



RESEARCH ARTICLE

The dynamics of physicochemical changes in various banana cultivars (*Musa* spp.) during storage

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Abstract

Banana is a climacteric fruit that undergoes significant physicochemical changes during storage. This study aimed to investigate the changes in moisture content, total dissolved solids (TDS) and peel colour in five banana cultivars (Raja, Kepok, Ambon, Cavendish and Susu) over 8 days of storage at room temperature. Observations were conducted daily to capture detailed ripening dynamics. Results showed a decrease in moisture content at the beginning of storage and a subsequent increase towards the end from an initial range of 61.09–69.69 % to 59.74–72.56 % by the 8th day, depending on the cultivar. This pattern is associated with water loss due to transpiration during the initial stage and the fruit ripening process in the later stage. The TDS increased markedly from 1.75–2.75 °Brix to 13.87–18.35 °Brix, indicating starch hydrolysis into simple sugars during ripening. Peel colour changes were evaluated using the CIE Lab* system. The L* value (lightness) fluctuates, starting from 45.63–56.83 to 54.87–72.55 varying from the fourth to the 6th day storage; subsequently, the L value decreased again to 51.51–66.32, reflecting peel darkening. The a* value shifted from negative (-6.4 to -8.2) to positive (3.6–7.9), indicating a transition from green to reddish hues. Additionally, the b* value increased from 10.26–14.07 to 23.12–29.41, suggesting enhanced yellow pigmentation. Variation in the rate and extent of these changes among banana types highlights the influence of cultivar characteristics on ripening behaviour and quality degradation during storage. These findings provide essential insights for post-harvest handling, shelf-life determination and cultivar-specific storage strategies in the banana supply chain.

Keywords: banana cultivars; cultivar comparison; physicochemical properties; post-harvest; ripening kinetics

Introduction

Banana (*Musa* spp.) is one of the most widely consumed tropical fruits due to its nutritional value, affordability and year-round availability. As a climacteric fruit, bananas undergo rapid physiological and biochemical changes during post-harvest storage, such as starch breakdown, sugar accumulation, moisture loss, peel colour change and firmness decline. For example, starch levels in bananas have been shown to decrease significantly during ripening (1). In tropical countries where cold-chain infrastructure is limited, storage at ambient temperature is common, which can accelerate ripening and quality degradation.

Different banana cultivars exhibit distinct ripening patterns and metabolic behaviours, which are influenced by their genetic background and physiological characteristics. These variations have practical implications in determining harvest maturity, storage duration and consumer acceptability. Understanding these differences among banana cultivars is therefore crucial not only for identifying specific ripening traits but also for guiding the development of appropriate post-harvest handling techniques and supporting cultivar improvement programs aimed at enhancing fruit quality and reducing economic losses.

Although several studies have examined ripening behaviours of individual banana cultivars, there remains limited comparative research assessing multiple popular cultivars under standardised ambient storage conditions, especially integrating parameters such as moisture content, total dissolved solids (TDS) and peel colour simultaneously. For instance, while one study on 5 and 9 cultivars measured physicochemical changes during ripening, it did not fully integrate all parameters under identical storage regimes (2). Another study focused on nutritional composition changes across ripening stages but did not emphasise comparative cultivar behaviour under ambient storage (3). Thus, a knowledge gap exists in the comparative dynamics of multiple banana cultivars' physicochemical changes during storage in tropical ambient conditions.

Given this context, the present study was designed to investigate the temporal changes in key ripening parameters, including moisture content, total dissolved solids (TDS) and peel colour across five banana cultivars (Raja, Kepok, Ambon, Cavendish and Susu) during an 8-day storage period. The results of this study are expected to provide valuable insights into the ripening physiology of various banana cultivars and contribute to the improvement of post-harvest management practices for maintaining quality and extending shelf life.

Materials and Methods

Five banana cultivars, namely Raja, Kepok, Ambon, Cavendish and Susu, were purchased from Rasamala Market, Semarang, Indonesia. Fruits with uniform maturity, size and free from visible physical defects were selected for the study. Each cultivar consisted of three biological replicates and observations were conducted on each replicate throughout the storage period. The fruits were stored at room temperature (28–30 °C) with a relative humidity of approximately 60 % for eight days to simulate typical post-harvest handling and household storage conditions. Observations were conducted once daily at 08:00 a.m. in the Food Chemical and Nutritional Laboratory, Department of Food Technology, Diponegoro University.

