Shelf Life, Fruit Quality and Safety of Banana (Musa Species) Ripened through Traditional Ripening Techniques in Nigeria

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ABSTRACT

Many fruit vendors in Nigeria adopt unhealthy practices to induce fruit ripening and increase the availability of ripe fruits in the markets. We investigated the safety of traditional induced ripening techniques on two banana species (Musa acuminata and Musa balbisiana). Unripe mature banana fruits were harvested and subjected to five different ripening procedures – exposure to sunlight, hot water priming, enclosure in sack bags and nylon bags as well as exposure to calcium carbide (CaC₂) in an enclosed container. The study included a control group, which was not exposed to any of the traditional ripening methods. Results showed that banana fruits primed in hot water turned dark throughout the period under review. Although it took control fruits six days to ripen, the fruits exposed to different weights of CaC₂ ripened fastest (within 48–hours) irrespective of the mode of application, whether as dried CaC₂ or in solution. Increased sugar accumulation was recorded in the CaC₂ – ripened fruits, with evidence of arsenic (0.026–0.164 mg/kg) in the endocarp. Arsenic is an impurity in CaC₂ and also known to be a harmful heavy metal. Post-harvest spoilage of both Musa species began on the fourth day after exposure to CaC₂ whereas spoilage was not reported within nine days for fruits exposed to other ripening procedures. With the accumulation of arsenic and the early post-harvest spoilage of banana fruits due to CaC₂ exposure, the local use of CaC₂ for fruit ripening should be discouraged. We recommend the use of nylon and sack bags as well as exposure to sunlight because of longer shelf life and minimal effects on fruit quality.

KEYWORDS

Banana (Musa species); induced ripening; calcium carbide; arsenic

Introduction

Consumption of fruits is promoted for human nourishment and wellbeing as a source of essential vitamins, amino acids, minerals, dietary fiber, antioxidants as well as chemicals that enhance cardiovascular health, liver function, muscle development and metabolism (Wargovich, 2000). Naturally, during fruit ripening, fruits release ethylene and increase cellular respiration (Moirangthem and Tucker, 2018) and two changes, for example, softness and sweetness, that is flavor, accompany it. The characters of fruits change to make them increasingly appealing to potential shoppers and consumers (Grierson, 2013). Natural fruit ripening may take time. Thereby, potentially affecting economic gains of fruit vendors and often motivate artificial ripening strategies, which have existed for centuries. In other to mimic nature, some techniques for induced fruit ripening additionally includes the use of ethylene as a ripening agent. Banana fruits are most desirable when ripe and are often induced to ripen faster. Ethylene is the hormone that triggers ripening but commercial application is relatively expensive and
requires an enclosed chamber provided with adequate ventilation to prevent carbon dioxide (CO₂) accumulation. The accumulation of CO₂ in the process can competitively bind with ethylene receptors through transcriptional regulation and retard the ripening process (Clendennen et al., 1997; Xiao et al., 2013). Besides the use of ethylene gas, acetylene gas produced from calcium carbide (CaC₂), ethephon, propylene, glycol, lamp fuel and ethanol are commercial ripening agents with wide applications, varied effectiveness and effects on fruit quality and safety (Dhembare, 2013; Maduwanthi and Marapana, 2019; Sazedur et al., 2014). However, in other to reduce cost these days calcium carbide is normally utilized for faster ripening. When calcium carbide application is exposed to moisture, acetylene gas is discharged, which has close qualities with ethylene (Ur-Rahman et al., 2008). Direct acetylene inhalation diminishes oxygen supply to the brain and causes hypoxia (Fattah and Ali, 2010). Calcium carbide distresses the mucosal tissue of the stomach area and reports of stomach issue in the wake of eating carbide-ripened mangoes have been recorded (Siddiqui and Dhua, 2010).

In Nigeria, fruit vendors covertly ripen banana fruits in encased vessels where an enormous amount of calcium carbide is added and sprinkled with water before concealing such vessels. This triggers the arrival of acetylene for ripening procedure in fruits, an inflammable gas including the danger of fire perils (Abhishek et al., 2016). This method is dangerous given the fact that CaC₂ contains arsenic hydride and phosphorus hydride impurities (Abhishek et al., 2016; Sazedur et al., 2014), and also given the fact that these traders just simply add CaC₂ into ripening vessels without recourse to concentrations required for safer outcomes. Other ripening procedures include bagging. Bagging strategy ensures and upgrades the visual nature of fruit by advancing skin coloration and diminishing blemishes, however, changes the miniaturized scale condition for fruit advancement, which can have various valuable impacts on inward fruit quality (Sharma et al., 2014). The disadvantage associated with bagging include diminished fruit size and weight due to low light transmittance of the bags (Arakawa et al., 1994; Hussein et al., 1994; Xu et al., 2008), and this discourages several vendors from indulgence in this method. This, therefore, leaves the use of carbide as the most commonly used method for induced fruit ripening. Compared to other common fruit ripening methods adopted by fruit vendors in Nigeria, to what extent is the reliance on CaC₂ effective for ripening? Based on the availability of impurities in CaC₂, is the accumulation of arsenic in the CaC₂ ripened fruit endocarp possible? The outcome of this study will contribute to creating awareness about the implications of traditional fruit ripening methods on fruit quality and value. The objective of this study is to ascertain the extent to which local ripening agents such as the use of calcium carbide, hot water, sunlight, normal ripening, nylon bag and sack bags have on edibility, appearance, and nutritional value of banana fruits. We also aim to determine the amount of calcium carbide impurities (arsenic) in the banana fruits ripened with the compound.

