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NON-DESTRUCTIVE BANANA RIPENESS DETECTION USING OPTICAL SPECTRAL BANDS AND WASTE AND ECONOMIC LOSS FROM WASTE AND BANANA COLOR CHARACTERISTICS

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Abstract

Vegetation indices using Red Green Blue- RGB bands are useful tools for assessing plant health and vigor. They can provide insights into the photosynthetic activity, chlorophyll content, and overall condition of vegetation. When applied to banana plants, these indices can help monitor the ripening stages by analyzing changes in color and other physiological parameters. The objective of this research was to study of the correlation between the banana's color changed during ripening stages and RGB color indices. Dessert bananas (Musa sap.) from nearby, specially designed banana ripening rooms in the city of Santa, Gharbia Governorate, were chosen for experimental work in this study in January 2024. A lot of data analysis was conducted on the RGB bands vegetation indices and the browning index of bananas during the ripening stages. The simple red-green ratio, green-red, hue, VEG, red and blue bands, green-red, and all vegetation index were evaluated to track the ripening stages by color analysis.The results recorded that there was a rise in the blue band band's color from 59 to 123 during the three stages of maturity, following the same pattern as the red and blue band's color. also, Brown index changed from 15.05 to 62.89 as a result of bananas reaching the brown stage. In contrast, the hue dropped from 121.89 to 41.45. The values of RGB bands vegetation indices are highest in the vegetative stage due to the high chlorophyll content in the banana fruit, so the value of NDVI Index is 0.43, VARI Index is 0.62, MGRVI Index is 0.72 and NGBDI Index is 0.41. The maximum values RGBVI1,2,3 Index were at the green stage (unripe banana) at 0.7, 1.48 and 3.68 respectively. In contrast, the maximum values BGI2 and RGRI Index were at the Brown Stage (Overripe Bananas) at 0.66 and 0.94 respectively. Banana waste results in significant economic losses throughout the supply chain, from farmers to consumers. By improving storage, transportation, retail strategies, and consumer habits, businesses and individuals can reduce waste and maximize banana value.

Key words: *banana, ripening rooms, fruit, RGB bands, colour, indicators, vegetation indicators, economic loss*

INTRODUCTION

Bananas are a popular fruit that are mostly grown in tropical and subtropical regions of the world. 1.21 million tons of bananas were produced in Egypt in 2022. Between 1973 and 2022, Egypt's banana production increased at an average annual rate of 5.52%, from 101,000 tons to 1.21 million tons [9]

Bananas are the most wasted fruit in shops because of their brown spots and rapid ripening, which lowers their appeal to consumers. The Food and Agriculture Organization (FAO) estimates that incorrect handling, storage, and maturity control cause 14% of bananas to be lost before they are consumed. Up to 40% of bananas are wasted at the retail and consumer levels in various nations [1].

Research shows that post-harvest banana losses can differ greatly depending on the area and how they are handled. For example, studies conducted in Northeast India found that poor post-harvest handling practices resulted in losses of up to 4.7% during the ripening stage. Banana waste is greatly influenced by consumer preferences. Even though they are still edible, many people throw away bananas with brown patches because they believe they are overripe. Banana waste in households is significantly increased by this tendency. An estimated 50 million tons of bananas are wasted every year worldwide as a result of browning and over ripeness, which causes large financial losses [5,18, 24, 30].

The causes of banana waste occur along the supply chain as presented in Table 1.

Table 1. The stages in which banana waste occurs and Economic Impact

Stage	Cause of Waste	Economic Impact
Farm Level	Oversupply, cosmetic imperfections, early spoilage	Loss of income for farmers
Transport & Shipping	Overripening, temperature mismanagement, ethylene exposure	Rejected shipments, lost export revenue
Retail & Supermarkets	Overstocking, consumer rejection of spotted bananas	Discounts, disposal costs
Consumer Level	Overbuying, poor storage	Household financial loss

Source: Adapted by author based on [18].

Among all fruits, bananas are among the most affordable, tasty, and nutritious. People of all ages prefer it. It also has a number of therapeutic qualities. Various elements of bananas act as food medicines for the treatment of diseases like diabetes, hypertension, cancer, diarrhea, Alzheimer's, and infections, according to numerous in vitro research, animal model studies, and clinical trials. The banana is a climacteric fruit that ripens naturally at 200°C, showing a respiratory peak after harvest. The color, flavor, and texture of the fruit deteriorates rapidly after harvesting, resulting in a sharp decline in fresh banana quality. In the summer, its post-harvest shelf life is a mere two to three days. It has therefore always been regarded as a problematic fruit. Investigating the potential for turning bananas into goods with value additions is one way to tackle this issue. Enzymatic browning of banana pulp is a processing issue. When exposed to oxygen, it quickly browns enzymatically due to cellular breakdown from peeling, slicing, and pulping processes [19].