The parameters measured included moisture content (%), total dissolved solids (°Brix) and peel colour. Moisture content was determined using the thermogravimetric method. Approximately 5 g of homogenised banana pulp was weighed into a pre-dried moisture dish and dried in a hot-air oven at 105 °C until a constant weight was achieved. Moisture content was then calculated as the percentage of weight loss relative to the initial sample weight.

The TDS were determined using a digital hand refractometer with slight modifications to a previously described method (4). Briefly, 10 g of banana pulp was homogenised and diluted with distilled water to a final volume of 50 mL. The homogenate was filtered through a filter cloth to obtain a clear filtrate. Prior to each measurement, the digital hand refractometer was calibrated using distilled water (0 °Brix). Subsequently, 2–5 drops of the filtrate were placed on the prism surface and the TDS value was recorded directly in °Brix. The measured value was multiplied by a dilution factor of five to obtain the final TDS value.

Peel colour was evaluated using a colourimeter based on the CIE Lab* colour system, which measures lightness (L^*), red–green chromaticity (a^*) and yellow–blue chromaticity (b^*). Prior to measurement, the instrument was calibrated using standard white and black calibration tiles according to the manufacturer's instructions. Colour measurements were taken at three different points on the equatorial region of each banana peel and the average value was used for subsequent analysis to minimise variability caused by uneven peel colouration.

Data analysis

All experimental data, including moisture content, total dissolved solids (TDS) and peel colour parameters (L^* , a^* and b^*), were processed using Microsoft Excel 2021. Linear and second-order polynomial regression models were applied to describe the temporal variations observed during eight days of ambient storage. The coefficient of determination (R^2) was calculated to assess the model fit, while the first derivative (dy/dx) of each regression equation was used to estimate the daily rate of change. The rate constant (k) was derived from the slope coefficient to compare the relative speed of physicochemical changes among the banana cultivars.

The resulting regression models were visualised as line graphs to illustrate the ripening dynamics and to identify critical points such as the peak in TDS, the onset of moisture decline and the transition in peel colour. This descriptive regression-based approach was selected to capture the inherent non-linear patterns of banana ripening without inferential testing. The analysis provides a quantitative representation of cultivar-specific ripening kinetics and contributes to a better understanding of post-harvest physiological behaviour under ambient storage conditions.

Results and Discussions

Moisture content

The changes in moisture content of different banana cultivars during storage are shown in Fig. 1 and the polynomial regression is shown in Table 1. Raja and Ambon cultivars demonstrated the most pronounced moisture loss, as evidenced by their high-rate constants ($k = 0.8138$ and 0.8114) and steeper quadratic coefficients. This rapid moisture reduction can be attributed to their thinner peel structure and higher respiration rates, which accelerate transpiration and water loss (5). The higher k -values indicate that these cultivars undergo more dynamic physiological changes, leading to quicker texture softening and reduced firmness, ultimately making them more perishable. In contrast, Cavendish and Susu bananas showed the most gradual moisture decline, with the lowest k -values (0.1846 and 0.1892). This stability is likely due to their thicker peel and slower metabolic activity, which better preserve internal water balance and

