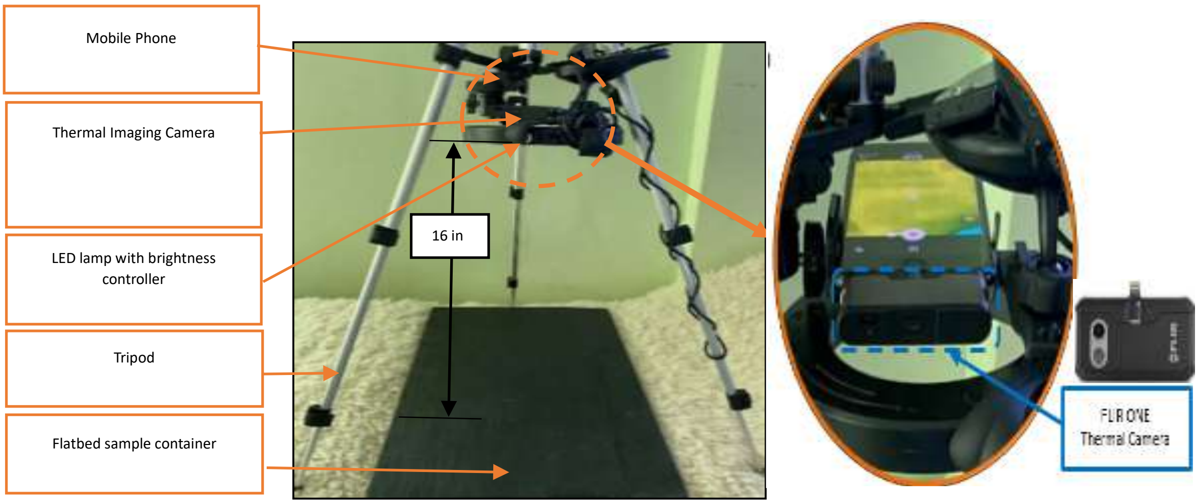


Figure 3. Experimental Setup

Figure 3. shows the experimental setup, which includes choosing an appropriate camera, making sure the lighting is right, and making sure the mounting is secure. Image acquisition entails gathering a variety of images and, if necessary, calibrating the camera. Processing is done using software and techniques like MATLAB, Python, and FLIR Thermal Studio. Preprocessing, setting parameters, and forming a control group are all included in the experiment design. Implementation requires code and handling of errors. Results are measured against predetermined parameters during performance review. Depending on the results, iteration and optimization may be carried out.

D. Image Acquisition

Infrared thermal images of the rough rice samples will be captured at regular intervals using FLIR One thermal camera. Multiple images will be captured to cover the entire sample area. This will be done to provide the raw thermal image additional raw data, resulting in a better vision as RGB scaled images. At least 1500 images for each rough rice sample were captured. The samples are obtained with a sampling distance of around 16 inches. Adjustable LED Ring Light (5 Watts to 150 Watts) was used to accurately light the rough rice samples and eliminate harsh shadows. The angle between the thermal imaging camera and the axis of the illumination source is kept at about 45 degrees. The thermal imaging camera is mounted on a modified tripod as illustrated in figure 2 to provide a rigid and stable support as well as simple vertical mobility.