Fruit maturity is indicated by the softening of the peels' texture and a shift in their golden hue. While peel color reflects shelf life, texture suggests eating quality. One of the key elements of retail distribution is shelf life. Global production exceeds 67 million metric tons, according to FAO (2002). Bananas that are uniformly green and matured are typically harvested in order to prolong their shelf life and minimize loss during transit. They don't undergo any appreciable chemical or physical (color and texture) changes; they stay green and hard. Bananas are mostly judged on the color of their skin by consumers. The color of the peel reflects changes that occur both chemically and physically during the ripening process. Bananas are typically graded commercially by visual assessment [10].

Ripeness is assessed using defined color schemes. The seven ripening stages of the color charts are used to distinguish between different skin tones. Instrumental methods are sometimes used to estimate ripeness as well. The initial stage of ripening is the disintegration of cell walls. The middle lamella becomes less cohesive as a result of the solubilization of pectic compounds. Second, osmosis causes water to migrate from the skin into the flesh. When a Musa cavendish reaches full ripening, the processes of starch hydrolysis and sugar synthesis are finished. However, the process goes on until a highly mature and senescent stage in other species of Musa [26].

The determination of color properties in plants is essential for understanding their biochemical composition and ecological roles. This process involves analyzing the pigments responsible for coloration, such as chlorophyll, carotenoids, and anthocyanins. These pigments not only give plants their distinctive colors but also play vital roles in processes like photosynthesis and the level of ripeness. Researchers study the color properties of plants to understand their ecological roles, nutritional value, and potential applications in industries like food, cosmetics, and textiles. By studying these color properties, scientists can also improve plant breeding programs, predict the quality of fruits and vegetables Also in design of processing systems for these fruits and vegetables Many studies have been reported on the color properties of fruits and vegetables, such as melon [7], Potato Sticks [11]Faba bean and corn [12], orange [13], soybean seeds [14], and green leafy [15].

Food preparation and preservation impact food's color, texture, flavor, and nutritional content. Food safety and quality are never entirely compatible. Modified environment storage is one method of food preservation that increases the shelf life of food products without sacrificing their natural quality. The storage life of food products is greatly increased by changing the atmosphere surrounding the food, which lowers the respiration rate of the food items and the activity of insects or bacteria in the food [8].

When fruit ripens, it experiences a number of physical changes. The most obvious change that many fruits undergo during the ripening process is to their exterior color. Ripening rooms require a good temperature control system, effective air circulation, an efficient fresh air supply mechanism, and gas tightness. If ventilation is not done on a regular basis, ripening may take longer or take on peculiar features [29].

The effects of ripening treatment on the qualities of banana fruit are discovered to be related to temperature. Additionally, research was done on the reciprocal effects of fruit length, temperature, and storage humidity on banana fruit attributes. the variations in banana texture and color when being stored at 10 and 20 degrees Celsius. The M. Cavendish samples showed a gradual change in peel color from green to yellow during storage, but the M. Paradisiacal variety showed a distinct pattern, staying green for the first eight days before abruptly shifting to a yellow tone starting on day twelve. While the M. Cavendish type bananas' flesh texture softened quite quickly after storage, the M. Paradisiacal variety's flesh texture changed more slowly and the flesh hardness values did not change much over the course of the storage period [27].

The peel of "Dwarf Cavendish" bananas showed brownish-red coloring after 40 minutes of exposure to 30 W UV-C at a distance of 45 cm. Another report reported a similar observation in a "Williams Cavendish" banana that was exposed to 1.2 W/m^2 UV-C radiation for 10 minutes at a distance of 18 cm. Both reports, however, did not list a fatal dose that results in browning bananas. Prior its application on a commercial scale, information regarding the lethal dose is required [28].

In Malaysia, the most popular banana fruit for dessert is called Brangan. When ripe, the fruit, which ranges in size from medium to large, has a beautiful orange-yellow peel and pale orange pulp. The most popular dessert among the locals is banana. The Cavendish and Brangan bananas have the same genome, which is AAA, however the fruit of the Brangan banana may ripen at a tropical temperature of 27 °C. After being exposed to UV-C radiation, Brangan banana fruit experienced browning just as Cavendish banana fruit [6].

Studies on the shelf life of bananas assessed the bananas' level of ripening based only on color; however, no quantitative analysis of their quality indices was conducted. To our knowledge, there has never been a case when the external color of a banana was used to determine its quality, though. Fruit quality is first assessed based on color, gloss, and size; it is then assessed based on texture, total soluble solids (TSS) concentration, and acidity. When selecting a food source, consumers may find this information to be helpful. In trading, attribution of quality should be given particular consideration. Ripening indices: these are commonly used to assess changes in volatile chemicals, soluble solids concentration, titratable acidity, softening, and skin color. However, the use of sensors—such as chemical, optical, and tactile ones—offers a strong association with human senses [3].

