

# Food Safety and Ripening Dynamics of Bananas and Plantains Treated with Chemical and Natural Agents

Samuel A. Akande, Titilope A. Fashanu, Israel O. Lawal, Akudo F. Onyegbula, and Eunice I. Bamishaiye

Perishable Crops Research Department, Nigerian Stored Products Research Institute, Ilorin, Kwara State, Nigeria.

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## CORRESPONDING AUTHOR

**Titilope A. Fashanu**

Perishable Crops Research Department,  
Nigerian Stored Products Research  
Institute (NSPRI), Ilorin, Kwara State,  
Nigeria.

titifashanu@gmail.com

+234-8066356597

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## Abstract

*The use of calcium carbide (CaC<sub>2</sub>) as a fruit ripening agent has been associated with the presence of various pollutant indices, which include phosphorus. This study evaluated the effects of three ripening agents: CaC<sub>2</sub>, African bush mango (ABM), and ethanol, on the ripening time and safety of banana and plantain. Two sample groups were examined: retailers' and intermediaries' fruit handlers. Six lots of banana and plantain were treated with CaC<sub>2</sub> (1 g, 2 g, and 5 g per 2 kg fruit), ABM, ethanol, and control. After treatments, they were divided into washed and unwashed sub-groups, peeled, and dried using the Nigerian Stored Products Research Institute's Parabolic Shaped Solar Dryer. Sensory evaluation was conducted on banana and plantain immediately after ripening, while phosphorus analysis was carried out on the dried samples following standard procedures. Results revealed that bananas treated with CaC<sub>2</sub> ripened in three days, while those treated with ABM and ethanol became fully ripe in five days. Plantains treated with CaC<sub>2</sub>, ABM, and ethanol became ripe in 5 days, while the control banana and plantain did not ripen during these 5 days. Phosphorus content of banana samples from retailers ranged from 7.296 to 12.544 mg/kg, while that of plantains ranged from 5.819 to 9.400 mg/kg. For middle holders' samples, phosphorus content ranged from 6.064 to 12.163 mg/kg and 6.881 to 15.293 mg/kg for banana and plantain, respectively. The findings in this study showed no statistical differences in the treatments of banana and plantain with respect to different ripening agents and washing.*

## Keywords:

Artificial ripening agents, banana, ethylene, plantain, Food safety

## Introduction

Ripening is a natural process in fruits that involves a series of irreversible physiological and biochemical activities leading to changes in physical appearance and chemical composition of the fruits. It is also coincidentally occurring with an increase in the rate of respiration of fruits and production of ethylene gas, which promotes the conversion of fruit's starch to sugar and consequently changes in taste (Adekalu et al., 2020). Artificial ripening agents are also used to simulate the natural phenomenon of ethylene passing over the fruits to hasten ripening using calcium carbide (CaC<sub>2</sub>). According to previous research by Nura et al. (2018), artificially ripened fruits, especially those treated with chemical methods, may develop a uniform and attractive surface colour. Still, the flesh inside often remains green (unripe), resulting in a generally shorter shelf life. The industrial-grade CaC<sub>2</sub> commonly used by fruit handlers frequently contains traces of impurities, such as calcium arsenide (Ca<sub>3</sub>As<sub>2</sub>) and calcium phosphide (Ca<sub>3</sub>P<sub>2</sub>) (Ismail et al., 2019). When these impurities interact with water, they produce phosphine (PH<sub>3</sub>) and arsine (AsH<sub>3</sub>). These substances are hydrides soluble in fats and can dissolve in the waxy layer of the fruit's peel, subsequently migrating into the flesh and posing potential health hazards (Kesse et al., 2019). One of the ways to establish if a particular

