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Physiochemical Responses of Raja Banana (Musa spp.) to Calcium Carbide and Desiccant Treatment

[1]Yasmin Aulia Rachma, [2]Ratih Paramastuti, [3]Swastika Dewi

[1 2 3] Food Technology, Faculty of Animal and Agricultural Sciences, Universitas Diponegoro, Semarang, Indonesia

ABSTRACT :

Raja banana (Musa spp.) is a climacteric fruit valued for its unique flavor, which is strongly influenced by ripening-induced changes in sugar and acid content. This study aimed to evaluate the effects of calcium carbide and silica gel treatments, combined with storage duration, on Total Dissolved Solids (TDS), total titratable acidity, and sugar–acid ratio during postharvest ripening. Bananas were treated with calcium carbide (1 g and 2 g per treatment) and silica gel (2 g and 4 g per treatment), and stored at ambient temperature for up to six days. The results showed that calcium carbide significantly accelerated ripening, as indicated by a sharp increase in TDS and sugar–acid ratio and a decrease in acidity. The 2 g calcium carbide treatment yielded the most pronounced changes. In contrast, silica gel treatments, particularly at 4 g, delayed ripening by maintaining lower sugar accumulation and more stable acidity levels. These findings suggest that calcium carbide is suitable for rapid ripening and enhanced flavor development, while silica gel can be used to extend shelf life in postharvest management.

Keywords: calcium carbide, postharvest ripening, Raja banana, silica gel, sugar–acid ratio.

Introduction

Banana (Musa spp.) is a climacteric fruit of significant economic and nutritional importance in tropical and subtropical regions, especially Indonesia. Globally ranked among the top five fruit commodities in production and consumption, bananas play a pivotal role in ensuring food security, supporting rural livelihoods, and contributing to local and international trade (Van den houwe et al., 2020). In Indonesia, the Raja banana cultivar holds cultural and commercial relevance due to its unique organoleptic attributes, including a distinctive aroma, firm yet tender pulp, and a balanced sweetness and acidity (Rachma & Darmanti, 2022). These features make Raja banana a preferred choice for direct consumption and processing, especially in traditional culinary preparations.

As with most climacteric fruits, bananas undergo a complex ripening process regulated by ethylene, a phytohormone that triggers a cascade of physiological and biochemical changes (Devi & Mirza, 2020). These include a transition in peel color from green to yellow, textural softening due to pectin degradation, conversion of starch into soluble sugars, respiration-driven loss of organic acids, and the development of characteristic volatile compounds (Devi & Mirza, 2020; Watharkar et al., 2020). While these changes enhance the fruit's sensory quality and market appeal, they also render it highly perishable, leading to rapid postharvest deterioration if not carefully managed (Ayo et al., 2020; Moreno et al., 2021). Consequently, the ability to control or modulate the ripening process is critical in postharvest technology to reduce losses and extend shelf life.

In response to this challenge, various ripening techniques have been adopted to influence the speed and extent of banana ripening. One such method involves using calcium carbide, a chemical ripening agent widely employed in commercial supply chains due to its cost-effectiveness and ease of application (Cissé et al., 2020; Gomes et al., 2023). Upon contact with moisture, calcium carbide liberates acetylene gas, which acts as an ethylene analogue, stimulating ripening by inducing ethylene-responsive gene expression (Gomes et al., 2023; Khairi et al., 2022). Despite its efficacy, the use of calcium carbide is not without controversy, as concerns persist regarding its impact on fruit safety, uniformity, and biochemical quality parameters (Cissé et al., 2020; Ogoun & Ayawei, 2022). Alternatively, passive methods such as the application of silica gel, a hygroscopic desiccant, have been explored for their potential to delay ripening by altering the storage microclimate. Silica gel reduces relative humidity and slows ethylene diffusion and action, thus providing a low-tech means of ripening suppression (Ebrahimi et al., 2022).