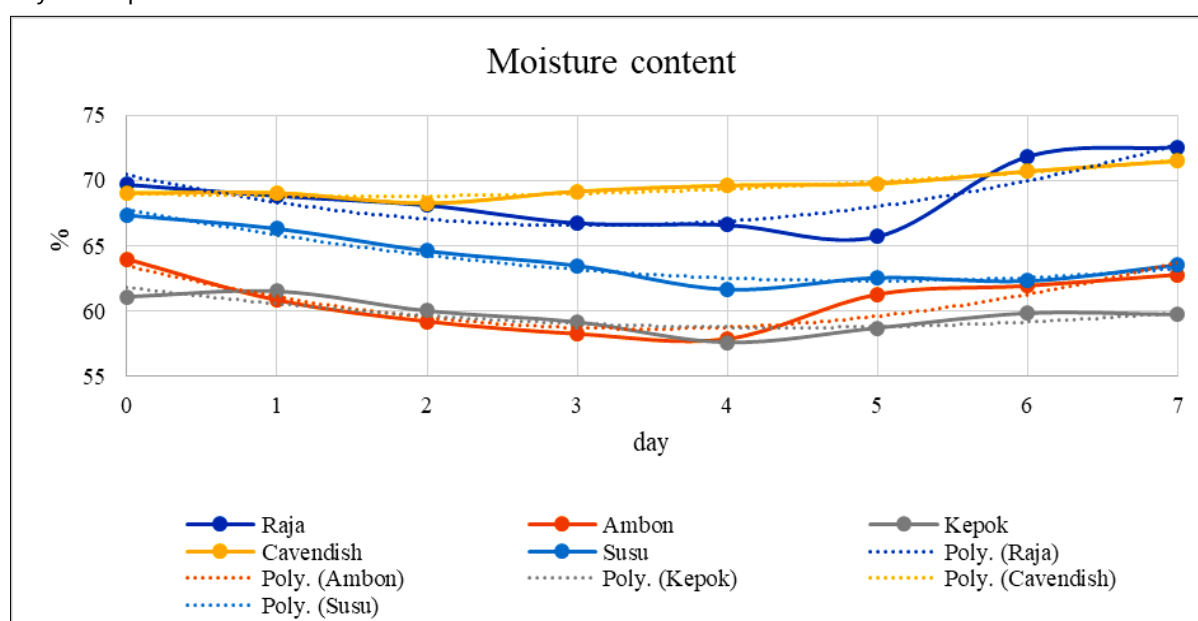


Fig. 1. Line chart of moisture content of five banana cultivars during 8 day storage at room temperature.

Table 1. Polynomial regression of moisture content of five banana cultivars during 8 day storage at room temperature.

Variety	Polynomial	R ²	dy/dx	k
Raja	$y = 0.4069x^2 - 2.5177x + 70.445$	0.7484	$0.8138x - 2.5177$	0.8138
Ambon	$y = 0.4057x^2 - 2.8048x + 63.491$	0.8327	$0.8114x - 2.8048$	0.8114
Kepok	$y = 0.1617x^2 - 1.1409x + 61.819$	0.6935	$0.3234x - 1.4109$	0.3234
Cavendish	$y = 0.0923x^2 - 0.2825x + 69.014$	0.9338	$0.1846x - 0.2825$	0.1846
Susu	$y = 0.2244x^2 - 2.2216x + 67.882$	0.9418	$0.4488x - 2.2216$	0.4488

extend shelf life (6). The slower rate of change (dy/dx) in these cultivars supports their suitability for longer storage and distribution cycles.

Kepok bananas exhibited intermediate behavior, with a moderate k-value (0.3234), suggesting a balanced rate of moisture loss. The differential moisture loss patterns among cultivars highlight the importance of cultivar-specific post-harvest management strategies. For instance, Raja and Ambon may benefit from modified atmosphere packaging or edible coatings to reduce water loss, whereas Cavendish and Susu may require less intervention under ambient conditions.