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fruit has been forced-ripe with  $\text{CaC}_2$  is to analyse the components for arsenic and/or phosphorus (Igbinauwa et al., 2018). Further,  $\text{CaC}_2$  used in fruit ripening can lead to phosphorus and other toxic compounds, posing health risks such as organ toxicity and hematopoietic derangement. Studies have shown that calcium carbide can cause liver and kidney damage, as well as anaemia and leukopenia in animal models (Doshi & Wish, 2022). Phosphorus in calcium carbide can exacerbate these health risks, as phosphorus is known to contribute to cardiovascular diseases, especially in patients with chronic kidney disease. Various other chemical and non-chemical alternatives to artificial ripening agents have been reported; these chemicals include: ethephon (2-chloroethylphosphonic acid), oxytocin, ethylene glycol ( $\text{C}_2\text{H}_6\text{O}_2$ ), ethanol, methanol, propylene, and methyl jasmonate (Adeyemi et al., 2018; Igbinauwa et al., 2018; Maduwanthi & Marapana, 2019; Adekalu et al., 2020). The non-chemical methods mentioned in literature and/or among handlers include: ripe fruits of bush mango, also known as African bush mango (ABM), orange, ripe banana or plantain, apple, red hot pepper (fresh or dried), and ripe banana (Sogo-Temi et al., 2014; Surbhi et al., 2016). Although most marketers denied using chemical ripening agents (Adekalu et al., 2020), the importance of safe handling practices, particularly washing, cannot be overlooked in maintaining consumer health and product quality. Washing of fruits and vegetables is one of the essential operations in post-harvest management and handling to remove or reduce dirt and field debris, microbial load, chemical residues, improvement of appearance, prevention of cross contaminations and preparation for further treatments of fruits and vegetables (Mishra et al., 2018; Rao & Ravishankar, 2019; Kaushik et al., 2020; Organization, 2023; Lalpekhlua et al., 2024). Washing was introduced in this study to decontaminate bananas and plantain from possible chemical residues on the surface of the produce after treatment (Pokhrel, 2020; Shakeel et al., 2022). This study was designed to compare the performance of a local method (ABM), food-grade ethanol, a generally regarded as safe (GRAS) compound, and  $\text{CaC}_2$  as artificial ripening agents for banana and plantain, and evaluate the effects of washing after treatment on the phosphorus contents of both peel and pulp of banana and plantain samples.

## Materials and Methods

### Chemicals used

Ethanol used in this work was food-grade. Other chemicals, such as ammonium molybdate,

hydrochloric acid, ammonium vanadate, potassium dihydrogenphosphate (standard phosphate solution), and ascorbic acid, were of analytical grade and were purchased from accredited dealers.

### Sample collection and treatment

Two sets of samples were purchased: green banana, green plantain, ripe banana, and ripe plantain, which were procured from retailers in Ganmo market, Ilorin, Kwara State, Nigeria. The second set of samples consisted of only green bananas and plantain purchased from the middle holder (for ripening trial) from the above location. Both samples were transported to the Central Laboratory, Nigerian Stored Products Research Institute (NSPRI), Ilorin, Kwara State, Nigeria. In the laboratory, samples obtained from retailers were divided into two groups (washed and unwashed), peeled, and then dried separately using the NSPRI Parabolic Shaped Solar Dryer (PSSD). The dried peels and pulps were kept airtight until needed for phosphorus analysis.

The middle holders' samples were divided into seven lots of 2 kg each (both banana and plantain). The first was not treated with any artificial ripening agents (negative control) but was peeled and dried to obtain its peel and pulp alongside other samples. The remaining six lots were treated with different artificial ripening agents as follows: sample A (positive control), B was treated with ABM (120 g), C was treated with ethanol (500 mL) by dipping, D was treated with 1g of  $\text{CaC}_2$ , E was treated with 2 g of  $\text{CaC}_2$ , and F was treated with 5 g  $\text{CaC}_2$ . The carbide was wrapped in moist tissue paper and kept at the bottom of the bowl. The layout of treatment is shown in Table 1. Each treatment was packed in a 10-litre plastic bowl after being wrapped with brown paper. The  $\text{CaC}_2$ -treated samples were placed in a separate room to avoid diffusion of acetylene gas ( $\text{C}_2\text{H}_2$ ) into the non-treated (control) and other samples. The room's conditions were monitored with a data logger (TEMLOG 20H) to evaluate the differences (if any) in temperature and humidity. The ripening process was monitored daily to observe the colour and texture changes of the banana and plantain. The ripening time of the fruit was evaluated as the period for the fruits to completely change from green to yellow colour and/or change in texture (Adeyemi et al., 2018). After five (5) days of treatment, lots were opened and fingers were randomly selected from each treatment and presented to panelist members for sensory analysis. The treatments were divided into two lots (washed and unwashed), peeled, and dried using NSPRI's PSSD.

The dried peels and pulps were also airtight until phosphorus analysis was needed. Washing was used in this study to reduce or remove chemical residues that might result from using  $\text{CaC}_2$  (Rowe, 2007; Pokhrel, 2020; Shakeel et al., 2022).