Materials and Methods

Selection of Ripening Methods

Selection of methods adopted for ripening in this study was based on a reconnaissance survey of banana farmers, sellers and vendors in Nigeria. These were independently visited and were interviewed via questionnaires on the various methods adopted for ripening banana (Supplementary Table 1). A total of 43 respondents were selected for the survey. The Mean item score was adopted in ranking which methods of ripening were most utilized by the respondents visited. The ranking was based on the premise that the factor with the highest mean item score was ranked as 1st, and then the others follow in descending order.

\[ \text{The formula for the mean score is, } MIS = \frac{\sum_{i=1}^{E} Ri}{N} \]

Where \( R \) is the rating per column, \( R_i = \text{Number of each of the rating scale point.} \) Also given that \( F \) is defined in the study as the sample size per rating, \( Fi = \text{Frequency of each questionnaire item.} \) \( N \) is the total sample
Thus the Qualitative strongly in Seventeen Exposure or as bunches Two Collection That is, any item in the instrument which had a mean equal to or higher than 3.0 was accepted while any mean score below 3.0 was rejected.

Collection of Banana

Two species of matured unripe banana (Musa acuminata Colla and M. balbisiana Colla, Musaceae) bunches (approximately 14 kg each) were collected from a plantation in Benin City, Southern Nigeria. As soon as these fruits were removed from parent plants (approximately 85 days after flowering), they were immediately taken to the Laboratory and subjected to experimental ripening procedures. Qualitative assessment of the banana epicarp after harvest suggest some of the peels had few spots or no spots (Supplementary Table 2).

Exposure of Banana to Ripening Conditions

Seventeen mature unripe banana fingers weighing 2 kg were exposed to different ripening conditions in the study. Calcium Carbide (CaC₂) was prepared in two different forms (wet and dry). For dry CaC₂, 2, 5 and 10 g CaC₂ per 2 kg fresh weight (FW) of banana was weighed and placed in the middle of a plastic container (58 cm long and in diameter 42 cm) containing the banana fruits. For wet CaC₂, the same quantity of CaC₂ was measured and transferred into 100 ml of water and placed in a container of similar dimension as the dry CaC₂. The banana was exposed to each quantity of the dry and wet CaC₂ for 48 hours and then kept at room temperature (23–25 °C) on a sterile laboratory bench. During ripening by exposure to CaC₂, care was taken not to touch the banana and the containers were immediately covered. Hot water ripening method involved the use of boiled 3.5 liters of water, which was allowed to cool to a temperature of 65 °C. Then 2 kg FW of banana was placed in the hot water for 30 seconds and then kept under ambient room temperature on a sterile laboratory bench. The use of sack bag was done at room temperature. The bananas were placed in the bags, covered properly to limit the entry of oxygen and then maintained under room temperature (24.5–27.5 °C) and relative humidity (48%) for nine days with 2 hours interval for observation and data collection. The same was done for bananas bagged in polyethylene materials. The respondents believed that nylon materials hardly allowed the inflow of oxygen. According to locals, this was the basis for ripening. For ripening in the sun, banana fruits were placed in an open field under the direct scorching heat of sunlight from dawn to dusk and then returned to the laboratory dry storage facility at dusk, which is maintained at room temperature and humidity. Benin City (6.33 °N and 5.62 °E) receives an average of 12 hours of sunlight every day and a global average daily solar radiation of 17.44–12.50 MJ/m² and average daily temperature of 26.5 °C (Njoku et al., 2018). The banana fruits exposed to the different ripening conditions were examined daily. The control group was not subjected to any form of treatment during the study period. Fruit firmness (softness), fruit color codes and spoilage were determined according to methods reported in Vilcarromero (2005) and Soltani et al. (2010) where they investigated the quality of banana during ripening and the characteristics of surface color.
**Determination of Total Phenol Content**

Total phenol content was measured using the Folin Ciocalteu reagent method adopted from McDonald et al. (2001) and Kopjar et al. (2009). About 1 ml of the banana endocarp sample extract was mixed in 3 ml of distilled water and 0.5 ml of Fe and C reagent (Folic cicatol reagent) was added. This was allowed to stand for 3 minutes and then a 2 ml 20% of Sodium Carbonate was added before mixing every part properly and allowed to stand. This resulted in a blue colored solution and the absorbance values were determined at 650 nm using a UV visible spectrophotometer. Catecholcol or gallic acid was used in running the standard and preparing the standard curve. The total phenol content was calculated from the standard curve.