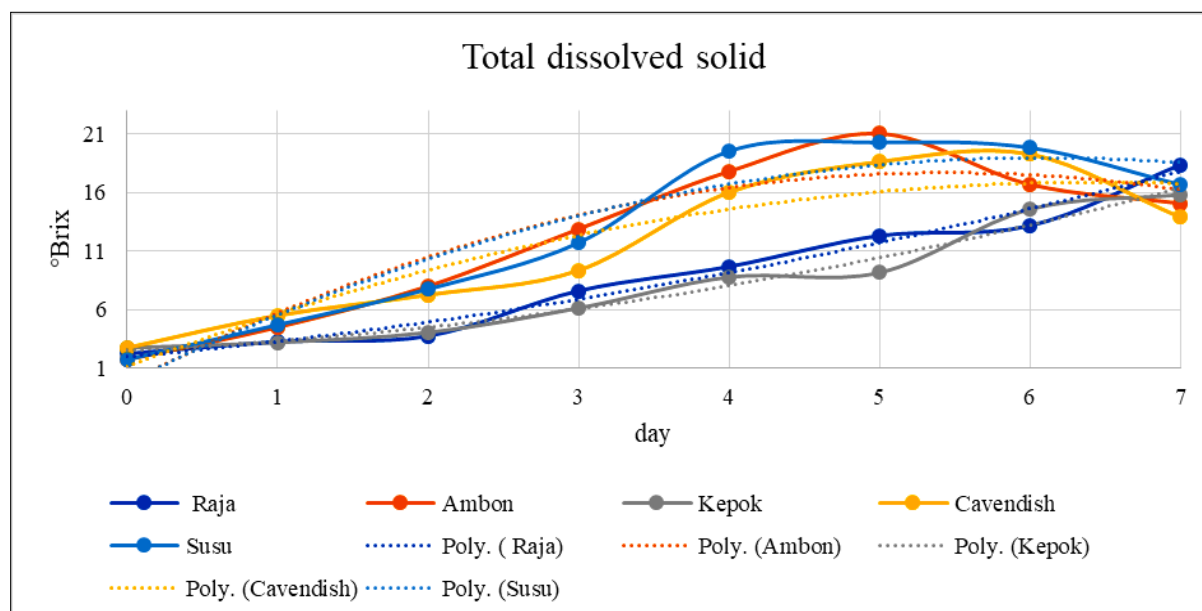
Total dissolved solids

The changes in TDS of different banana cultivars during storage are shown in Fig. 2 and the polynomial regression is shown in Table 2. All cultivars showed an overall increasing trend in TDS from day 0 to day 5, followed by a gradual decrease or plateau during the later days of storage. The highest TDS value was observed in the Ambon cultivar, which peaked at 21 °Brix on day 5, followed by Susu (20.25 °Brix), Cavendish (18.6 °Brix), Raja (12.3 °Brix) and Kepok (9.15 °Brix). The increase in TDS during the early storage period is primarily attributed to starch hydrolysis, whereby complex carbohydrates are enzymatically converted into soluble sugars such as glucose, fructose and sucrose, resulting in increased sweetness and soluble solids (7). Raja and Kepok exhibited positive k-values, indicating a more gradual increase in TDS throughout the storage period and

suggesting a slower ripening process than the other cultivars. After the banana reaches its maximum ripening stage (indicated by high °Brix values), the sugar content gradually declines due to ongoing metabolic processes, including respiration, fermentation, enzymatic degradation and microbial activity. TDS was found to decrease after the maturity period due to the increase in water content and the cessation of the starch hydrolysis process (8). Metabolomic studies on banana fruit have shown that after the stage of increasing soluble sugar concentration (TDS), these sugars are subsequently utilised through metabolic pathways such as respiration and are converted into organic acids, alcohols and other bioactive compounds during storage (9).

Peel colour

The changes in peel colour of different banana cultivars during storage are shown in Fig. 3–5 and the polynomial regression is shown in Table 3–5. Banana colour changes during storage are based on the L*a*b* value. The L* (Lightness) value in fruit quality evaluation is an important parameter for assessing changes in appearance, particularly brightness, over time. An increase in the L* value generally indicates that the fruit becomes brighter, which can correlate with the ripening process (10). Based on the data obtained, the Raja and Susu bananas experienced the most rapid colour darkening, as seen from a significant decrease in the L* value, as well as a rapid loss of yellow colour, reflected in a decrease in the b* value. A significant decrease in the L* value also indicates the beginning of

**Fig. 2.** Line Chart of total dissolved solids of five banana cultivars during 8 day storage at room temperature.**Table 2.** Polynomial regression of total dissolved solids of five banana cultivars during 8 day storage at room temperature.

Variety	Polynomial	R ²	dy/dx	k
Raja	$y = 0.1554x^2 + 1.1724x + 1.9679$	0.9775	$0.3108x + 1.1724$	0.3108
Ambon	$y = -0.604x^2 + 6.5838x - 0.27$	0.9105	$1.208x + 6.5838$	-1.208
Kepok	$y = 0.1995x^2 + 0.581x + 2.5271$	0.9739	$0.399x + 0.581$	0.399
Cavendish	$y = -0.376x^2 + 4.8614x + 1.1342$	0.8563	$0.752x + 4.8614$	-0.752
Susu	$y = -0.5161x^2 + 6.2923x - 0.2292$	0.9147	$1.0322x + 6.2923$	-1.0322