### Sensory Evaluation

The sensory attributes were evaluated on the banana and plantain lots immediately after ripening to assess skin colour, fruit's firmness, appearance, odour, and overall acceptability using 20 semi-trained panelist members on a five-point hedonic scale (Berdos et al., 2021). The description of various scales used for different attributes is presented in Table 2.

### Phosphorus Analysis

Phosphorus content was determined by the molybdate colourimetric methods after dry ashing (Pulliainen & Wallin, 1996). The determination of phosphorus content using molybdate colourimetric methods involves the formation of a colored complex between

phosphorus and molybdate ions, which can be measured spectrophotometrically (Gupta et al., 1993; Pulliainen & Wallin, 1996; Sun et al., 2024). Briefly, the sample is dry-ashed to remove organic material. The acid-soluble inorganic residue is used for a colour reaction based on the formation of a blue complex  $[(\text{MoO}_2-4\text{MoO}_3)_2-\text{H}_3\text{PO}_4]$  between phosphate and sodium molybdate in the presence of ascorbic acid as a reducing agent. Intensity of blue colour is measured spectrophotometrically at  $823 \pm 1$  nm using a UV-visible spectrophotometer (SEARCHTECH: UV1902PC) (Pulliainen & Wallin, 1996).

### Data Analysis

Values were expressed as mean  $\pm$  SD of triplicate readings. The data collected were analysed using a One-way Analysis of Variance (ANOVA) with the SPSS Software Package Version 20.0.0 (IBM Statistics Inc.). Means comparison was done through the use of New Duncan Multiple Range F-Test (DMRT) at a confidence level of 95% ( $p \leq 0.05$ ).

**Table 1: Sample treatment (middle holder)**

Sample	Treatment	Banana (kg)	Sample	Treatment	Plantain (kg)
A1	No treatment (Control)	2	A2	No treatment (Control)	2
B1	Bush mango fruit (120 g)	2	B2	Bush mango fruit (120 g)	2
C1	Ethanol (dipping)	2	C2	Ethanol (dipping)	2
D1	1 g $\text{CaC}_2$	2	D2	1 g $\text{CaC}_2$	2
E1	2 g $\text{CaC}_2$	2	E2	2 g $\text{CaC}_2$	2
F1	5 g $\text{CaC}_2$	2	F2	5 g $\text{CaC}_2$	2

**Table 2: Description of 5-point hedonic sensory scales**

Scale	Colour	Appearance	Firmness/Texture	Odour	Overall Acceptability
1	Green	Dislike extremely	Very mushy	Strongly unpleasant	Dislike extremely
2	Slightly yellow or blotchy	Dislike moderately	Too soft	Off-smell	Dislike moderately
3	Mixed green/yellow	Neither like nor dislike	Average	Neutral	Neither like nor dislike
4	Mostly yellow with green spots	Like moderately	Slightly soft but acceptable	Mild	Like moderately
5	Bright yellow	Like extremely	Firm but tender	Strong or pleasant	Like extremely

## Results and Discussion

### Effect of artificial ripening agents on the ripening time of banana and plantain

The effect of ripening agents on the ripening time of banana and plantain is shown in Table 3. The results showed that the ripening time for bananas and plantains ranged from 3 to 5 days, while the control did

not ripen within five days. Banana samples treated with bush mango and ethanol ripened in five days, while those treated with  $\text{CaC}_2$  ripened in three days. All the plantain samples treated with bush mango, ethanol, and calcium carbide ripened in five days. These observations agreed with the findings in the literature (Sogo-Temi et al., 2014), which states that the ripening time of bananas treated with calcium carbide or potash

is three (3) days. However, a research paper reported a lower ripening time of two days when 10 g CaC<sub>2</sub> per kg of banana was used (Adeyemi et al., 2018).

