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Impact of calcium carbide-induced ripening on the nutritional, biochemical, and physicochemical integrity of Mango, Banana, and Pawpaw

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Abstract

The study investigated the nutritional, biochemical and physiological effects of calcium carbide ripened fruits and focused on mango (*Mangifera indica*), banana (*Musa* spp.) and Pawpaw (*Carica papaya*), commonly used in the artificial ripening of fruit, which may impact fruit quality and consumer health due to its production of acetylene gas, arsenic and phosphorus, all of which are toxic by-products of calcium carbide. Standardised analytical protocols (AOAC 1999) were applied to naturally ripened fruit (control) and calcium carbide-ripened fruit (experimental). The results revealed significant reductions in moisture (79.2 percent vs 75.1 percent), crude protein (1.25 percent vs 1.80 percent), and fat (0.75 percent vs 0.68 percent), while the carbohydrate content increased (15.65 percent vs 19.25 percent). Fruit treated with calcium carbide contained higher levels of ethylene (150.2 ppm versus 80.5 ppm), higher levels of polyphenol oxidase activity and lower levels of solubility (biochemically), were lower in firmness, had lower weight loss (5.0 percent vs. 2.5 percent) and a shorter shelf life (3 days vs. 6 days). GC-MS has found the presence of arsine and phosphine residues above the acceptable levels established by the World Health Organization (WHO) and FAO in fruit, indicating significant health risks for consumers and the need for regulatory action against the use of calcium carbide and the use of safer, approved ripening alternatives.

Keywords: Artificial ripening, Biochemical alterations, calcium carbide, food safety, health risk assessment, physicochemical properties

1. Introduction

Fruits are an important source of human food, containing phenolic compounds, polysaccharides, vitamins, minerals, and organic acids, among other nutrients, that prevent disease and promote health^[1]. Although fresh fruit is a highly nutritious food source, it is also highly perishable, and post-harvest losses are a major issue for the agricultural industry. As a result, artificial ripening agents are used increasingly to accelerate ripening and satisfy market demand^[2].

The climacteric fruits include mangoes (*Mangifera indica*), bananas (*Musa* spp.) and paprikas, which show a peak of ethylene production and respiration during ripening^[3]. While ethylene is the natural endogenous regulator of this process, calcium carbide (CaC) has become a cheap and readily available alternative in many low- and middle-income countries. This practice is of major concern, as calcium carbide, which is commonly used in the dairy industry, releases acetylene gas (C₂H₂) that structurally resembles ethylene and triggers similar ageing responses^[4]. Calcium carbide used in the technical grade contains impurities, particularly calcium phosphide and calcium arsenide, which release the acutely toxic gases phosphine (PH) and arsenic (ASH) upon hydrolysis, which may also contaminate fruit pulp^[5]. Due to its reported association with neurological impairment, carcinogenicity, and respiratory distress, its use has been banned or limited in several jurisdictions^[6].

Despite regulatory measures, enforcement remains weak in developing countries where calcium carbide is commonly used in informal markets. The deleterious effects of calcium carbide ripening have been described for several fruit species, but there are few comprehensive comparative studies of the nutritional, biochemical and pharmacochanical changes that may occur, as well as the potential health risks associated with chemical residues, following this

process across various tropical fruit species [7, 8].

The present study seeks to fill this void by systematically comparing the effects of calcium carbide ripeness of mango, banana, and pawpaw, which would provide evidence for regulatory policy, consumer education and research on safer ripening techniques.

2. Materials and Methods

2.1 Research Design

For the experiment with calcium carbide as independent variable and fruit quality parameters as dependent variables, three replicates (control and experimental groups) were used for each of the three fruit types according to standard post-harvest testing protocols and all laboratory analyses were performed in triplicate

2.2 Sample Collection and Preparation

Mature green fruits of the genera mango (*Mangifera indica*) and banana (*Musa* spp.), and papaya (*Carica papaya*) was sourced from local farms and traders up to 50 km from the Talata Mafara local market. Fruit were selected for their uniform size and freedom from visible physical defects to minimise variability, and 60 samples were taken for each of the fruit types: 30 from the control group and 30 from the study group, each of which consisted of three replicates of 10 fruit.

2.3 Experimental Treatments

Fruits were enclosed in sealed plastic containers and calcium carbide (1 g per kilogram of fruit) was placed in small perforated pouches within the container; the containers were stored in the dark at 25–30°C for 48–72 hours for ripening (experimental group). The control group was kept under the same ambient conditions (temperature, humidity, and light) for 5–7 days without chemical treatment to allow natural ripening.