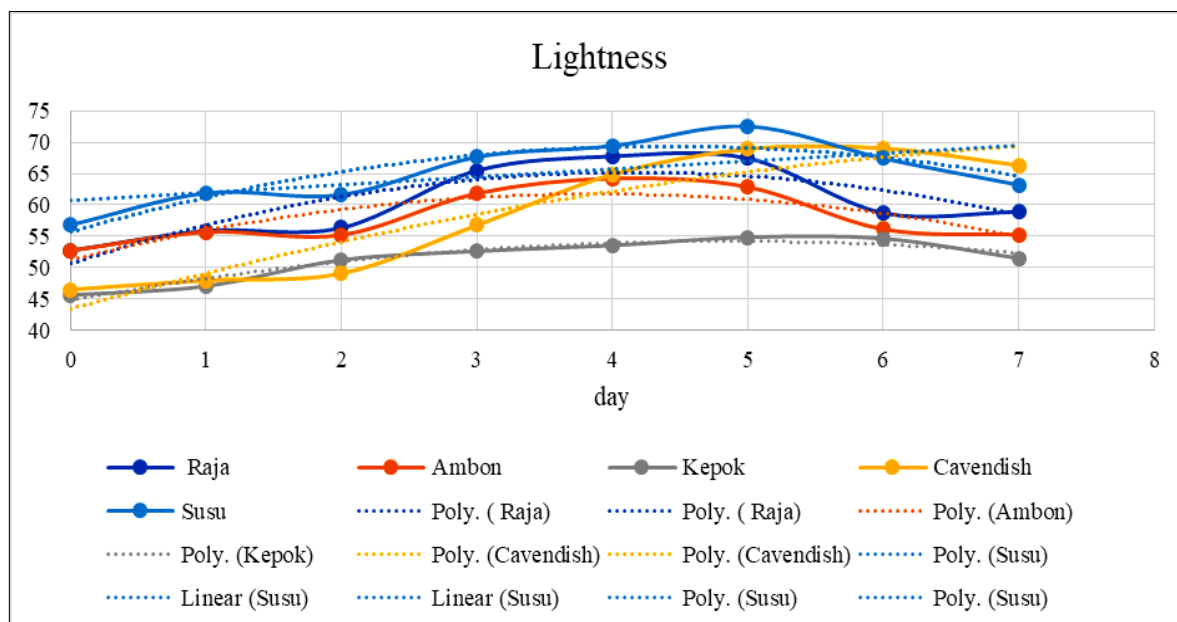


Fig. 3. Line chart of L* value peel colour of five banana cultivars during 8 day storage at room temperature.

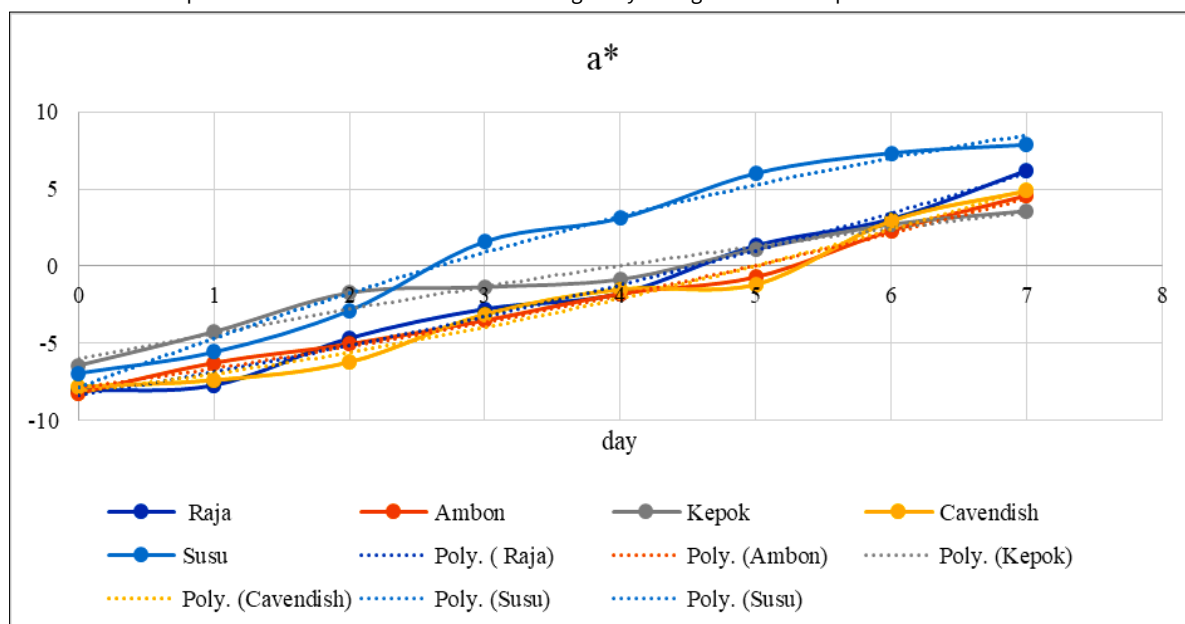


Fig. 4. Line chart of a* value peel colour of five banana cultivars during 8 day storage at room temperature.