### Effects of different ripening agents on the sensory attributes of ripe banana and plantain

The sensory properties of banana and plantain immediately after ripening are presented in Table 4. The results showed ratings for colour, appearance, firmness, odour, and overall acceptability ranged from 1.58 to 3.83, 3.11 to 4.00, 1.72 to 3.67, 3.67 to 4.67, and 3.17 to 4.00, respectively. Plantains treated with CaC<sub>2</sub> (1 g, 2 g, and 5 g) had more acceptability in colour, appearance, and texture, while there were no significant differences in odour and overall acceptability of banana and plantain. It was observed

that the results of ripening time (Table 3) and the sensory scores were not in agreement. This is probably due to the effect of forced ripening on the banana and plantain. Treated samples, particularly plantains, exhibited external ripening as indicated by their surface colour, yet their texture remained firm, suggesting incomplete internal ripening even after exposure to CaC<sub>2</sub> for five days. This observation aligns with the findings of Nura et al. (2018), who reported that artificially ripened fruits, especially those subjected to chemical agents, often display uniform and visually appealing external colouration while the internal tissues remain physiologically unripe, thereby compromising fruit quality, which typically leads to a reduced shelf life.

**Table 3: Effect of artificial ripening agents on the ripening time of banana and plantain**

Sample/treatment	Ripening time in days (banana)	Sample/treatment	Ripening time in days (plantain)
A1	Not ripe	A2	Not ripe
B1	5	B2	5
C1	5	C2	5
D1	3	D2	5
E1	3	E2	5
F1	3	F2	5

A1=2 kg Banana-Control, B1=2 kg Banana/Bush Mango, C1=2 kg Banana/Ethanol, D1=2 kg Banana/ 1g CaC<sub>2</sub>, E1=2 kg Banana/2 g CaC<sub>2</sub>, F1=2 kg Banana/5 g CaC<sub>2</sub>, A2=2 kg Plantain/Control, B2=2 kg Plantain/Bush Mango, C2=2 kg Plantain/Ethanol, D2=2 kg Plantain/1 g CaC<sub>2</sub>, E2=2 kg Plantain/2 g CaC<sub>2</sub>, F2=2 kg Plantain/5 g CaC<sub>2</sub>.

**Table 4: Effect of different ripening agents on the sensory attributes of banana and plantain**

Treatment	Colour	Appearance	Texture	Odour	Overall Acceptability
<b>Banana</b>					
A1	1.78 <sup>abc</sup> ±0.81	3.89 <sup>bcd</sup> ±0.76	2.39 <sup>bc</sup> ±0.78	4.61 <sup>bc</sup> ±0.61	4.00 <sup>b</sup> ±0.84
B1	1.67 <sup>abc</sup> ±0.77	3.61 <sup>abcd</sup> ±0.70	3.39 <sup>de</sup> ±0.98	4.33 <sup>abc</sup> ±0.97	3.83 <sup>ab</sup> ±0.79
C1	1.50 <sup>a</sup> ±0.62	3.33 <sup>ab</sup> ±0.97	1.94 <sup>ab</sup> ±1.00	4.72 <sup>c</sup> ±0.58	3.67 <sup>ab</sup> ±1.03
D1	1.56 <sup>ab</sup> ±0.71	3.11 <sup>a</sup> ±0.83	3.67 <sup>e</sup> ±0.97	3.67 <sup>a</sup> ±1.33	3.17 <sup>a</sup> ±1.10
E1	2.28 <sup>cd</sup> ±1.23	3.50 <sup>abcd</sup> ±0.79	3.50 <sup>e</sup> ±0.99	4.06 <sup>abc</sup> ±1.11	3.72 <sup>ab</sup> ±0.90
F1	1.78 <sup>abc</sup> ±0.94	3.56 <sup>abcd</sup> ±1.04	3.61 <sup>e</sup> ±0.92	3.94 <sup>ab</sup> ±1.16	3.67 <sup>ab</sup> ±0.84
<b>Plantain</b>					
A2	1.78 <sup>ab</sup> ±0.81	3.67 <sup>abcd</sup> ±1.14	1.78 <sup>a</sup> ±0.81	4.67 <sup>c</sup> ±0.69	3.67 <sup>ab</sup> ±1.14
B2	2.44 <sup>c</sup> ±0.86	3.83 <sup>bcd</sup> ±0.92	2.78 <sup>cd</sup> ±0.81	4.28 <sup>abc</sup> ±0.96	3.78 <sup>ab</sup> ±0.81
C2	2.17 <sup>b</sup> ±0.86	3.39 <sup>abc</sup> ±0.98	1.72 <sup>a</sup> ±0.58	4.72 <sup>c</sup> ±0.58	3.39 <sup>ab</sup> ±1.09
D2	3.72 <sup>e</sup> ±0.75	4.06 <sup>e</sup> ±0.64	3.28 <sup>de</sup> ±0.83	4.00 <sup>abc</sup> ±0.97	4.00 <sup>b</sup> ±0.84
E2	3.57 <sup>d</sup> ±0.86	4.00 <sup>cd</sup> ±0.34	3.22 <sup>de</sup> ±0.88	4.17 <sup>abc</sup> ±1.04	3.94 <sup>b</sup> ±0.64
F2	3.83 <sup>e</sup> ±0.51	4.00 <sup>cd</sup> ±0.69	3.22 <sup>de</sup> ±0.94	4.28 <sup>abc</sup> ±0.83	3.83 <sup>ab</sup> ±0.51