The quality indices of bananas were estimated using artificial neural networks (ANN) based on color features (L*a*b*, HSV, and YUV) at various storage temperatures (20, 25, 27.5, and 30 ◦C) during the ripening process. The banana's hardness and TSS were successfully anticipated by the ANN model, but the pH and pulp-to-peel ratio were not well predicted. Furthermore, the RPD values showed good predictive power for TSS and hardness, but not for pH or the pulp-to-peel ratio. At the laboratory level, a deep learning image processing system could be a helpful tool for predicting banana quality indices. Their study showed that consumers and employees in the general supply chain may be able to judge food quality using a smartphone's camera. To compensate for changing ambient light, the process of capturing images can be made simpler. For example, a gray color chart placed next to the fruit could be used [4].

The biochemistry and physiology of the fruit alter during the final stage of growth, known as ripening, which improves the fruit's texture, flavor, and appearance and makes it more palatable and pleasurable to eat. Most of the fruit's sensory and nutritional properties occur during ripening, therefore controlling it is crucial to maintaining the fruit's quality traits throughout its postharvest shelf life. Banana quality and postharvest life are dependent on how they ripen and are treated postharvest. In the wild, bananas ripen slowly, which results in severe weight loss, desiccation, uneven ripening, and poor color and scent production. Marketable quality is therefore deteriorating [21].

One of the fundamental physical characteristics of agro-food items is color. As a matter of fact, color is a significant factor in the assessment of exterior quality in the food engineering and food industry. While color plays a significant role in assessing food quality, researchers have not yet fully examined the potential of using color factors to forecast particular food quality indicators. An online imaging system was used to monitor and control the quality of industrial food products. On the other hand, the kinetics of green-yellow conversions in fruits and vegetables have been the subject of very few investigations [25].

The main objectives of this study were monitored the ripening stages of bananas using various color characteristics indices, including intensity, brown index, and hue. Also, the study examined the waste and economic loss from banana color characteristics.

MATERIALS AND METHODS

The investigation was carried out. To confirm the color features indices for banana ripening stages, a variety of dessert bananas (Musa sap.) with varied maturity stages were procured from adjacent authorized banana ripening rooms located in Santa, Gharbia Governorate, in January 2024. These features were employed to investigate the changes brought about by the various stages of banana ripening in refrigerators used for banana manufacturing. Samples were chosen at random and manually cleaned.

Measurements and determinations

The color characteristics of the three banana ripening stages were determined by averaging 100 repetitions of banana fruits as shown in Photo 1.

Photo 1. Changes in color and brown spot development
Source: Authors' determination.

The three primary colors of banana ripening stages were measured using MATLAB software The values RGB denoted by 'R', 'G', and 'B' stand for the red, green, and blue bands, respectively. Hue, the intensity and RGB bands vegetation indices for banana was also measured. Additionally, (La b) was measured using a digital colorimeter for computed the browning index. Here are some key equations used to analyze banana color properties:

-Intensity, candela= lumen per Ste radian [23]

$I = \frac{1}{3}(R + G + B)$………………….......... (1)

I2 = (R-B)/2…………………………….…….... (2)

-Browning Index [23]

BI = $\frac{100*(X-0.31)}{0.17}$……………….…..………. (3)

$$X = \frac{a+1.75L}{5.645L+a-0.3012b} \ldots\ldots\ldots\ldots\ldots (4)$$

-Hue (Hue) [11]

$$\text{Hue} = COS^{-1}\left(\frac{(2R-G-B)/2}{(R-G)^2+(R-B)(COSG-B)^{0.5}}\right) \ldots. (5)$$

-Normalized Difference Vegetation Index (NDVI) Adaptation [17]

$$\text{NDVI} = \frac{G-R}{G+R} \ldots\ldots\ldots\ldots\ldots (6)$$

-Visible Atmospherically Resistant Index (VARI) [16]

$$\text{VARI} = \frac{G-R}{G+R-B} \ldots\ldots\ldots\ldots\ldots (7)$$

-Modified Green-Red Vegetation Index (MGRVI) [2]

$$\text{MGRVI} = \frac{G^2-R^2}{G^2+R^2} \ldots\ldots\ldots\ldots\ldots (8)$$

-Normalized Green-Blue Difference Index (NGBDI) [20]

$$\text{NGBDI} = \frac{G-B}{G+B} \ldots\ldots\ldots\ldots\ldots (9)$$

-Simple blue–green ratio (BGI2) [32]

$$\text{BGI2} = \frac{B}{G} \ldots\ldots\ldots\ldots\ldots (10)$$

-Red-Green Ratio Index (RGRI) [22]

$$\text{RGRI} = \frac{R}{G} \ldots\ldots\ldots\ldots\ldots (11)$$

-RGB-based vegetation index (RGBVI) [2]

$$\text{RGBVI} = \frac{G^2-(B\times R)}{G^2+(B\times R)} \ldots\ldots\ldots\ldots\ldots (12)$$