Key quality parameters that reflect bananas' physiological status and market readiness include Total Dissolved Solids (TDS), total titratable acidity, and the sugar–acid ratio. TDS serves as an indirect measurement of soluble sugar content, providing insight into sweetness and energy density (Thomason & Bialkowski, 2019). Total titratable acidity reflects the concentration of organic acids such as malic and citric acids, which contribute to the fruit's tartness and participate in respiration and flavor development (Jia et al., 2023). The sugar–acid ratio integrates these two dimensions as a sensory benchmark for flavor acceptability. Understanding the interactions between ripening agents, storage duration, and these critical quality indices is essential for designing effective postharvest protocols that optimize eating quality while minimizing spoilage.

Despite the widespread use of calcium carbide in ripening management and the growing interest in alternative physical treatments such as silica gel, comparative data on their physicochemical impact on Raja banana during storage remain limited. Therefore, this study aims to evaluate the influence of calcium carbide application and storage time on the TDS, total acidity, and sugar–acid ratio in Raja banana fruit. The findings are expected to provide valuable insights into postharvest treatment optimization, contributing to improved fruit quality, extended shelf-life, and informed decision-making in banana supply chain management.

Materials and Methods

1.1. Plant Material and Experimental Design

Mature-green Raja bananas (Musa spp.) were harvested from a commercial farm [Semarang, Central Java, Indonesia]. Fruits were selected for uniformity in size, shape, physiological maturity (approximately 85–90% maturity), and the absence of physical defects or fungal contamination. After harvest, fruits were transported under ambient conditions (~26°C, 65–75% RH) to the Food Processing Laboratory, Faculty of Animal and Agricultural Sciences, Universitas Diponegoro.

The study employed a completely randomized design (CRD) with four postharvest treatment groups and four sampling intervals (0, 2, 4, and 6 days). The treatment groups included T1: Calcium carbide 1 g per treatment; T2: Calcium carbide 2 g per treatment; T3: Silica gel 2 g per treatment; T4: Silica gel 4 g per treatment. Each treatment was replicated three times, with each replicate consisting of three banana fingers placed in ripening chambers (plastic containers, 30 × 20 × 15 cm). Calcium carbide and silica gel were enclosed in perforated paper sachets and placed in the chamber without direct contact with the fruit. All fruits were stored at ambient temperature (26 ± 2°C) and monitored under controlled room conditions without additional light or airflow.

1.2. Measurement of Total Dissolved Solids (TDS)

TDS was measured using a digital handheld refractometer (Atago PAL-1, Japan). Approximately 2–3 mL of juice was extracted from the homogenized pulp and placed on the refractometer prism. The TDS value was recorded in degrees Brix (°Brix) and measured in triplicate.

1.3. Determination of Total Titratable Acidity

Total titratable acidity (TTA) was determined following AOAC (2005) guidelines. A 10 g portion of banana pulp was homogenized with 50 mL distilled water, filtered, and titrated with standardized 0.1 N NaOH using phenolphthalein as an indicator. Results were expressed as a percentage of citric acid equivalents (% citric acid).

1.4. Calculation of Sugar–Acid Ratio

The sugar–acid ratio was calculated as the quotient of TDS (°Brix) and total acidity (% citric acid), providing a dimensionless index that reflects the sweetness-to-acidity balance, which is a critical sensory parameter in banana quality evaluation.

1.5. Statistical Analysis

All data were subjected to analysis of variance (ANOVA) using SPSS statistical software (IBM Corp., Armonk, NY, USA). When significant differences were found ($p < 0.05$), treatment means were compared using Duncan's Multiple Range Test (DMRT). Data are presented as mean ± standard deviation (SD). Differences among means were considered significant when $p < 0.05$.