Data are represented as Mean ± SD. Means with unshared superscripts along the same column differ significantly ( $p \leq 0.05$ ). A1=2 kg Banana-Control, B1=2 kg Banana/Bush Mango, C1=2 kg Banana/Ethanol, D1=2 kg Banana/ 1g CaC<sub>2</sub>, E1=2 kg Banana/2 g CaC<sub>2</sub>, F1=2 kg Banana/5 g CaC<sub>2</sub>, A2=2 kg Plantain/Control, B2=2 kg Plantain/Bush Mango, C2=2 kg Plantain/Ethanol, D2=2 kg Plantain/1 g CaC<sub>2</sub>, E2=2 kg Plantain/2 g CaC<sub>2</sub>, F2=2 kg Plantain/5 g CaC<sub>2</sub>.

**Table 5: Effects of washing on the phosphorus content of peel and pulp of banana and plantain obtained from retailers**

Sample	Treatment	Phosphorus content (mg/kg)			
		Banana		Plantain	
		Peel	Pulp	Peel	Pulp
Green	Washed	7.296 <sup>a</sup> ±0.000	8.809 <sup>g</sup> ±0.002	8.651 <sup>f</sup> ±0.002	8.796 <sup>g</sup> ±0.002
	Unwashed	7.307 <sup>b</sup> ±0.000	7.559 <sup>c</sup> ±0.002	9.400 <sup>h</sup> ±0.002	8.575 <sup>e</sup> ±0.001
Ripe	Washed	11.966 <sup>f</sup> ±0.001	7.884 <sup>d</sup> ±0.001	7.843 <sup>d</sup> ±0.001	6.064 <sup>b</sup> ±0.001
	Unwashed	12.544 <sup>h</sup> ±0.000	7.947 <sup>e</sup> ±0.001	5.819 <sup>a</sup> ±0.000	6.522 <sup>c</sup> ±0.001

Data are represented as Mean ± SD of triplicate readings. Means with unshared superscript along the same column showed a significant difference at a 95 % confidence level.

However, this result (the phosphorus content) was much lower than those reported for other locations in Nigeria for samples taken from retailers; for instance, samples taken from Benin City market, Igbina duwa et al. (2018) reported phosphorus contents of 254.0 and 289.0 mg/kg for banana peel and pulp respectively and that of plantain as 263.0 and 12.5 mg/kg for peel and pulp respectively. Therefore, the phosphorus contents observed in banana and plantain from retailers in this study might be due to their endogenous phosphorus contents rather than any exogenous source or contamination from using CaC<sub>2</sub>.

#### Effects of artificial ripening agents and washing on the phosphorus contents of peel and pulp of banana and plantain from middle holders

The effect of different ripening agents and washing after treatment on the phosphorus contents of peel and pulp of banana and plantain in the laboratory is shown in Table 6. The results showed phosphorus contents of

banana and plantain ranged from 8.172 to 12.163 mg/kg (banana peel), 6.064 to 8.796 mg/kg (banana pulp), and 7.347 to 15.293 mg/kg (plantain peel), 6.881 to 13.363 mg/kg (plantain pulp). Significant differences ( $p \leq 0.05$ ) existed in the phosphorus contents of washed and unwashed peel and pulp of both banana and plantain treated with various ripening agents. However, the differences could not be attributed to washing effects because some samples had significantly higher phosphorus contents than the unwashed ones. Washing was purposefully introduced in the study to remove calcium carbide residues, if any (Rowe, 2007; Pokhrel, 2020; Shakeel et al., 2022). Also, the phosphorus content of peels was significantly higher ( $p \leq 0.05$ ) than pulps in both treated and untreated banana, except the plantain sample treated with 5 g CaC<sub>2</sub>, where the content was larger in the pulp. Furthermore, the phosphorus content recorded for bananas and plantain in this study was lower than that of some literature reports.