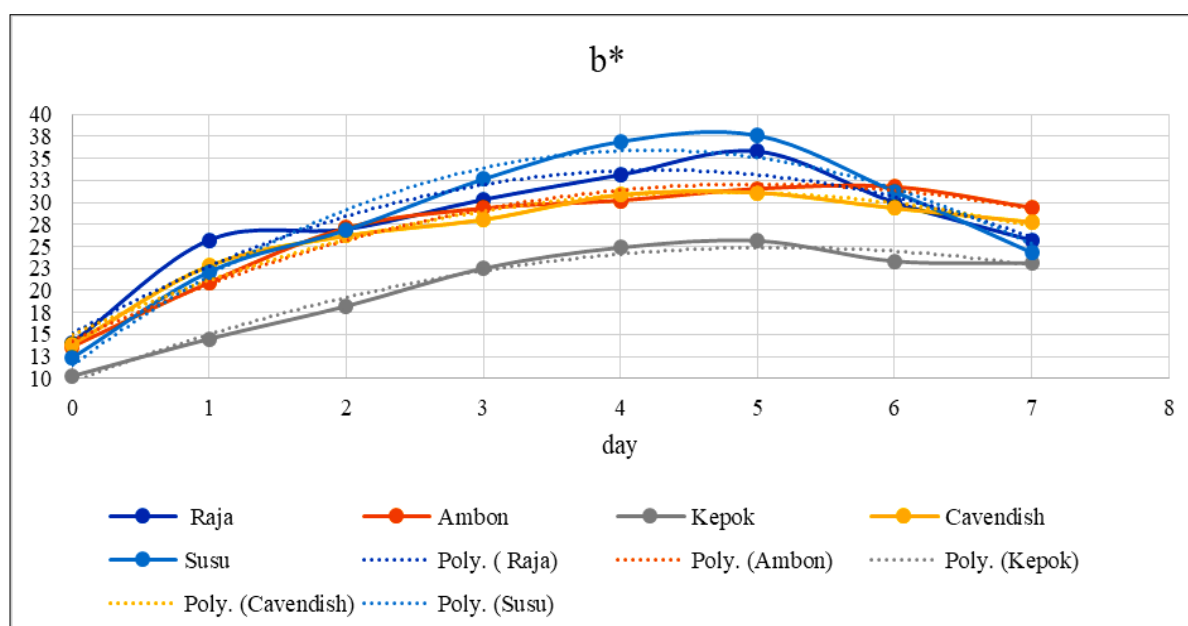


Fig. 5. Line chart of b* value peel colour of five banana cultivars during 8 day storage at room temperature.

Table 3. Polynomial regression of L* value peel colour of five banana cultivars during 8 day storage at room temperature.

Variety	Polynomial	R ²	dy/dx	k
Raja	$y = -0.8421x^2 + 7.0043x + 50.633$	0.7407	-1.6842x+7.0043	-1.6842
Ambon	$y = -0.6965x^2 + 5.4161x + 51.228$	0.7242	-1.3930x+5.4161	-1.3930
Kepok	$y = -0.4015x^2 + 3.8937x + 44.789$	0.9438	-0.8030x+3.8937	-0.8030
Cavendish	$y = -0.3295x^2 + 6.0171x + 43.392$	0.8933	-0.6590x+6.0171	-0.6590
Susu	$y = -0.7044x^2 + 6.2035x + 55.693$	0.8387	-1.4088x+6.2035	-1.4088

Table 4. Polynomial regression of a* value peel colour of five banana cultivars during 8 day storage at room temperature.