Results and Discussion

1.6. The Total Dissolved Solids (TDS) (°Brix)

The Total Dissolved Solids (TDS), measured in degrees Brix (°Brix), represent the concentration of soluble sugars such as glucose, fructose, and sucrose in the banana pulp, which increased markedly during ripening due to starch degradation. The TDS value can be seen in Table 1. In this study, TDS values increased significantly across all treatments, with calcium carbide-treated fruits exhibiting the most rapid and substantial rise. The 2 g calcium carbide group achieved the highest TDS (26.33 ± 3.78 °Brix) by day 6, followed closely by the 1 g treatment. Calcium carbide releases acetylene upon contact with moisture, which functions analogously to ethylene, a critical hormone in climacteric fruit ripening (Gomes et al., 2023). Ethylene activates key ripening-related enzymes, including amylase and invertase, which catalyze the hydrolysis of starch into soluble sugars (Y. Tian et al., 2023; Xia et al., 2020a). This biochemical activity explains the sharp increase in °Brix in calcium carbide-treated bananas, and the greater magnitude observed in the 2 g treatment supports the hypothesis of a dose-dependent effect on ethylene stimulation and metabolic acceleration.

Table 1. TDS Value of Raja Banana between Treatments

Treatment	**Day**			
	0	**2**	**4**	**6**
Calcium Carbide 1 gr	**$3.33±1.53^{aD}$**	**$17.00±4.36^{aC}$**	**$22.67±0.57^{aB}$**	**$24.00±1.00^{aA}$**
Calcium Carbide 2 gr	**$3.00±1.00^{aD}$**	**$16.67±1.53^{aC}$**	**$22.00±2.00^{aB}$**	**$26.33±3.78^{aA}$**
Silica Gel 2 gr	**$4.00±0.00^{bD}$**	**$13.67±1.15^{bC}$**	**$19.67±2.08^{bB}$**	**$21.33±0.57^{bA}$**
Silica gel 4 gr	**$2.33±0.57^{cD}$**	**$11.67±4.04^{cC}$**	**$15.00±1.73^{cB}$**	**$18.00±1.00^{cA}$**

*Data are presented as mean ± standard deviation (n = 3). *Different superscripts in the same column and row indicate significant differences ($p < 0.05$) between treatment (lower case) and day (upper case).*

In contrast, fruits treated with silica gel showed a significantly slower accumulation of soluble solids, especially at the 4 g dosage. The final TDS of this group remained the lowest (18.00 ± 1.00 °Brix), reflecting a substantial delay in sugar synthesis. Silica gel's hygroscopic nature likely reduced the ambient humidity in the storage environment, thereby suppressing both endogenous ethylene production and the diffusion of ethylene gas within fruit tissues (Al-Obaidi et al., 2022; You et al., 2022). This reduction in ethylene bioavailability would limit the activation of ripening-related metabolic pathways, including enzymatic starch hydrolysis (Asrey et al., 2023). Furthermore, lower humidity conditions may impair the activity of hydrolase enzymes by limiting the availability of free water necessary for biochemical reactions (Koo et al., 2020). These findings agree with Modified Atmosphere Storage (MAS) principles, where reduced moisture and ethylene are employed to slow down physiological ageing and ripening in climacteric fruits (Ramiro et al., 2024).

The statistical differences observed among treatments at each time point affirm the strong influence of ripening agents on TDS dynamics. The sharp increase in TDS in calcium carbide groups aligns with expected ethylene-driven ripening physiology. It is also correlated with improved sensory attributes such as sweetness and flavor (Wang et al., 2018). However, using calcium carbide as a ripening agent must be cautiously approached due to food safety concerns arising from possible arsenic or phosphine residue contamination (Ikhajiagbe et al., 2022). Meanwhile, the delaying effect of silica gel suggests its potential for use in postharvest strategies aiming to extend shelf life and control market timing (Brindisi & Simon, 2023). In summary, manipulating TDS through ripening agents offers practical value for postharvest management, with calcium carbide enhancing sugar accumulation and silica gel effectively decelerating ripening under controlled storage conditions.