**Table 6: Effects of ripening agents and washing on the phosphorus contents of the peel of banana and plantain purchased from middle holders**

Sample	Treatment	Phosphorus content (mg/kg)			
		Banana		Plantain	
		Peel	Pulp	Peel	Pulp
Green		10.237 <sup>l</sup> ±0.002	7.293 <sup>e</sup> ±0.001	10.707 <sup>b</sup> ±0.001	7.355 <sup>b</sup> ±0.001
A	Washed	8.940 <sup>h</sup> ±0.000	7.686 <sup>i</sup> ±0.000	13.231 <sup>j</sup> ±0.002	8.004 <sup>d</sup> ±0.000
	Unwashed	9.103 <sup>i</sup> ±0.000	7.995 <sup>l</sup> ±0.001	12.485 <sup>f</sup> ±0.002	6.881 <sup>a</sup> ±0.002
B	Washed	8.195 <sup>b</sup> ±0.002	7.915 <sup>k</sup> ±0.001	12.525 <sup>g</sup> ±0.000	10.307 <sup>k</sup> ±0.001
	Unwashed	8.172 <sup>a</sup> ±0.001	7.347 <sup>f</sup> ±0.001	13.086 <sup>i</sup> ±0.002	8.197 <sup>f</sup> ±0.002
C	Washed	9.893 <sup>j</sup> ±0.002	6.842 <sup>c</sup> ±0.002	11.238 <sup>c</sup> ±0.002	9.851 <sup>i</sup> ±0.001
	Unwashed	12.163 <sup>m</sup> ±0.005	6.064 <sup>a</sup> ±0.002	11.396 <sup>d</sup> ±0.003	9.183 <sup>h</sup> ±0.000
D	Washed	10.151 <sup>k</sup> ±0.003	6.962 <sup>d</sup> ±0.001	11.755 <sup>e</sup> ±0.002	8.113 <sup>e</sup> ±0.002
	Unwashed	8.624 <sup>f</sup> ±0.002	6.821 <sup>b</sup> ±0.001	12.700 <sup>h</sup> ±0.000	7.529 <sup>c</sup> ±0.001
E	Washed	8.479 <sup>c</sup> ±0.009	7.600 <sup>h</sup> ±0.001	15.293 <sup>m</sup> ±0.017	10.120 <sup>j</sup> ±0.004
	Unwashed	8.921 <sup>g</sup> ±0.002	8.796 <sup>m</sup> ±0.001	13.767 <sup>l</sup> ±0.002	11.043 <sup>l</sup> ±0.001
F	Washed	8.400 <sup>c</sup> ±0.001	7.714 <sup>j</sup> ±0.000	13.260 <sup>k</sup> ±0.004	8.729 <sup>g</sup> ±0.001
	Unwashed	8.458 <sup>d</sup> ±0.002	7.373 <sup>g</sup> ±0.000	7.347 <sup>a</sup> ±0.019	13.363 <sup>m</sup> ±0.003

As reported, laboratory-treated samples had 161.0 and 174.5 mg/kg phosphorus contents for peel and pulp of banana, respectively, and 142.0 and 30.5 mg/kg phosphorus for peel and pulp of plantain, respectively (Igbinađuwa et al., 2018). This irregular pattern in observed phosphorus contents in this study suggests that it could probably not be attributed to contamination resulting from calcium carbide or any other external sources, but rather due to endogenous phosphorus contents in the sample itself. This was evident as certain chemically treated samples exhibited lower phosphorus content than the control

### Conclusion

This study highlighted the varying effects of artificial ripening agents, particularly calcium carbide, African bush mango, and ethanol, on the ripening times and safety of bananas and plantains. The results indicate that while calcium carbide accelerates ripening significantly, both fruits remained visually ripe but arguably unripe internally, raising serious quality and safety concerns. The phosphorus levels observed in the fruits post-treatment were primarily attributed to endogenous sources rather than external contaminants, underscoring the need for further investigation into the natural nutrient profiles of these produce. The findings highlight the importance of regulatory oversight to curb the misuse of chemical ripening agents, thereby ensuring consumer safety and preserving the integrity of food quality. Future research should explore alternative ripening methods that promote safety without compromising fruit quality.

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