**Determination of Ascorbic Acid Content**

Total ascorbic acid content was determined using the 2,4-dinitrophenylhydrazine method (Kapur et al., 2012). The method relies on the oxidation of ascorbic acid to hydroascorbic acid by bromine water in the presence of acetic acid. About 1.5 ml of 4% trichloroacetic acid was added to 0.5ml of the sample extract. This was followed by adding 0.5 ml of DNPH, a drop of 10% Thiourea and boiling at 37°C of the sample extract for 3hrs was carried out. It was allowed to cool and 2.5 ml of 85% H₂SO₄ was added, and thereafter allowed to stand for 30 minutes, before taking absorbance readings at 540 nm using a UV visible spectrophotometer.

**Determination of Total Sugar Content**

Total sugar content in the banana samples was measured following the phenol-sulfuric method (Dubois et al., 1956). About 0.1 ml of sample extract was pipetted and then to 1 ml with water was added to it, to make it up. Thereafter, 1 ml of phenol solution and 5 ml concentrated H₂SO₄ was added to the sample extract before boiling for 20 minutes in a water bath and taking absorbance readings at 490 nm using the spectrophotometer.

**Determination of Arsenate in Banana Samples**

Arsenate content of the calcium carbide treated banana fruits were determined using the atomic absorption spectrophotometric (AAS) Model-Solaar 969 Unicam Series and air acetylene flame. The digestion process was carried out by following the method of Radiojevic and Bashkin (1999). Aqua regia was used by measuring 75 ml of concentrated HCl and 25 ml concentrated HNO₃ into 100 ml (3:1) volumetric flask. Then 1 g each of the banana endocarps from samples that were ripened with calcium carbide samples was placed in a beaker and 10 ml aqua regia added before leaving it to stay for a day to dissolve completely after which 90 ml of distilled water was added before filtering with Whatman filter paper, which was then taken to the AAS for the determination of As (Arsenic).

**Data Analysis**

The study adopted a completely randomized design with three replicates per treatment. The experimental data were subjected to analysis of variance and mean comparison using SPSS statistical software version 21 for Windows.

**Results**

We examined the effects of calcium carbide, hot water priming, sacking, nylon bagging and exposure to sunlight on fruit quality, safety and spoilage of banana. The methods were selected through a recognizance survey aimed at documenting the diverse traditional fruit ripening practices associated
banana (Supplementary Table 1). Results of the survey showed that the most prominently used method of ripening was bagging with sack bag (Supplementary Table 1). However, the use of calcium carbide was also prominent. Most of the respondents were afraid to give information on the use of carbide; probably they already knew that it is unhealthy. The information provided was given on the grounds of anonymity. 

Figure 1 shows the measurement of ripening period based on epicarp (peel) colors and number of days after exposure to different local induced ripening conditions for *M. acuminata* (Figure 1a) and *M. balbisiana* (Figure 1b). The fruits of *M. balbisiana* were majorly forest green at harvest. At the second day, the banana exposed to hot water acted a khaki green color, which was prominent for the entire 9 days. However, in CD2, CD5, CD10, CW2, CW5 and CW10, ripening had begun in the second day, wherein the banana epicarp showed lime green color. Ripening was fully achieved by the 3rd day after harvest wherein the color of the banana was completely yellow. However, when compared with the control, the color of the banana did not turn yellow until the 6th day in which case, one would say the fruit ripening physically may have been achieved in control at the 6th day after harvest as compared to the 3rd day after harvest in the fruits exposed to CaC2. For *M. acuminata*, results showed that ripening (complete yellowness) was achieved earlier than in *M. Balbisiana* on the

![Graph](image-url)