-RGB-based vegetation index 2 (RGBVI2) [2]

$$\text{RGBVI2} = \frac{G-R}{R} \ldots\ldots\ldots\ldots\ldots (13)$$

-RGB-based vegetation index 3 (RGBVI3) [2]

$$\text{RGBVI3} = \frac{G+R}{R} \ldots\ldots\ldots\ldots\ldots (14)$$

-Triangular Greenness Index (TGI) [14]

$$\text{TGI} = -0.5 \times (190(R-G) - 120(R-B))..(15)$$

-Excess Green Index (ExG) [31]

$$\text{ExG} = 2G - R - B \ldots\ldots\ldots\ldots (16)$$

where:
RGB Red, Green, Blue Bands
L= lightness of the colour, which range from 0 (dark) to 100 (white).
a = indicates green colour.
-b = indicates blue colour
+b = indicates yellow colour

RESULTS AND DISCUSSIONS

The optical properties, RGB bands vegetation indices and browning index of banana during ripening stages were statistically examined. and red and blue bands, Hue, VEG, the simple red–green ratio, green–red and all vegetation index were tested to monitor the ripening stages by analysing changes in color. The banana's color changed during ripening stages, according to the results.

Figure 1 shows the how the color features indices for banana ripening stages. The red band's color increased from 55 to 174 during the three stages of maturity, also the green band's color increased from 139 to 186, following the same pattern as the blue band.

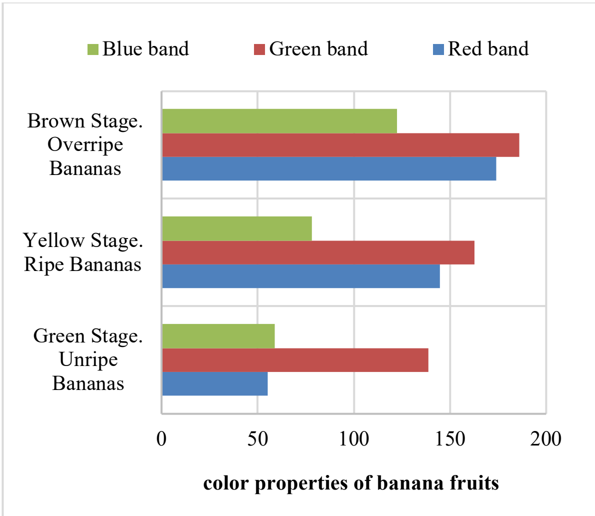

Fig. 1. The RGB bands Indices of banana during ripening stages
Source: Authors' determination.

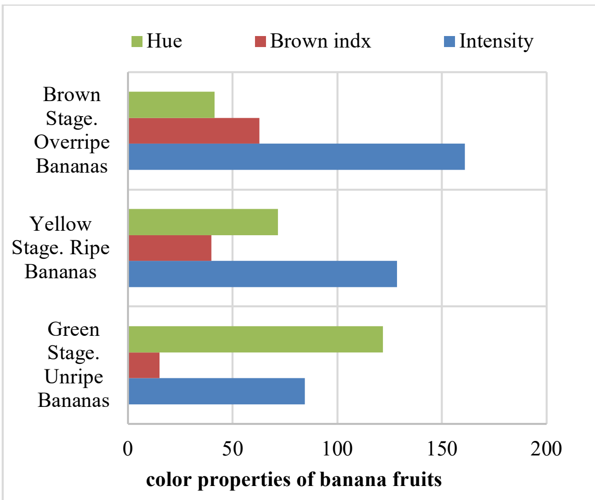

Fig. 2. The Hue, intensity and browning index of banana during ripening stages
Source: Authors' determination.

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Figure 2 shows the intensity, hue and Brown index. which Brown index went from 15.05 to 62.89 during the three stages of maturity following the same pattern as the intensity. In contrast, the hue dropped from 121.89 to 41.45.