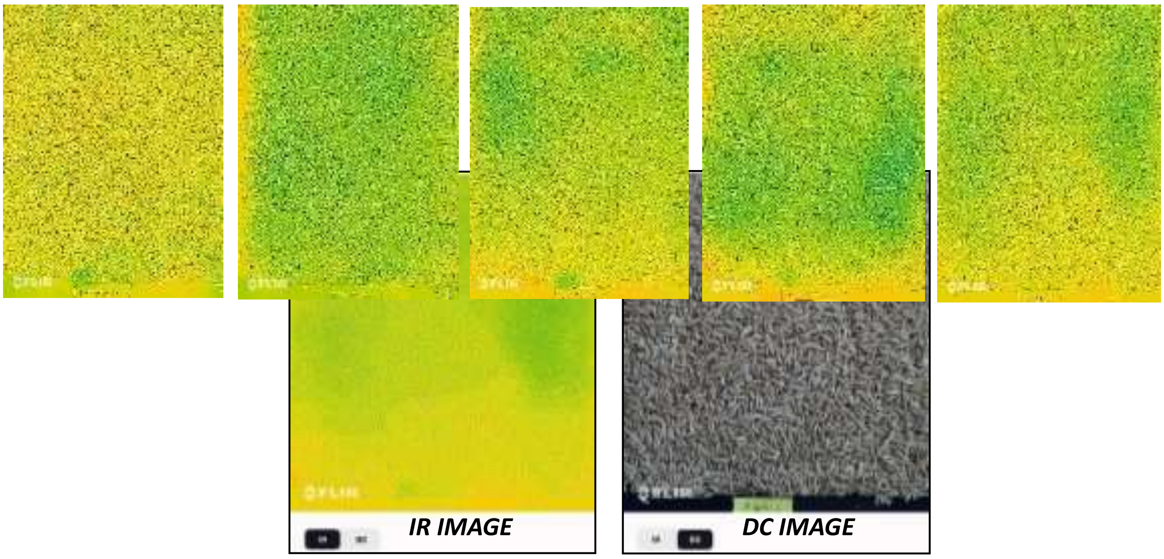


Figure 4. Infrared image acquired from FLIR ONE thermal camera.

E. Moisture Content

Many properties of rough rice are greatly affected by moisture content (MC). The amount of water in the rough rice divided by the oven-dry mass is known as oven-dry basis MC, and it is widely employed in the agriculture sector. But there are other ways to measure MC besides the oven-dry method.

Using the extracted information from a IR image of the rough rice, we can measure the MC of the sample using the relative humidity and temperature. Rough rice sample will ultimately achieve moisture equilibrium with the experiment based on the temperature and relative humidity. Using FLIR Thermal Studio Software, temperature and relative humidity were measured.

Equilibrium Moisture Content (EMC), can be calculated using the equation below. The relative humidity (h) is expressed in decimals in the equation below (e.g., 0.70 instead of 70%), and T is the temperature (in degrees Fahrenheit).

$$W = 330 + 0.452T + 0.00415T^2 \qquad (1)$$

$$K = 0.791 + 0.000463T - 0.000000844T^2 \qquad (2)$$

$$K_1 = 6.34 + 0.000775T - 0.0000935T^2 \qquad (3)$$

$$K_2 = 1.09 + 0.084T - 0.0000904T^2 \qquad (4)$$

Where *T* is the dry-bulb temperature (°F). Thus, given two pieces of information, dry-bulb (or ambient) temperature and the RH, the EMC can be readily calculated.

$$EMC(\%) = \frac{1800}{\mathrm{W}}\left[\frac{Kh}{1-Kh} + \frac{K_1Kh+2K_1K_2K^2h^2}{1+K_1Kh+K_1K_2K^2h^2}\right] \qquad (5)$$

Where *EMC* is the equilibrium moisture content (%), *h* is the relative humidity expressed in decimal form (% / 100), and *W*, *K*, *K1*, and *K2* are coefficients defined by Eqs. 1 through 4, respectively [12

F. Data Analysis

The acquired images will be processed using FLIR Thermal Studio a software to extract thermal data, such as temperature distribution, humidity and thermal patterns. Correlations will be established between the obtained thermal data and the corresponding moisture content of the samples.

After determining the moisture content of the rough rice. A confusion matrix is a table that is often used to describe the performance of a classification model (or "classifier") on a set of test data for which the true values are known. It allows the visualization of the performance of an algorithm. It allows easy identification of confusion between classes [13]. The *Confusionmat* function, one of the useful Matlab functions, was utilized by the researcher [14]. The accuracy of the model can be easily calculated using the confusion matrix.

		Actual Values	
		Positive (1)	Negative (0)
Predicted Values	Positive (1)	TP	FP
	Negative (0)	FN	TN