**Figure 1.** Measurement of the ripening period of banana using the epicarp color and number of days after exposure to different local induced ripening techniques of (a) *Musa acuminata* and (b) *Musa balbisiana*. **Key: Color codes:** 0 = Black and dark golden rod (rotten), 1 = Khaki, 2 dark green, 3 = Forest green, 4 = lime green, 5 = olive drab, 6 = yellow green, 7 = yellow. **Treatments:** H = Immersion in hot water, CD2 = 2 g dry CaC2 for 2 kg FW of banana, CD5 = 5 g dry CaC2 for 2 kg FW of banana, CD10 = 10 g dry CaC2 for 2 kg FW of banana, CW2 = 2 g CaC2/100 ml water for 2 kg FW of banana, CW5 = 5 g CaC2/100 ml water for 2 kg FW of banana, CW10 = 10 g CaC2/100 ml water for 2 kg FW of banana, NB = banana wrapping in nylon bag, SB = banana wrapping in Sack bag, SL = banana under direct Sunlight, CTR = Control.
3rd day for fruits exposed to CaC₂. However, for the control, complete yellowness was achieved on the 6th day. Supplementary Table 2 shows the physical observation on the banana skin immediately after harvest and after exposure to experimental treatments. On the day of harvest, the skin was entire, which meant that there were no spots or blemish on the banana skin. Whereas, whenever it is reported that the skin is spotted, it meant that they were dark legions on the skin. On the very day of harvest, the skin was entire, however from the 3rd day, some parts of the skin showed spottiness, however for those banana fruits that were exposed to CaC₂, the skin was entire and they were no sign of dark legions on the banana epicarp. However, for those banana fruits that were either placed in the sun or placed in a sack bag or nylon bag after 3 days, there were signs of dark necrotic legions on the skin. This may be as a result of injury particularly whenever the banana was been carried to the field to be placed under the sun or the injury may have occurred inside the bag where they were kept. The same observation regarding the entireness of the skin as observed in M. acuminata was also observed in M. balbisiana.

Figures 2 and 3 show M. acuminata and M. balbisiana fruits at 3 days after exposure to the different local induced ripening treatment conditions. The banana exposed to individual treatments was placed side by side against the control for proper comparison. The same has been presented for M. acuminata and M. balbisiana fruits at 6 days after exposure to the different local induced ripening treatment conditions (Supplementary Figures 1 and 2). M. acuminata and M. balbisiana fruits at 7 days (Figures 4 and 5). At the 9th day after exposure to the various experimental treatments, it could be observed that all bananas exposed to CaC₂ treatments as well as hot water treatments had significantly decayed whereas M. acuminata still appeared yellow-green although ripe. Those exposed to CaC₂ treatment were already rotten (Figure 6a). The same was presented for M. balbisiana (Figure 6b).

![Figure 2. Musa acuminata at 3 days after exposure to different local induced ripening treatments. H = Hot water treatment, CD2 = 2 g of dry CaC₂ for 2 kg FW of banana treatment, CDs = 5 g of dry CaC₂ for 2 kg FW of banana treatment, CD10 = 10 g of dry CaC₂ for 2 kg FW of banana treatment, CW2 = 2 g of CaC₂/100 ml of water for 2 kg FW of banana treatment, CW5 = 5 g of CaC₂/100 ml water for 2 kg FW of banana treatment, CW10 = 10 g of CaC₂/100 ml of water for 2 kg FW of banana treatment, NB = Nylon bag treatment, SB = Sack bag treatment, SL = Sunlight treatment, CTR = Control.](image-url)
Further, the study attempted to investigate the degree of softness of each of the banana species exposed to the various ripening regimes (Table 1). Endocarp firmness is a useful indicator of banana ripeness. For *M. acuminata*, softness was achieved on the 5th day after harvest for banana species that were exposed to hot water treatment. Softness was achieved one day after exposure to experimental treatment for all *M. acuminata* species exposed to CaC₂ either dry or wet. The degree of softness increased up till the 3rd day and then by the 6th day, it attained a 3+ softness. Whereas, in *M. balbisiana*, the degree of softness was 1+ for species exposed to CaC₂ one day after treatment but this worsened and increased to 3+ degree of softness at 7 days after exposure. The banana that was ripened by placement in nylon bags were only 1+ soft 5 days after exposure to this method and could only attain a 2+ degree of softness at both 8th and 9th day after exposure to ripening methods. The control *M. acuminata* and *M. balbisiana* showed a 1+ degree of softness at 4th day after exposure thus increased to 2+ degree of softness on the 9th day for *Musa acuminata* and the 6th day for *M. balbisiana*. Table 2 shows the degree of spoilage due to the ripening of the banana fruits. Results showed that for banana species exposed to hot water treatment, the fruits got bad as from the 2nd day upon exposure. However, for the controlled fruit as well as fruit exposed to nylon bag treatment, sack bag treatment and ripening through sunlight there was no report of spoilage up till 9 days after exposure to ripening measures for both *M. acuminata* and *M. balbisiana*. However, as from the 4th day after exposure to ripening measures using CaC₂ either wet or dry, fruit spoilage was reported. The degree of spoilage was worsened on the 6th day for *M. acuminata* and the 7th day for *M. balbisiana*.