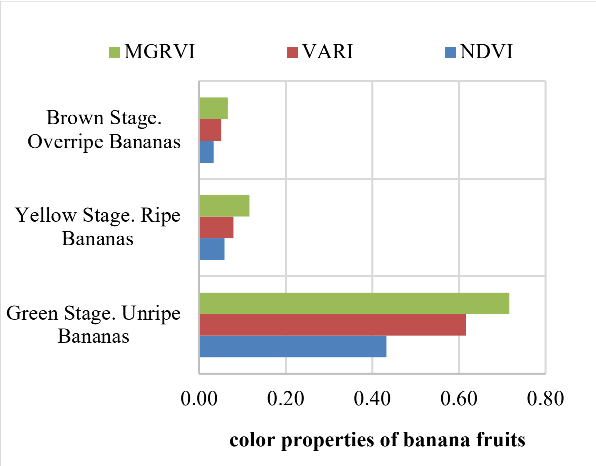

Fig. 3. The normalized Difference Vegetation Index, Visible atmospherically resistant index and modified green–red vegetation index of banana during ripening stages
Source: Authors' determination.

Figure 3 shows that the normalized Difference Vegetation (NDVI) index can indicate changes in chlorophyll content as bananas ripen. Its value increases in the green stage (unripe bananas) and gradually decreases in the yellow stage (ripe bananas) until it reaches its lowest value in the brown stage where the bananas are overripe, so the values are 0.43, 0.06, and 0.03 respectively. While the Visible atmospherically resistant (VARI) index provides a measure of ripening progress. Its value rises when the bananas are green (unripe), progressively falls when they are yellow (ripe), and finally reaches its lowest value when the bananas are brown (overripe), its values 0.62, 0.08, and 0.05, respectively.As for modified green–red vegetation (MGRVI) index highlighting the intensity differences between green and red. Its value ranges between 0.72, 0.12 and 0.07 during the three stages of maturity.

Figure 4 illustrates the convergence between the values of Simple blue–green ratio (BGRI) and Red-Green Ratio Index (RGRI) in the green stage (unripe bananas) which were 0.43 and 0.4. While in Yellow Stage (Ripe Bananas), the values of the RGRI index increase over the BGRI index by 0.41, and the values of the same two indices also increase by 0.28 in Brown Stage (Overripe Bananas) .On the contrary, the NGBDI index decreases from 0.41 then 0.35 then 0.21 in the last stage, which is the brown stage.

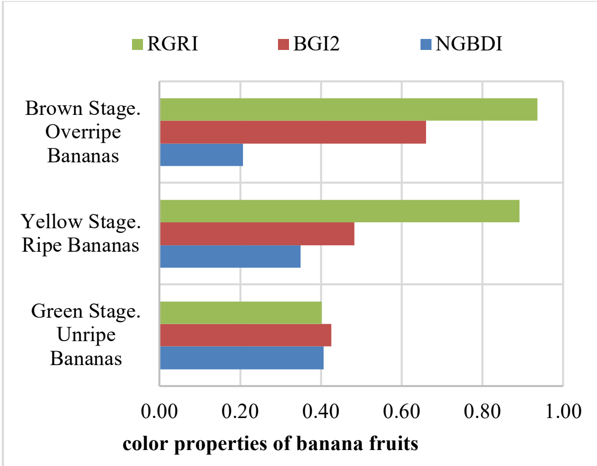

Fig. 4. The normalized green-blue difference index, Simple blue–green ratio and Red-Green Ratio Index of banana during ripening stages
Source: Authors' determination.

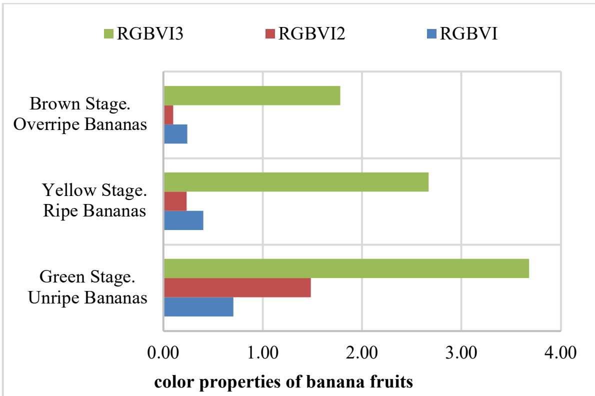

Fig. 5. RGB-based vegetation index, RGB-based vegetation index 2 and RGB-based vegetation index 3 of banana during ripening stages
Source: Authors' determination.