Variety	Polynomial	R ²	dy/dx	k
Raja	$y = 0.0898x^2 + 1.4274x - 8.3592$	0.9894	0.1796x+1.4274	0.1796
Ambon	$y = 0.0848x^2 + 1.158x - 7.8638$	0.9929	0.1696x+1.158	0.1696
Kepok	$y = -0.051x^2 + 1.7117x - 5.9946$	0.9723	-0.102x+1.7117	-0.102
Cavendish	$y = 0.1212x^2 + 1.0224x - 8.1167$	0.9771	0.2424x+1.0224	0.2424
Susu	$y = -0.1467x^2 + 3.3633x - 7.8825$	0.9809	-0.2934x+3.3633	-0.2934

Table 5. Polynomial regression of b* value peel colour of five banana cultivars during 8 day storage at room temperature.

Variety	Polynomial	R ²	dy/dx	k
Raja	$y = -1.0206x^2 + 8.7165x + 15.068$	0.9248	-2.0412x+8.7165	-2.0412
Ambon	$y = -0.7139x^2 + 7.1308x + 14.278$	0.9847	-1.4278x+7.1308	-1.4278
Kepok	$y = -0.5769x^2 + 5.9286x + 9.6483$	0.9803	-1.1538x+5.9286	-1.1538
Cavendish	$y = -0.7311x^2 + 6.8742x + 14.984$	0.9745	-1.4622x+6.8742	-1.4622
Susu	$y = -1.3758x^2 + 11.604x + 11.467$	0.9674	-2.7516x+11.604	-2.7516

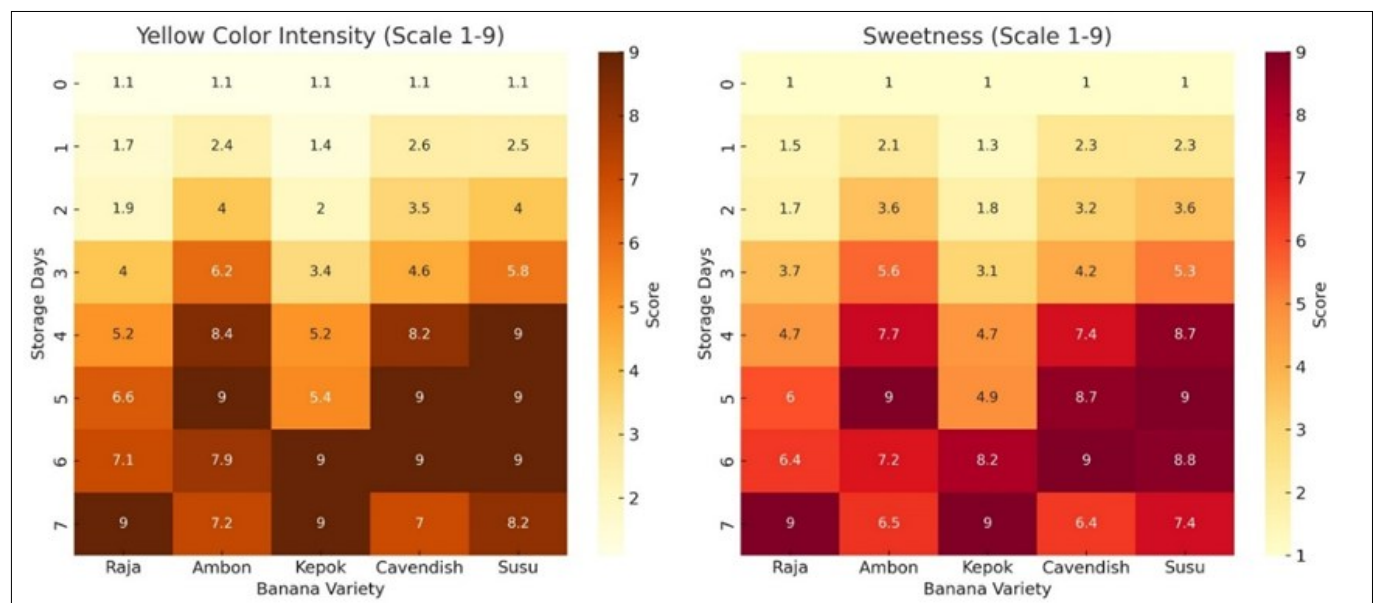
degradation processes such as browning and wilting. This darkening is often associated with a decline in fruit quality, where enzymatic reactions such as polyphenol oxidase activity cause browning, indicating overripe or early fruit decay (11). Meanwhile, the Susu cultivar exhibited an unusual decrease in the a* value, indicating an abnormal ripening process. In contrast, Cavendish bananas maintained their brightness well and exhibited the strongest red colour change, indicated by an increase in the a* value. Kepok bananas were the most colour-stable during storage, with the slowest browning and yellow colour loss. Meanwhile, Ambon bananas exhibited moderate colour change overall.