Total phenols content in the banana after exposure to different local induced ripening conditions is for both the second and fifth day (Table 3). Results showed that for *M. acuminata*, the total phenols

![Figure 3. Musa balbisiana at 3 days after exposure to different local induced ripening treatments. H = Hot water treatment, CD2 = 2 g of dry CaC₂ for 2 kg FW of banana treatment, CD5 = 5 g of dry CaC₂ for 2 kg FW of banana treatment, CD10 = 10 g of dry CaC₂ for 2 kg FW of banana treatment, CW2 = 2 g of CaC₂/100 ml of water for 2 kg FW of banana treatment, CW5 = 5 g of CaC₂/100 ml of water for 2 kg FW of banana treatment, NB = Nylon bag treatment, SB = Sack bag treatment, SL = Sunlight treatment, CTR = Control.](image-url)
were 115.65 mg/100 g fresh weight (FW) in the second day after exposure to hot water ripening measure and this significantly increased to 413.55 mg/100 g FW on the 5th day. Results showed that on the 2nd day after exposure to ripening measures by either using dry or wet carbide, total phenols ranged from 278.74 to 332.94 mg/100 g FW at the 2nd day after exposure to treatment or this rose on the 5th day from 380 to 911.21 mg/100 g FW. Observably, total phenols were significantly higher in the banana fruits that were ripened using carbide for both the second and fifth day. For *M. balbisiana*, total phenols were also higher in the CaC2 exposed banana fruits compared to banana fruits ripened by other measures. Overall, the results for total phenol content suggest that as ripening progress the phenol content increases.

The ascorbic acid content of the ripened banana were significantly higher in the fruits ripened by CaC2 (Table 4). At 2 days after exposure to CaC2, the ascorbic acid content of *M. acuminata* ranged from 113.79 to 331.03 mg/100 g FW, whereas ascorbic acid content in *M. balbisiana* ranged from 154–363.80 mg/100 g FW. By comparing ascorbic acid levels for 2nd and 5th days after exposure to ripening measures, the result showed significant increases for CaC2 exposed fruits from the 2nd to the 5th day after exposure in both banana species. However, there were no increases in ascorbic acid levels for 2nd and 5th days after exposure into ripening measures for those fruits that were ripened using a hot water treatment, coverage in nylon bags and sack bags, as well as banana exposure to sunlight.

Total sugar content in the ripened banana was 4.84 g/100 g in the control for *M. acuminata*. This significantly rose to 12.45 g/100 g 5 days after treatment (Table 5). For *M. balbisiana*, there were no significant differences in total sugar content of the ripened fruits as total sugar ranged from 15.85 to 17.45 g/100 g in 2nd and 5th days after harvest. Similarly, total sugar in *M. acuminata* exposed to hot water treatments increased from 6.18 g/100 g on the second day after harvest to 29.70 g/100 g 5 days after harvest. Results generally showed that significant increases in total sugar content were reported for fruits exposed to CaC2 whether dry or wet for *M. acuminata*. However, in *M. balbisiana* results
showed that there were no significant differences in total sugar content between the second and fifth day after exposure to CaC₂ whether wet or dry, as total sugar content values ranged from 41.41 to 47.91 g/100 g FW in the 2nd day after harvest to between 59.87 and 69.13 g/100 g FW 5 days after harvest of *M. balbisiana*.

Table 6 shows the arsenic concentration in the fruit endocarp, whereas the concentration of arsenate in raw calcium carbide was 10.12 mg/kg. Arsenic concentration in ripe *M. acuminata* ranged from 0.026 to 0.083 mg/kg in the carbide exposed plants compared to non-detectable values in the control. Similarly, in *M. balbisiana*, arsenic concentration was also non-detectable. However, in those fruits exposed to CaC₂ wet or dry, arsenate concentration ranged from 0.084 to 0.164 mg/kg.

**Discussion**

We have studied the rate of spoilage, fruit quality and safety of local induced fruit ripening techniques for banana and found varying effects associated with the different methods. The experiment of Hartshorn (1931), recognized the impacts of acetylene on the ripening procedure of banana through a consistent yellow fruit color, great flavor, medium starch content, and a soft texture. During ripening, textural changes and fruit softening are brought about by depolymerization and solubilization of cell wall segments and loss of cell structure (Maduwanthi and Marapana, 2019). This in line with the observations made in this study albeit with different textural quality determined by the ripening techniques. Changes in turgor pressure, a decrease of cell wall polysaccharides and enzymatic reduction of starch are determinant systems of fruit softening. Cell-wall polysaccharides experience
solubilization, de-esterification, and depolymerization during ripening (Clendennen et al., 1997; Maduwanthi and Marapana, 2019). In the present study, the rate of fruit softening was enhanced with the application of calcium carbide, a substance that mimics ethylene-based ripening by releasing acetylene, which reacted with moisture. In climacteric fruits like bananas, which contain a high measure of starch in its flesh, enzymatic hydrolysis of starch is a central factor in fruit yellowing. From this examination, softness was accomplished one day after introduction to experimental treatment for all *M. acuminata* species presented to CaC$_2$ either dry or wet. The fruits attained the highest level of softness (3+) presented for the study. However, in *M. balbisiana*, the level of softness was 1+ for species presented to CaC$_2$ one day after treatment. Notwithstanding, softness levels increased to 3+ at 7 days after exposure. During ripening, there is an expansion in the breakdown of starch inside the fruit, and a comparing increment in the measure of basic sugars, which taste sweet, for example, sucrose, glucose, and fructose and a reduction in acidity as the fruit ripen and a lessening in bitter plant substances, for example, alkaloids (Moirangthem and Tucker, 2018). This is in line with findings from this study as total sugar content in the ripened banana, was 4.84 g/100 g in the control for *M. acuminata*, which ascended significantly to 12.45 g/100 g 5 days after treatment (Table 5).