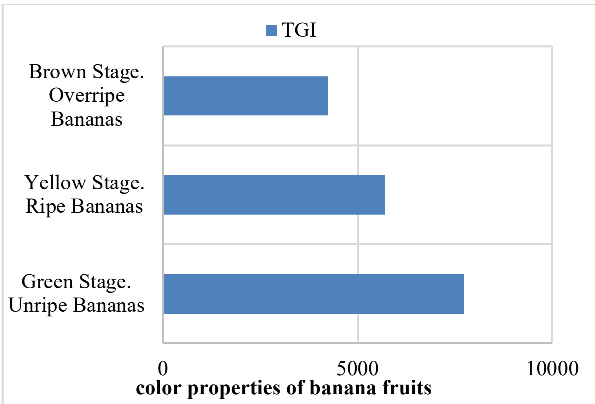

Fig. 6. The triangular Greenness Index of banana during ripening stages
Source: Authors' determination.

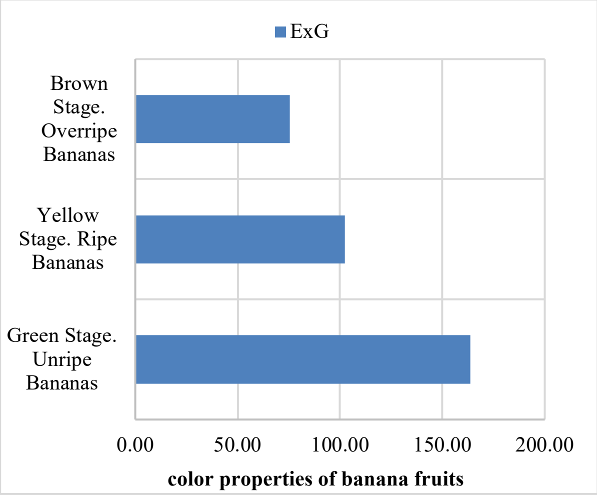

Fig. 7. The excess green index of banana during ripening stages
Source: Authors' determination.

As shown in Figure 5, the RGB-based vegetation 1, 2, 3 index that useful for vegetation detection. Their maximum values were at the green stage (unripe banana) at 0.7, 1.48 and 3.68 respectively and decreased to 0.24, 0.1 and 1.78 at the Brown Stage (Overripe Bananas), respectively. The TGI provides a measure of greenness and is useful for assessing the initial stages of ripening as green bananas turn yellow.

Figure 6, the Triangular Greenness Index (TGI) values decrease from 7732 to 5700 and then 4230 as the bananas lose their green color.

As in Figure 7, the Excess green index (ExG) value decreases, indicating a reduction in chlorophyll, as bananas ripen and turn yellow from 163.7 to 102.5 then 75.5 respectively.

Waste and Economic Loss from Banana Color Characteristics

Figure 8 shows that for one ton of bananas, the highest waste occurs in the brown stage where 60% are discarded, resulting in an economic loss estimated at 9252 EGP.

In the green stage, about 20% are wasted, resulting in an economic loss of 3084 EGP.

While in the yellow stage, this stage has the lowest waste, where 5% are discarded, corresponding to an economic loss of 771 EGP.

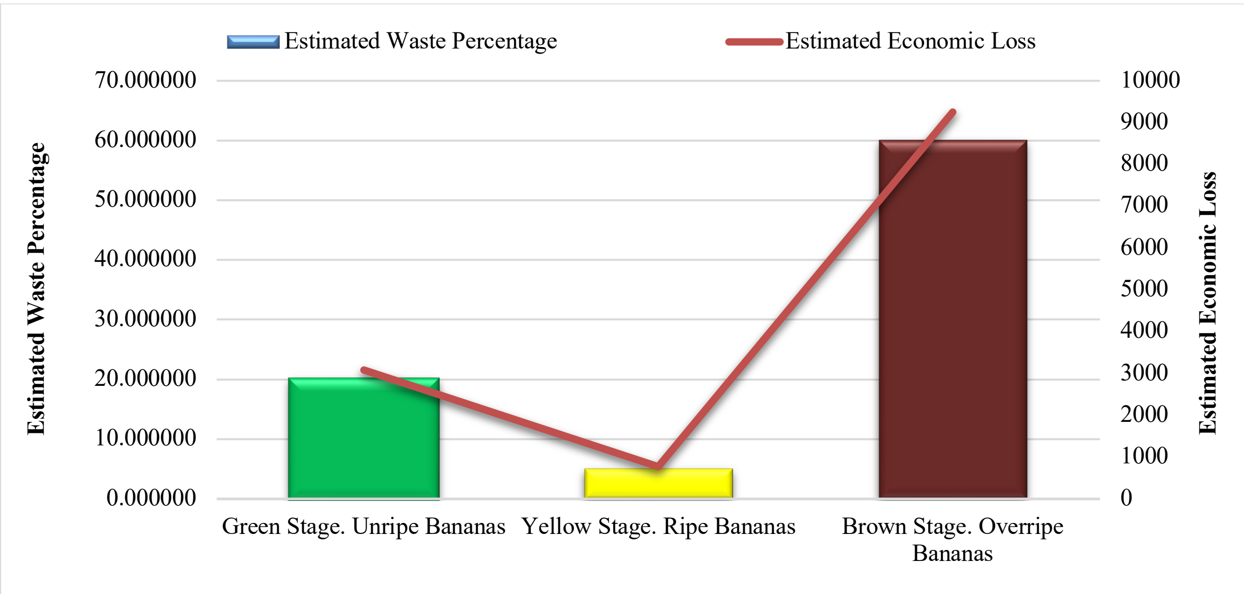

Fig. 8. The Estimated Waste Percentage and Economic Loss of banana during ripening stages
Source: Authors' determination.