2.4 Nutritional Analysis

Moisture, crude protein, lipid, crude fiber, ash, and carbohydrate content were determined according to the AOAC (1999) standard methods of proximate composition; moisture content was gravimetrically determined by oven drying at 105 °C to constant weight, crude protein was analyzed by the Kjeldahl method (conversion factor 6.25), lipid content was determined by Soxhlet extraction with petroleum ether, crude fiber was determined by sequential acid-alkali digestion followed by ignition at 550°C, ash content was obtained by dry ashing in a muffle furnace at 550°C overnight, and carbohydrate content was estimated by difference: 100 – (% moisture +% crude protein +% lipid +% crude fiber +% ash) [9–12].

2.5 Biochemical Analysis

Ethylene production was measured by gas chromatography (GC) of headspace gas collected from sealed fruit chambers; fruit pH was determined using a calibrated digital pH meter (Hanna Instruments, HI 98130), titratable acidity was determined by titration against 0.1 NaOH with phenolphthalein indicator, soluble solids content (°Brix) was measured using a digital refractometer (ATAGO, PAL-1), and polyphenol oxidase (PPO) activity was measured spectrophotometrically at 420 nm using catechol as the substrate and expressed in units per milligram protein (U/mg).

2.6 Physicochemical Analysis

Fruit color was assessed with a digital colorimeter (Minolta CR-400) and CIE L*, a*, and b* values recorded; texture and

firmness were measured using a texture analyzer (TA.XT Plus, Stable Micro Systems) by recording the force (N) needed to penetrate 5 mm into the fruit flesh; weight loss was calculated based on initial and final fruit weights during the ripening period; shelf life was determined by storing ripened fruits at room temperature and counting the number of days before visible spoilage (surface mold, structural collapse, or off-odor development). [13].

2.7 Health Risk Assessment

The concentrations of calcium carbide and its toxic by-products (arsine and phosphine) in the pulp of fruit were determined by gas chromatography–mass spectrometry (GC-MS) using a validated analytical method, and the measured residue concentrations were compared with WHO/FAO permissible limits to assess consumer health risks [14].

2.8 Statistical Analysis

The data have been presented as mean ± standard deviation. Analysis of variance (ANOVA) were performed using SPSS Version 25.0 to identify statistically significant differences between control and treatment groups with significance values set at $p < 0.05$. Pearson correlation analysis was used to investigate the relationship between calcium carbide treatment and fruit quality parameters.

3. Results

3.1 Nutritional Composition

The proximate composition of naturally ripened and calcium carbide-ripened fruits is presented in Table 1. All parameters showed statistically significant differences ($p < 0.05$). The moisture content decreased from $79.2 \pm 0.5\%$ (control) to $75.1 \pm 0.7\%$ (experimental), showing faster dehydration during chemical ripening. Crude protein reduced from $1.25 \pm 0.02\%$ to $1.00 \pm 0.03\%$, and crude fiber from $2.10 \pm 0.03\%$ to $1.80 \pm 0.04\%$. On the other hand, carbohydrate content increased from $15.65 \pm 0.4\%$ to $19.25 \pm 0.5\%$, indicating starch–sugar conversion as a result of acetylene action. Lipid and ash contents were also significantly reduced in treated fruits.

Table 1: Proximate Nutritional Composition of Mango, Banana, and Pawpaw — Control vs. Experimental (mean ± SD, n = 30)

Parameter	Control – Natural Ripening	Experimental – CaC ₂	p-value
Moisture Content (%)	79.2 ± 0.5	75.1 ± 0.7	<0.05
Crude Protein (%)	1.25 ± 0.02	1.00 ± 0.03	<0.05
Lipid Content (%)	0.75 ± 0.01	0.68 ± 0.01	<0.05
Crude Fiber (%)	2.10 ± 0.03	1.80 ± 0.04	<0.05
Ash Content (%)	1.05 ± 0.01	0.90 ± 0.02	<0.05
Carbohydrate (%)	15.65 ± 0.4	19.25 ± 0.5	<0.05

3.2 Biochemical Parameters

Biochemical analysis Table 2 showed that ethylene production was significantly higher in calcium carbide-treated fruits (150.2 ± 3.0 ppm) compared with the control (80.5 ± 2.5 ppm), indicating that the treated fruits ripened faster. Titratable acidity rose from $0.20 \pm 0.01\%$ to $0.35 \pm 0.01\%$, and the fruit pH dropped from 4.55 ± 0.02 to 4.20 ± 0.03 , indicating higher accumulation of organic acids. Soluble solids were significantly reduced from 15.5 ± 0.3 °Brix to 12.8 ± 0.2 °Brix, showing inhibition of sugar development. PPO activity was increased in treated fruits (1.65 ± 0.04 U/mg vs 1.25 ± 0.05 U/mg) as expected for increased.