Banana ripening also involves complex physiological processes that result in colour changes, such as variations in a* (red-green chromaticity) and b* (yellow-blue chromaticity) values. An increase in the a* value indicates a transition from green to yellow and finally to a reddish hue during ripening, while the b* value indicates stability during storage. Physiological dynamics during ripening include chlorophyll degradation, which is associated with the appearance of black spots on the skin of Kepok bananas. Colour

changes in bananas are caused by the loss of chlorophyll and the appearance of other pigments, such as carotenoids, which give the fruit its yellow and red colours (12). The decrease in L* value after peak ripeness is caused by the enzymatic browning process triggered by the activity of polyphenol oxidase (PPO), which will form brown melanin pigment (13). Thus, changes in L*, a* and b* values during storage are closely related to the biochemical processes that occur in the fruit.

Intensity of colour and sweetness

The evaluation of yellow colour intensity and sweetness scores further shown in Fig. 6. The results confirm that each banana cultivar exhibits distinct ripening dynamics, reflected by changes in yellow colour and sweetness intensity throughout storage. Yellow colour intensity increased from an initial score of 1.0 to a maximum score of 9.0 during storage. Susu reached the highest yellow colour intensity earliest (day 4), followed by Ambon and Cavendish (day 5), Kepok (day 6) and Raja (day 7), indicating cultivar-dependent differences in the rate of peel yellowing during ripening. The increase in yellow colour intensity indicates chlorophyll degradation and the

**Fig. 6.** Intensity representation of five banana cultivars during 8 day storage at room temperature.

accumulation of carotenoid pigments, such as lutein and β -carotenoid, which are responsible for the characteristic yellow hue of ripe bananas (14). This transition occurred more rapidly in Susu, Ambon and Cavendish cultivars suggesting faster chlorophyll breakdown compared to Raja and Kepok cultivars. Similarly, the sweetness score increased from an initial score of 1.0 to a maximum score of 9.0 during the storage period. Ambon and Susu reached the highest sweetness scores earlier (day 5), followed by Cavendish (day 6), whereas Raja and Kepok attained the same score on day 7. The increase in sweetness is associated with starch hydrolysis and the conversion of polysaccharides into soluble sugars, such as glucose, fructose and sucrose (15). The rate of increase was cultivar dependent, with Ambon and Susu showing early peaks in sweetness, indicating faster enzymatic activity of amylase and invertase. While Raja and Kepok show a gradual rise, consistent with slower ripening kinetics. These results align with previous findings that post-harvest ripening behaviour and sensory attributes of bananas are strongly influenced by genetic differences among cultivars, which affect pigment metabolism and sugar accumulation rates during storage (1).

Conclusion

During eight days of storage at room temperature, all banana cultivars exhibited significant physicochemical changes associated with the ripening process. Moisture content, total dissolved solids (TDS) and peel colour parameters changed at different rates depending on the cultivar. Raja and Ambon showed the most rapid moisture changes, while Cavendish and Susu exhibited greater stability. The TDS generally increased during ripening due to starch hydrolysis, whereas peel colour shifted from green to yellow and gradually darkened during senescence. These findings demonstrate that cultivar characteristics strongly influence ripening behavior and post-harvest quality, highlighting the importance of cultivar-specific storage and handling strategies to optimise shelf life and reduce post-harvest losses.

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Authors' contributions

HBPP conceived the study, supervised the project and critically reviewed the manuscript. RZK developed the methodology and performed the data processing and statistical analyses. SD contributed to data interpretation, provided the theoretical framework and assisted in reviewing the manuscript. KWW, SK, SHR and MAA contributed to data collection and experimental work. KWW analysed and wrote the section on colour and sweetness intensity, SK analysed and wrote the section on moisture content, MAA analysed and wrote the section on peel colour and SHR analysed and wrote the section on total dissolved solids. All authors have read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: The authors do not have any conflict of interest to declare.

Ethical issues: None

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