CONCLUSIONS

A banana's color changes significantly as it ripens, and RGB color indices can be used to objectively assess these variations.

The optical spectral bands reflex from Bananas are initially green because they contain chlorophyll.

As ripening advances, the chlorophyll breaks down, revealing yellow carotenoids, which results in a decrease in the green component (G) value and an increase in red (R) and blue (B) values, shifting the banana's color towards yellow. RGB-based vegetation indices, which combine these RGB values, can offer a more detailed analysis of these changes, providing a quantitative way to monitor the ripening process.

These indices help in accurately determining the ripeness stage, aiding in decisions related to harvesting, storage, and predict the best time to consumption.

Banana color is a crucial economic factor, influencing price, waste, consumer behavior, and supply chain logistics. Innovations in storage, transport, and alternative markets help mitigate losses associated with color changes.

REFERENCES

[1]Banana Market Review 2019. Rome. http://www.fao.org/publications/card/es/c/CB0168EN/ Accessed on 23 August, 2024.

[2]Bendig, J., Yu, K., Aasen, H., Bolten, A., Bareth, G., 2015, Combining UAV-based plant height from crop surface models, visible, and near infrared vegetation indices for biomass monitoring in barley. International Journal of Applied Earth Observation and Geoinformation, 39, 79-87. Accessed on 23 August 2024.

[3]Bora, G. C., Lin, D., Bhattacharya, P., Bali, S. K., Pathak, R., 2015, Application of bio-image analysis for classification of different ripening stages of banana. Journal of Agricultural Science, 7(2), 152. Accessed on 23 August 2024.

[4]Cho, B. H., Koseki, S., 2021, Determination of banana quality indices during the ripening process at different temperatures using smartphone images and an artificial neural network. Scientia Horticulturae, 288, 110382. Accessed on 23 Augsut 2024.

[5]Das, T., Ahmad, A., 2023, Evaluation of Postharvest Losses of Banana Growers in North East India: An Ordered Probit Analysis. Current Agriculture Research Journal, 11(2). Accessed on 23/8/2024.

[6]Ding, P., Ahmad, S.H., Razak, A.R.A., Mohamed, M.T.M., Saari, N., 2007a. Plastid ultrastructure, chlorophyll contents and colour expression during ripening of Cavendish at 18 and 27o C. New Zealand Journal of Crop and Horticultural Science 35: 201-210. Accessed on 23 August 2024.

[7]Emadi, B., Abbaspour-Fard, M. H.K.D.V., Yarlagadda, P., 2009, Mechanical properties of melon measured by compression, shear, and cutting modes. International Journal of Food Properties 2009; 12(4): 780-790. Accessed on 23 August 2024.

[8]Fan, K., Zhang, M., Fan, D., Jiang, F., 2019, Effect of carbon dots with chitosan coating on microorganisms and storage quality of modified-atmosphere-packaged fresh-cut cucumber. J. Sci. Food Agric. 99, 6032–6041.Accessed on 23 August 2024.

[9]FAO, 2022, Banana's production quantity Data. https://www.fao.org/faostat/ar/#data/QI. Accessed on 23 August 2024.

[10] Food and Agriculture Organization (FAO), 2002, FAO statistical databases. FAO/United Nations. http://apps.fao.org. Accessed on 23 Ausgut 2024.

[11]Fouda, T., Kassab, N., 2024, Measuring the color change of potato sticks and plant oil during frying processes. Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development Vol. 24(1), 443-451. Accessed on 23 August 2024.

[12]Fouda, T., Abdelsalam, A., 2023, Determination of color properties of some seeds. Accessed on 23 August 2024.

[13]Fouda, T., Derbala, A., Elmetwalli, A., Salah, S., 2013, Detection of orange color using imaging analysis. AgroLife Scientific Journal, 2(1). Accessed on 23 August 2024.

[14]Fouda, T., Derbala, A., Helal, A., Albebany, A., 2020, Monitoring white moldsclerotia perorates to reduce the risks impact on imported soybean seeds. Scientific Papers Series Management, Economic Engineering in Agriculture & Rural Development, 20(3), 259-266. Accessed on 23 August 2024.