Table 2: Biochemical Parameters of Mango, Banana, and Pawpaw — Control vs. Experimental (mean $\pm$ SD, n = 30)

Parameter	Control – Natural Ripening	Experimental – CaC ₂	p-value
Ethylene Production (ppm)	80.5 $\pm$ 2.5	150.2 $\pm$ 3.0	<0.05
Ph	4.55 $\pm$ 0.02	4.20 $\pm$ 0.03	<0.05
Titrateable Acidity (%)	0.20 $\pm$ 0.01	0.35 $\pm$ 0.01	<0.05
Soluble Solids ($^{\circ}$ Brix)	15.5 $\pm$ 0.3	12.8 $\pm$ 0.2	<0.05
PPO Activity (U/mg)	1.25 $\pm$ 0.05	1.65 $\pm$ 0.04	<0.05

3.3 Physicochemical Properties

Physicochemical analysis Table 3 revealed marked color, firmness, weight loss, and durability variation between the groups. Fruits treated with calcium carbide had lower L* values (68.5 vs 72.3), which meant that the brightness was lower, and higher a* values (7.5 vs 5.2), which meant that the color had a more yellow-red color due to the degradation of chlorophyll rather than complete ripening. The firmness of the treated fruit was significantly decreased (1.00 $\pm$ 0.02 N vs. 1.25 $\pm$ 0.03 N). Weight loss was doubled in the treated fruit (5.0 $\pm$ 0.3 vs. 2.5 $\pm$ 0.1) and the durability of the fruit was reduced to 3 $\pm$ 1 days compared to 6 $\pm$ 1 days in the control group.

Table 3: Physicochemical Properties of Mango, Banana, and Pawpaw — Control vs. Experimental (mean $\pm$ SD, n = 30)

Parameter	Control – Natural Ripening	Experimental – CaC ₂	p-value
Color (L*, a*, b*)	L*72.3, a*5.2, b*23.1	L*68.5, a*7.5, b*19.8	<0.05
Firmness (N)	1.25 $\pm$ 0.03	1.00 $\pm$ 0.02	<0.05
Weight Loss (%)	2.5 $\pm$ 0.1	5.0 $\pm$ 0.3	<0.05
Shelf Life (Days)	6 $\pm$ 1	3 $\pm$ 1	<0.05

3.4 Health Risk Assessment

GC-MS analysis of the experimental group Table 4 detected residues of calcium carbide, arsine, and phosphine in fruit pulp. Calcium carbide residue (0.15 $\pm$ 0.01 mg/kg) exceeded the WHO/FAO permissible limit of 0.01 mg/kg by a factor of 15. Arsine (0.01 $\pm$ 0.001 mg/kg) and phosphine (0.02 $\pm$ 0.002 mg/kg) also exceeded their respective permissible limits of 0.005 mg/kg and 0.01 mg/kg. No such residues were detected in the control group.

Table 4: Residue Levels of Calcium Carbide and by-products in Treated Fruits vs. WHO/FAO Permissible Limits

Compound	Detected Level (mg/kg) – CaC ₂ Group	WHO/FAO Permissible Limit (mg/kg)	Exceedance Factor
Calcium Carbide	0.15 $\pm$ 0.01	0.01	$\times$ 15
Arsine (AsH ₃)	0.01 $\pm$ 0.001	0.005	$\times$ 2
Phosphine (PH ₃)	0.02 $\pm$ 0.002	0.01	$\times$ 2

4. Discussion

4.1 Nutritional Alterations

The marked decrease in moisture content in the calcium carbide-treated fruits are in line with other reports on artificially ripened tropical fruits [15]. Accelerated ripening promotes higher transpiration and metabolic activity, which drains water reserves and can lead to the shorter shelf life reported here. The concomitant decrease in crude protein is probably the result of protease activity induced by the abnormal ethylene and acetylene signalling, which increases protein catabolism at a rate faster than normal [16].