1.7. Total Acid

Total acidity, typically expressed as a percentage of titratable acidity, reflects the concentration of organic acids such as malic, citric, and oxalic acids in banana fruit (Zakharova et al., 2011). Table 2 shows the Total Acid of Raja banana between treatments. These acids play an essential role in determining fruit flavor, contributing to the sourness that balances sweetness. In this study, total acidity generally showed a decreasing trend during storage, particularly in bananas treated with calcium carbide. Fruits subjected to 1 g and 2 g of calcium carbide experienced a marked and significant reduction in acidity from day 0 to day 6, with final values of 0.96 ± 0.28% and 1.02 ± 0.18%, respectively. This decline is consistent with the natural progression of climacteric fruit ripening, during which organic acids are metabolised through the tricarboxylic acid (TCA) cycle to provide energy for ripening-related physiological processes (Batista-Silva et al., 2018). Moreover, ethylene-induced respiratory bursts accelerate acid catabolism, further explaining the substantial reduction observed in the calcium carbide groups (Gan et al., 2021).

Table 2. Total Acid of Raja Banana between Treatments

Treatment	**Day**			
	0	**2**	**4**	**6**
Calcium Carbide 1 gr	**1.66 ± 0.27^{aA}**	**1.32 ± 0.16^{aAB}**	**1.10 ± 0.33^{aB}**	**0.96 ± 0.28^{aB}**
Calcium Carbide 2 gr	**1.94 ± 0.06^{aA}**	**1.40 ± 0.41^{aAB}**	**1.30 ± 0.12^{aB}**	**1.02 ± 0.18^{aB}**
Silica Gel 2 gr	**1.10 ± 0.07^{aA}**	**1.11 ± 0.10^{aAB}**	**1.01 ± 0.09^{aB}**	**1.27 ± 0.55^{aB}**
Silica Gel 4 gr	**1.33 ± 0.55^{aA}**	**1.30 ± 0.55^{aAB}**	**1.29 ± 0.54^{aB}**	**1.27 ± 0.52^{a}**

*Data are presented as mean ± standard deviation (n = 3). *Different superscripts in the same column and row indicate significant differences ($p < 0.05$) between treatment (lower case) and day (upper case).*

In contrast, the acidity values in fruits treated with silica gel remained relatively stable throughout the storage period, with no statistically significant changes across days. The 2 g and 4 g silica gel treatments maintained acid levels between 1.10% and 1.30%, suggesting a significant retardation of acid metabolism. This phenomenon can be attributed to the desiccant properties of silica gel, which lower the relative humidity of the storage environment, thereby slowing ethylene action and respiratory activity (Calvo-Polanco et al., 2017; Sängerlaub et al., 2019). Ethylene signaling, which is central to ripening, is sensitive to gas diffusion and tissue hydration (Tipu & Sherif, 2024). In drier conditions, the production and effectiveness of ethylene are impaired, limiting the activation of enzymes responsible for organic acid degradation. Furthermore, limited water availability may directly constrain the enzymatic processes required for the biochemical conversion of acids, thus preserving acidity levels in silica gel-treated bananas (Zhao et al., 2023).

These contrasting patterns between treatments highlight the role of ethylene and environmental conditions in modulating acid metabolism during fruit ripening (Brindisi & Simon, 2023). The rapid acid degradation in calcium carbide-treated bananas aligns with increased metabolic turnover associated with accelerated ripening (Loupatty et al., 2023). At the same time, the delayed decline in the silica gel groups reflects suppressed physiological activity. Although acidity reduction contributes to improved sweetness perception, maintaining a balanced acid profile is critical for achieving optimal flavor and postharvest quality (Painda et al., 2022). The findings suggest that ripening agents influence sugar development and play a decisive role in modulating acidity, thereby altering the sensory profile and shelf-life of bananas (Tian et al., 2021). Therefore, understanding and controlling acidity dynamics through postharvest treatments can provide practical benefits for both quality control and commercial distribution of climacteric fruits such as Raja banana.