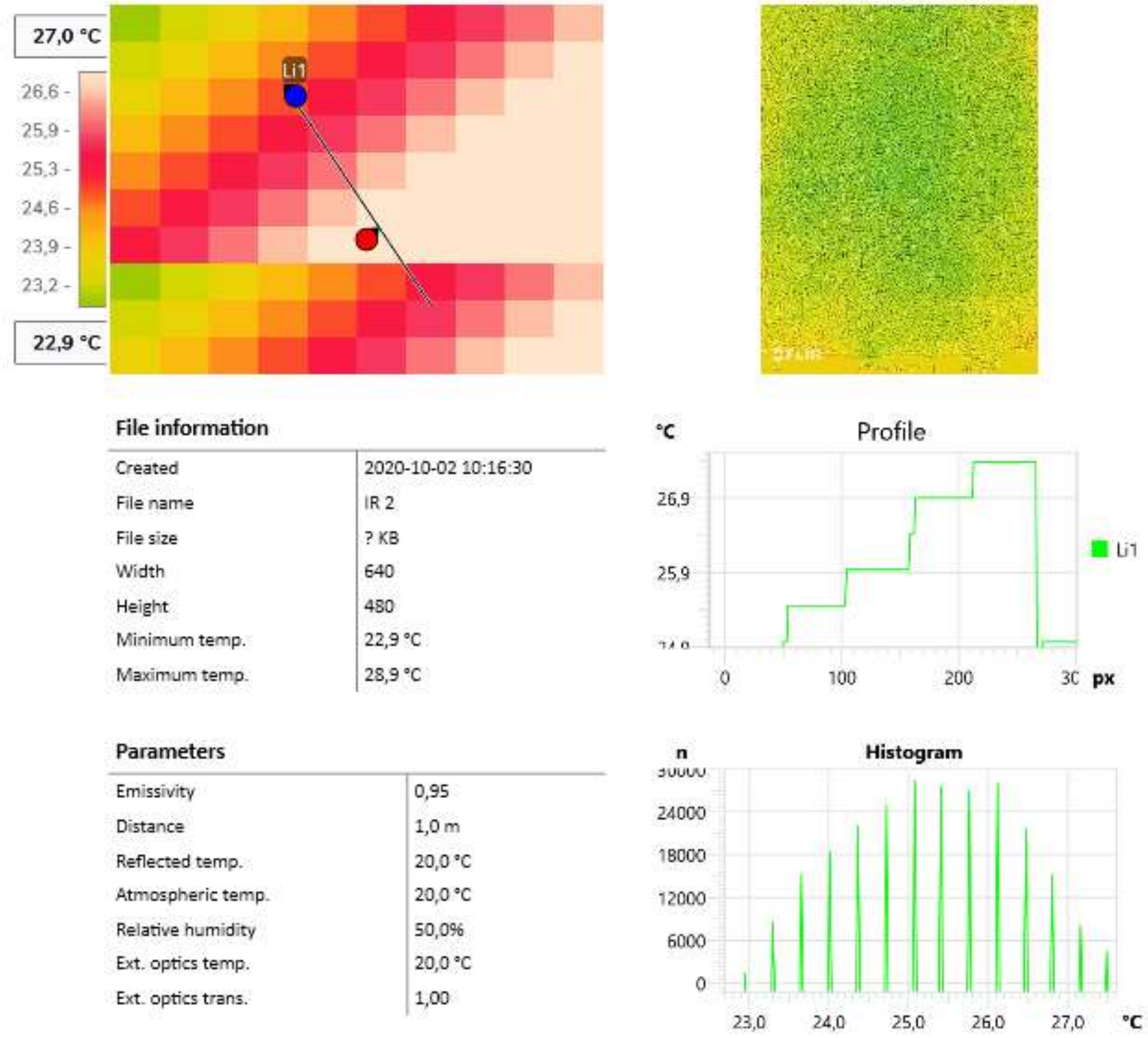
The formula for calculating accuracy is:

$$Accuracy = \frac{\mathrm{TP+TN}}{\mathrm{TP+TN+FP+FN}} \qquad (6)$$

III. RESULTS AND DISCUSSION

The results obtained from the study will be presented and discussed, highlighting the potential of IRT for moisture content evaluation in rough rice.