Again, results from this present examination uncovered that absolute sugar in *M. acuminata* presented to hot water medications expanded from 6.18 g/100 g at day 2 after harvest to 29.7 g/100 g 5 days after harvest as well as for results showing significant increases in total sugar content reported for fruits exposed to CaC$_2$ whether dry or wet for *M. acuminata*. Ascorbic acid values of both ripened banana
species in this study where fundamentally higher in the fruits ripened by CaC₂. Thompson et al. (2019) revealed that ascorbic acid content of ‘Dwarf Cavendish’, ‘Rasabale’ and ‘Rajabale’ increased during ripening at 20°C for 21 days and diminished marginally up to 35 days.

The use of calcium carbide imposes health implications on both the users and the consumers of the CaC₂-ripened bananas. Acetylene gas exposure by the fruit vendors brings about migraine, vertigo, discombobulation, wooziness, seizure, and even unconsciousness (Maduwanthi and Marapana, 2019). Moreover, with calcium carbide ripening, arsenate impurities were found present in banana fruits. Studies from this examination uncovered that arsenic concentration in ripe *M. acuminata* ran from 0.026 to 0.083 mg/kg in the Carbide-exposed plants contrasted with non-perceptible values in the control. Thus, in *M. balbisiana*, arsenic concentrations were likewise non-perceptible. Arsenic impurities stored in the banana samples are in all probability because of the fume discharges radiated when the calcium carbide is applied on the fruit, giving rise to its non-detectable values as obtained from this study with *M. Balbisiana*. However, for the fact that the banana fruit skin has an extraordinary capacity for moisture retention of these disintegrated impurities during the release of acetylene gas from Calcium Carbide, arsenic impurities were imbibed by both banana species. Calcium carbide ripened fruits are soft, have a decent peel color development but with lesser flavor (Surbhi et al., 2016). Moreover, these heavy metals are non-biodegradable and have long natural half-lives just as the capacity for aggregation in various organs of the body prompting undesirable issues (Ogunkunle et al., 2014). Importantly, the possible adverse effects associated with some of the heavy metals, including arsenic, have been widely reported in anemia, hepatotoxicity, renal failure and gastrointestinal disorders, gastrointestinal disturbances such as nausea, abdominal cramp, vomiting and diarrhea, central nervous system disorder leading to permanent disability (Tchounwou et al., 2012; Thirulogachandar et al., 2014). Most importantly is the fact that arsenic exposure has been found to

| Table 1. Number of days and degree of softness of the fruits after exposure to the experimental treatments. | Days after harvest |
|---|---|---|---|---|---|---|---|---|---|
| *M. acuminata* | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| H | - | - | - | - | - | + | + | + | ++ | ++ |
| CD2 | - | + | + | ++ | ++ | ++ | +++ | +++ | +++ | +++ |
| CD5 | - | + | + | ++ | ++ | ++ | +++ | +++ | +++ | +++ |
| CD10 | - | + | + | ++ | ++ | ++ | +++ | +++ | +++ | +++ |
| CW2 | - | + | + | ++ | ++ | ++ | +++ | +++ | +++ | +++ |
| CW5 | - | + | + | ++ | ++ | ++ | +++ | +++ | +++ | +++ |
| CW10 | - | + | + | ++ | ++ | ++ | +++ | +++ | +++ | +++ |
| NB | - | - | - | + | + | + | + | + | + | + |
| SB | - | - | - | + | + | + | + | + | + | + |
| SL | - | - | - | + | + | + | + | + | + | + |
| CTR | - | - | - | - | + | + | + | + | + | + |

**Key:** - = Not soft at all, + = Soft, ++ = Very soft, +++ = Very very soft.

H = Hot water treatment, CD2 = 2 g of dry CaC₂ for 2 kg FW of banana treatment, CD5 = 5 g of dry CaC₂ for 2 kg FW of banana treatment, CD10 = 10 g of dry CaC₂ for 2 kg FW of banana treatment, CW2 = 2 g of CaC₂/100 ml of water for 2 kg FW of banana treatment, CW5 = 5 g of CaC₂/100 ml of water for 2 kg FW of banana treatment, CW10 = 10 g of CaC₂/100 ml of water for 2 kg FW of banana treatment, NB = Nylon bag treatment, SB = Sack bag treatment, SL = Sunlight treatment, CTR = Control.
Table 2. Number of days and the degree of spoilage observed in the fruits after treatment with different local induced ripening conditions.