[15]Fouda, T., Mady, E., Al Bay, N., Salah, S., 2024, Distinguishing heavy metals concentration in green leafy vegetables by using the RGB color model. Scientific Papers Series Management, Economic Engineering in Agriculture & Rural Development, 24(1).Accessed on 23 August 2024.

[16]Gitelson, A. A., Kaufman, Y. J., Merzlyak, M. N., 1996, Use of a green channel in remote sensing of global vegetation from EOS-MODIS. Remote Sensing of Environment, 58(3), 289-298. Accessed on 23/8/2024.

[17]Guijarro, M., Pajares, G., Riomoros, I., Herrera, P. J., Burgos-Artizzu, X. P., Ribeiro, A., 2011, Automatic segmentation of relevant textures in agricultural images. Computers and Electronics in Agriculture, 75(1), 75-83. Accessed on 23 August 2024.

[18]Gupta, G., Baranwal, M., Saxena, S., Reddy, M. S., 2023, Utilization of banana waste as a resource material for biofuels and other value-added products. Biomass Conversion and Biorefinery, 13(14), 12717-12736. Accessed on 23/8/2024.

[19]Jyothirmayi, N., Rao, N.M., 2015, Banana medicinal uses. Journal of Medical Science Technology, 4(2), 152- 160. Accessed on 23 August 2024.

[20]Louhaichi, M., Borman, M. M., Johnson, D. E., 2001, Spatially located platform and aerial photography for documentation of grazing impacts on wheat. Geocarto International, 16(1), 65-70. Accessed on 23 August 2024.

[21]Mebratie, M. A., Woldetsadik, K., Ayalew, A., Haji, J., 2015, Comparative study of different banana ripening methods. Sci. Tech. and Arts Res. J. 4(2):32-38. Accessed on 23 Augsut 2024.

[22]Meyer, G. E., Hindman, T. W., Laksmi, K., 1999, Machine vision detection parameters for plant species identification. Precision Agriculture, 1(1), 113-120. Accessed on 23 August 2024.

[23]Nayaka, V. K., Tiwari, R. B., Narayana, C. K., Ranjitha, K., Shamina, A., Vasugi, C., ... &Sujayasree, O. J., 2022, Comparative effect of different sugars

instigating non-enzymatic browning and Maillard reaction products in guava fruit leather. Journal of Horticultural Sciences, 17(1), 174-183. Accessed on 23 August 2024.

[24]Panagiotou, M., Ioannou, C., Hachem, L., Huang, Q., Mugampoza, E., Gkatzionis, K., 2024, Consumer Perception of Banana Waste in Response to Ripeness: A Case Study of European and Chinese Panels. Accessed on 23 August 2024.

[25]Pathare, P. B., Opara, U. L., Al-Said, F. A. J., 2013, Colour measurement and analysis in fresh and processed foods: A review. Food and bioprocess technology, 6, 36-60. Accessed on 23 August 2024.

[26] Rizzo, M., Marcuzzo, M., Zangari, A., Gasparetto, A., Albarelli, A., 2023, Fruit ripeness classification: A survey. Artificial Intelligence in Agriculture, 7, 44-57. Accessed on 23 August 2024.

[27]Salvador, A., Sanz, T., Fiszman, SM., 2007, Changes in color and texture and their relationship with eating quality during storage of two different dessert bananas. Postharvest Biology and Technolog, 43: 319–325. Accessed on 23 August 2024.

[28]Siddiqui, M. W. (Ed.), 2015, Postharvest biology and technology of horticultural crops: principles and practices for quality maintenance. CRC Press. Accessed on 23 August 2024.

[29]Thompson, A. K., 2003, Fruit and vegetables: Harvesting, handling and storage. 2nd ed. Oxford, UK. 460. Accessed on 23/8/2024.

[30]Wang, P., 2024, Mitigation of Climate Anxiety by Improving the Integration of a Circular Economy; The Effect of Ripening Stages of Banana Peels to Thermal Stability. Accessed on 23 August 2024.

[31]Woebbecke, D. M., Meyer, G. E., Von Bargen, K., Mortensen, D. A., 1995, Color indices for weed identification under various soil, residue, and lighting conditions. Transactions of the ASAE, 38(1), 259-269. Accessed on 23 August 2024.

[32]Zarco-Tejada, P. J., Berjón, A., Lopez-Lozano, R., Miller, J. R., Martín, P., Cachorro, V., ... & De Frutos, A., 2005, Assessing vineyard condition with hyperspectral indices: Leaf and canopy reflectance simulation in a row-structured discontinuous canopy. Remote Sensing of Environment, 99(3), 271-287.Accessed on 23 August 2024.