FLIR Thermal Studio Report



File information

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Maximum temp.	28,9 °C

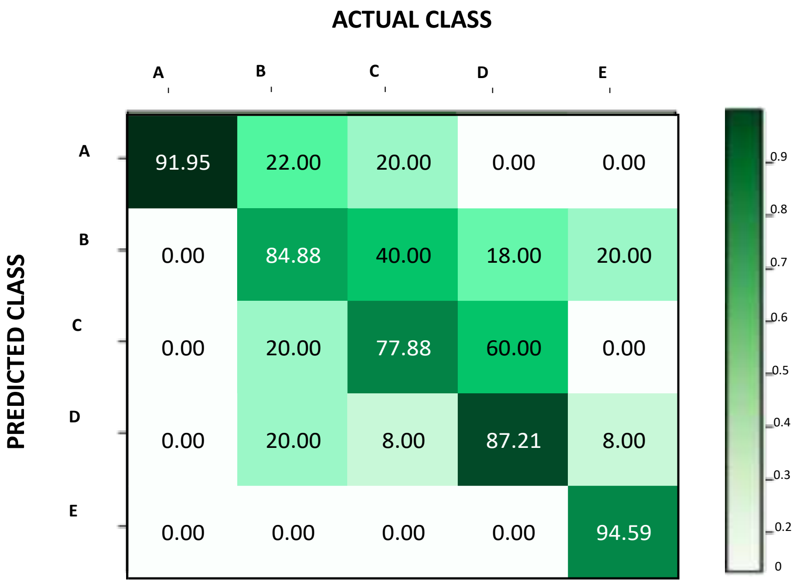
Parameters

Emissivity	0,95
Distance	1,0 m
Reflected temp.	20,0 °C
Atmospheric temp.	20,0 °C
Relative humidity	50,0%
Ext. optics temp.	20,0 °C
Ext. optics trans.	1,00

Figure 5. Generated report from FLIR Thermal Studio

As can be seen in figure 5, it illustrates a report generated through FLIR Thermal Studio software, which identifies the relative humidity and temperature extracted from the thermal image to determine the required parameter to measure the moisture content of rough rice. It also shows a graphical representation using a histogram graph. Figure 5 shows that the sample has a maximum temperature of 28.9 and a humidity level of 50.

Moisture content



CONFUSION MATRIX

LEGEND:
A = 20.9%, **B** = 15.23%, **C** = 14.57%, **D** = 13.91%, **E** = 12.63%

PREDICTED CLASS \ ACTUAL CLASS	A	B	C	D	E
A	91.95	22.00	20.00	0.00	0.00
B	0.00	84.88	40.00	18.00	20.00
C	0.00	20.00	77.88	60.00	0.00
D	0.00	20.00	8.00	87.21	8.00
E	0.00	0.00	0.00	0.00	94.59

Figure 6. The confusion matrix for moisture content detection with accuracy rate of 87.30%.

The diagonal components represent the predicted observations, as seen in Figure 6. A total of 2,2002 observations out of 2,238 were predicted correctly. Therefore, the overall accuracy is 87.30%. The accuracy rate for classification for Class E - 12.63%MC was highest (94.59%), followed by Class A - 20.29%MC (91.95%), Class D - 14.57, and Class B - 17.52 (87.21% and 84.88%, respectively). Nevertheless, with a classification accuracy rate of 77.88%, Class C-15.23 appeared to have the lowest rate. Keeping the Class C-15.23 expected outcomes in mind will help the model perform effectively. With the probable exception of the sample, the classifier misclassified 80 samples in total from Class C-15.23, which is the greatest misclassification rate of any class. This indicates that 77.88% of predictions for Class C-15.23 were correct.

Impedance and near-infrared spectroscopy's effectiveness at determining out rough rice's moisture content was examined in one study. The findings showed the exceptional precision of both approaches, with near-infrared spectroscopy having a significantly higher accuracy (0.55% error) than impedance (0.79% error) [15],[16].

IV. CONCLUSION

In accordance to the study's results, an image processing technique that measures the average rough rice pixel can be used for determining the moisture content of rough rice. The moisture content measurement can be determined scientifically making use of the Equilibrium Moisture Content (EMC) to predict the moisture content of the rough rice by examining the presence of relative humidity and temperature from the IR image and process using FLIR thermal studio.

The accuracy rate of detecting moisture content using the thermal imaging algorithm has an average success rate of 87.30%. The results of this study indicate that using infrared thermography, it may be possible to determine the moisture content of rough rice. It is recommended to develop new methods for image enhancement, feature extraction, machine learning, dataset creation, and real-time rough rice classification systems in order to help ensure that the quality of rice meets the necessary standards. Research on the application of this technology can, however, be done in the future.

The study's outcomes will contribute to improving quality control measures in the rice industry, enabling more efficient handling, processing, and storage practices. The improvement of rice classification accuracy and efficiency, which is essential for guaranteeing food security and meeting the increasing demand for high-quality rice, will also be highlighted along with future research directions and potential applications of IRT in agricultural moisture content evaluation.

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