|          | Days after harvest |
|----------|--------------------|
|          | 0  | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  |
| **M. acuminata** |     |    |    |    |    |    |    |    |    |    |
| H        | -  | -  | -  | +  | +  | +  | +  | ++ | ++ | ++ |
| CD2      | -  | -  | -  | -  | +  | +  | +  | ++ | ++ | ++ |
| CD5      | -  | -  | -  | -  | +  | +  | +  | ++ | ++ | ++ |
| CD10     | -  | -  | -  | -  | +  | +  | +  | ++ | ++ | ++ |
| CW2      | -  | -  | -  | -  | +  | +  | +  | ++ | ++ | ++ |
| CW5      | -  | -  | -  | -  | +  | +  | +  | ++ | ++ | ++ |
| CW10     | -  | -  | -  | -  | +  | +  | +  | ++ | ++ | ++ |
| NB       | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  |
| SL       | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  |
| CTR      | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  |

|          |     |    |    |    |    |    |    |    |    |    |
| **M. balbisiana** |     |    |    |    |    |    |    |    |    |    |
| H        | -  | -  | +  | +  | +  | +  | +  | ++ | ++ | ++ |
| CD2      | -  | -  | -  | -  | +  | +  | +  | ++ | ++ | ++ |
| CD5      | -  | -  | -  | -  | +  | +  | +  | ++ | ++ | ++ |
| CD10     | -  | -  | -  | -  | +  | +  | +  | ++ | ++ | ++ |
| CW2      | -  | -  | -  | -  | +  | +  | +  | ++ | ++ | ++ |
| CW5      | -  | -  | -  | -  | +  | +  | +  | ++ | ++ | ++ |
| CW10     | -  | -  | -  | -  | +  | +  | +  | ++ | ++ | ++ |
| NB       | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  |
| SL       | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  |
| CTR      | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  |

**KEY:** – = Negative (No spoilage), + = Positive (Beginning of Spoilage), ++ = Increased spoilage.

H = Hot water treatment, CD2 = 2 g of dry CaC2 for 2 kg FW of banana treatment, CD5 = 5 g of dry CaC2 for 2 kg FW of banana treatment, CD10 = 10 g of dry CaC2 for 2 kg FW of banana treatment, CW2 = 2 g of CaC2/100 ml of water for 2 kg FW of banana treatment, CW5 = 5 g of CaC2/100 ml of water for 2 kg FW of banana treatment, CW10 = 10 g of CaC2/100 ml of water for 2 kg FW of banana treatment, NB = Nylon bag treatment, SB = Sack bag treatment, SL = Sunlight treatment, CTR = Control.

Table 3. Total phenols content of banana after exposure to different local induced ripening conditions.

|     | 2 DAH        | 5 DAH        | p-value | 2 DAH        | 5 DAH        | p-value |
|-----|--------------|--------------|---------|--------------|--------------|---------|
| FD  | 148.83<sup>b</sup> | 445.09<sup>c</sup> | 0.021   | 171.73<sup>d</sup> | 206.78<sup>b</sup> | 0.085   |
| H   | 115.65<sup>a</sup> | 413.55<sup>cd</sup> | 0.006   | 220.79<sup>c</sup> | 357.48<sup>ab</sup> | 0.219   |
| CD2 | 280.28<sup>a</sup> | 686.92<sup>a</sup> | <0.001  | 630.84<sup>a</sup> | 322.43<sup>b</sup> | <0.001  |
| CD5 | 278.74<sup>a</sup> | 476.64<sup>c</sup> | 0.014   | 248.83<sup>cd</sup> | 571.26<sup>a</sup> | 0.042   |
| CD10| 290.89<sup>a</sup> | 380.37<sup>cd</sup> | 0.634   | 297.94<sup>cd</sup> | 255.84<sup>ab</sup> | 0.633   |
| CW2 | 332.94<sup>a</sup> | 911.21<sup>a</sup> | <0.001  | 382.01<sup>bc</sup> | 231.31<sup>b</sup> | 0.128   |
| CW5 | 282.24<sup>a</sup> | 459.11<sup>c</sup> | 0.046   | 360.99<sup>cd</sup> | 420.56<sup>b</sup> | 0.421   |
| CW10| 231.31<sup>ab</sup> | 280.37<sup>cd</sup> | 0.132   | 245.33<sup>cd</sup> | 287.38<sup>ab</sup> | 0.677   |
| NB  | 189.25<sup>a</sup> | 452.11<sup>c</sup> | 0.002   | 175.23<sup>d</sup> | 161.21<sup>b</sup> | 0.429   |
| SB  | 213.64<sup>ab</sup> | 253.97<sup>d</sup> | 0.082   | 204.81<sup>cd</sup> | 243.46<sup>d</sup> | 0.071   |
| SL  | 318.93<sup>a</sup> | 445.09<sup>c</sup> | 0.249   | 455.61<sup>ab</sup> | 357.48<sup>ab</sup> | 0.103   |
| CTR | 183.64<sup>ab</sup> | 210.24<sup>d</sup> | 0.126   | 157.48<sup>cd</sup> | 117.54<sup>b</sup> | <0.001  |