1.8. Sugar Acid Ratio

The sugar–acid ratio is a critical index for evaluating fruit flavour quality, as it integrates the effects of sweetness and sourness into a single parameter that reflects overall palatability (Mao et al., 2024). This ratio typically increases in climacteric fruits such as bananas as ripening progresses due to simultaneous sugar accumulation and acid degradation. The sugar acid ratio in this study is shown in Table 3. In the present study, bananas treated with calcium carbide exhibited the most pronounced and statistically significant sugar–acid ratio increases during storage. The 1 g and 2 g calcium carbide treatments showed dramatic elevations from initial values of 3.15 and 1.56 to 26.51 and 26.84, respectively, by day 6. These sharp increases are attributable to ethylene-induced stimulation of metabolic processes, including enzymatic starch hydrolysis and organic acid respiration. Ethylene enhances the activity of enzymes such as amylase and invertase, leading to increased sugar levels, while simultaneously promoting the catabolism of organic acids via the TCA cycle (Xia et al., 2020b). The resulting effect is a steep rise in the sugar–acid ratio, contributing to a sweeter, more desirable sensory profile.

Table 3. Sugar Acid Ratio of Raja Banana Between Treatments

Treatment	**Day**			
	0	**2**	**4**	**6**
Calcium Carbide 1 gr	**3.15 ± 1.34^{aC}**	**13.05 ± 4.02^{aB}**	**22.78 ± 8.74^{aA}**	**26.51 ± 7.34^{aA}**
Calcium Carbide 2 gr	**1.56 ± 0.56^{aC}**	**12.77 ± 4.28^{aB}**	**17.59 ± 3.36^{aA}**	**26.84 ± 7.77^{aA}**
Silica Gel 2 gr	**3.79 ± 0.25^{abC}**	**12.37 ± 0.70^{abB}**	**19.51 ± 2.63^{abA}**	**18.75 ± 6.72^{abA}**
Silica gel 4 gr	**1.96 ± 0.82^{bC}**	**9.26 ± 1.11^{bB}**	**13.12 ± 5.45^{bA}**	**16.31 ± 7.88^{bA}**

*Data are presented as mean ± standard deviation (n = 3). *Different superscripts in the same column and row indicate significant differences ($p < 0.05$) between treatment (lower case) and day (upper case).*

On the other hand, bananas treated with silica gel, particularly at the 4 g dose, exhibited a consistently lower sugar–acid ratio throughout the storage period. Although the ratio gradually increased from 1.96 to 16.31 over six days, it remained significantly below the values recorded in the calcium carbide-treated groups. This lower ratio can be attributed to the slower rate of sugar accumulation coupled with the preservation of acidity, both of which result from the delayed ripening caused by reduced moisture levels. The hygroscopic properties of silica gel decrease ambient humidity, suppressing ethylene production and activity. This inhibition of the ethylene signalling pathway interferes with the activation of genes responsible for sugar biosynthesis and acid catabolism, ultimately slowing the development of flavor. Notably, the 2 g silica gel treatment produced a slightly higher sugar–acid ratio compared to the 4 g treatment, indicating that ripening suppression may be dose-dependent on the level of environmental dryness (Zenoni et al., 2020). These results clearly demonstrate the sugar–acid ratio's dual dependence on biochemical and environmental factors that influence postharvest ripening dynamics. Treatments that accelerate ripening, such as calcium carbide, enhance the ratio by rapidly shifting the biochemical balance toward sweetness, whereas treatments that retard ripening, like silica gel, maintain a lower ratio and preserve fruit in a less mature state. The sugar–acid ratio serves as a reliable marker of fruit maturity (Phan et al., 2020). It provides a basis for predicting consumer acceptability, since a higher ratio is generally associated with improved flavour quality. From a postharvest management perspective, modulating the sugar–acid ratio through external treatments offers a practical tool for targeting specific market preferences and optimizing fruit quality during distribution. These findings underscore the importance of treatment selection in shaping the flavour profile and commercial readiness of Raja banana during storage.

Conclusion

This study confirmed that calcium carbide significantly accelerated the ripening of Raja bananas, as shown by higher Total Dissolved Solids (TDS), reduced total acidity, and increased sugar–acid ratio, with the 2 g dose producing the most pronounced effects. In contrast, silica gel delayed ripening by maintaining lower TDS and stable acidity, especially at the 4 g dose. These results highlight the potential of calcium carbide for rapid ripening and improved flavor, while silica gel is more suitable for extending shelf-life in postharvest handling.

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