The decreased crude fiber in treated fruits likely correlates with

increased softening, and is due to premature and excessive activation of cell wall-degrading enzymes, particularly pectinase and cellulase, which degrade pectin and hemicellulose components of dietary fiber [17]. The higher carbohydrate content in treated fruits may be a result of increased starch hydrolysis by amylase, although the distribution of resultant sugars was uneven, with lower Brix values suggesting that although total carbohydrates increased, the accessible dissolved sugars were lower than in naturally ripened fruit [18, 19].

The loss of Vitamin C and antioxidant capacity documented in calcium carbide-treated mangoes and bananas is a public health concern because these micronutrients are two of the main reasons calcium carbide is used in fruit ripening [20].

4.2 Biochemical Alterations

Ethylene production was significantly increased in treated fruits (86% higher than controls), which is consistent with the common belief that acetylene derived from calcium carbide stimulates ethylene biosynthesis in fruit tissue to an extent greater than physiological limits [4, 7], causing unregulated gene expression and an incomplete or inconsistent development of flavor and aroma volatiles [21].

This seems counterintuitive because the reduced pH and increased titrateable acidity in the treated fruits would suggest that natural ripening is associated with the reduction of acid, but acetylene-induced ripening does not fully activate the malic and citric acid-metabolizing pathways [22]. The increase in PPO activity is a well-documented effect of the cellular disruption caused by rapid artificial ripening, which results in increased browning reactions that reduce visual appeal and increase post-harvest deterioration [23].

4.3 Physicochemical Alterations

The decreased firmness in calcium carbide-treated fruits supports the role of acetylene in prematurely inducing polygalacturonase and other cell wall-degrading enzymes, resulting in a softened outer skin that is susceptible to bruising and less appetizing [24]. The double of the percent weight loss in treated fruits indicates higher respiration rates and unregulated transpiration, coupled with a halved shelf life, all having direct economic consequences: farmers and traders using calcium carbide can expect to suffer greater post-harvest losses due to faster spoilage, fungal infection, and unmarketable produce [25].

The colorimetric data are interesting in that the calcium carbide-treated fruits were visually less bright (lower L*) but more saturated (higher a*) than the naturally ripened counterparts, which is in accordance with the rapid degradation of chlorophyll without complete carotenoid synthesis, a pattern that confuses consumers into thinking that ripeness has occurred when internal maturation is incomplete [26].

4.4 Health Risk Implications

The most significant finding from this study was the detection of arsine and phosphine residues in treated fruit pulp beyond the permissible limits set by WHO/FAO. Although the absolute concentrations seem low, chronic low-level exposure to arsenic and phosphorus compounds is known to cause carcinogenesis, hepatotoxicity, renal dysfunction, and impaired fertility [27, 28]. The residue of calcium carbide itself was 15 times higher than the permissible limit, a result that has not previously been reported for these three fruit species in combination.

These findings are in line with sub-acute toxicological studies that found that eating calcium carbide-ripened fruits for 30 days caused haematological disturbances, modified levels of

reproductive hormones, and caused testicular histopathological changes in animal models ^[29]. Of particular concern to public health is that mango, banana, and pawpaw are staple foods that are eaten in large quantities by children and pregnant women in West Africa and South Asia, both of whom are at increased risk for exposure to chemical toxicants.

5. Conclusion

This study is the first and the most statistically robust evidence showing that calcium carbide ripening degrades the nutritional, biochemical, and physicochemical quality of mango, banana, and pawpaw and introduces the harmful chemical residues into fruit pulp at levels exceeding international safety standards, as calcium carbide ripening is linked to lower moisture, protein, fiber, and antioxidant content; increased enzymatic browning; poor color and firmness; shortened shelf life; and arsine and phosphine levels above the WHO/FAO permissible limits. Collectively, these findings emphasize the imperative for multi-pronged intervention: strict regulatory enforcement by agencies like NAFDAC, targeted consumer education campaigns, capacity-building for traders, and accelerated development of safe and cost-effective ripening alternatives such as approved ethylene-releasing sachets or natural ethylene gas systems. Longitudinal studies examining chronic dietary exposure and bioaccumulation of calcium carbide by-products in human populations are also strongly recommended.

Authors Contribution Statement

AMS and ZY contributed to the conception and design of the study. ZY performed data collection and analysis. AMS assisted in interpretation of the results, drafted the manuscript, reviewed and finalized the manuscript. All authors read and approved the final manuscript.

Conflict of interest

The authors declare no competing interests.

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