**DAH:** days after harvest. Means with similar alphabetic superscripts in the same column do not differ from each other (p > 0.05).

**Key:** H = Immersion in hot water, CD2 = 2 g dry CaC2 for 2 kg FW of banana, CD5 = 5 g dry CaC2 for 2 kg FW of banana, CD10 = 10 g dry CaC2 for 2 kg fresh weigh of banana, CW2 = 2 g CaC2/100 ml water for 2 kg FW of banana, CW5 = 5 g CaC2/100 ml water for 2 kg FW of banana, CW10 = 10 g CaC2/100 ml water for 2 kg FW of banana, NB = banana wrapped in nylon bag, SB = banana wrapped in sack bag, SL = banana kept under direct sunlight, CTR = Control.

exert cytotoxic, mutagenic and carcinogenic effects to major tissues and organs of the body (Tchounwou et al., 2012).
Table 4. The ascorbic acid content of banana after exposure to different local induced ripening conditions.

|                  | M. acuminata (mg/100 g FW) | M. balbisiana (mg/100 g FW) |
|------------------|-----------------------------|-----------------------------|
|                  | 2 DAH | 5 DAH | p-value | 2 DAH | 5 DAH | p-value |
| **FD**           | 14.86b | 10.45c | 0.084 | 55.90b | 41.34b | 0.149 |
| **H**            | 41.07b | 68.07c | 0.153 | 18.60b | 21.31b | 0.014 |
| **CD2**          | 250.03b | 689.31a | <0.001 | 154.14b | 686.55a | <0.001 |
| **CD5**          | 261.03a | 476.55b | <0.001 | 194.48b | 489.31a | 0.003 |
| **CD10**         | 113.79a | 632.76a | <0.001 | 323.80b | 686.55a | 0.003 |
| **CW2**          | 122.76a | 689.31a | <0.001 | 301.38b | 512.41b | 0.254 |
| **CWS**          | 331.03a | 684.14a | 0.027 | 265.52b | 494.50a | 0.147 |
| **CW10**         | 236.21a | 652.59a | 0.003 | 363.80b | 618.38b | 0.270 |
| **NB**           | 9.82a  | 13.34c  | 0.138 | 25.00b  | 18.38b  | 0.113 |
| **SB**           | 16.07b | 19.76c  | 0.645 | 29.24b  | 19.70b  | 0.391 |
| **SL**           | 21.70b | 16.21c  | 0.329 | 33.79b  | 11.20b  | 0.735 |
| **CTR**          | 26.21b | 18.23c  | 0.245 | 13.97b  | 17.54b  | 0.385 |
| **p-value**      | <0.001 | 0.002  | <0.001 | <0.001 | 0.001  | <0.001 |

DAH: days after harvest. Means with similar alphabetic superscripts in the same column do not differ from each other (P > 0.05).

Key: **H** = Immersion in hot water, **CD2** = 2 g dry CaC2 for 2 kg FW of banana, **CD5** = 5 g dry CaC2 for 2 kg FW of banana, **CD10** = 10 g dry CaC2 for 2 kg FW of banana, **CWS** = 2 g CaC2/100 ml water for 2 kg FW of banana, **CW10** = 10 g CaC2/100 ml water for 2 kg FW of banana, **NB** = banana wrapped in nylon bag, **SB** = banana wrapped in sack bag, **SL** = banana kept under direct sunlight, **CTR** = Control.

Table 5. Total sugar concentration in banana after exposure to the experimental conditions.

|                  | M. acuminata (g/100 g FW) | M. balbisiana (g/100 g FW) |
|------------------|-----------------------------|-----------------------------|
|                  | 2 DAH | 5 DAH | p-value | 2 DAH | 5 DAH | p-value |
| **FD**           | 10.44b | 18.08b | 0.162 | 21.14b | 11.84c | 0.213 |
| **H**            | 6.18b | 29.71b | <0.001 | 23.76b | 55.00ab | 0.039 |
| **CD2**          | 29.8a  | 69.56a | 0.025 | 47.91a | 60.12ab | 0.092 |
| **CD5**          | 33.91a | 59.71a | 0.041 | 47.03a | 67.32a | 0.065 |
| **CD10**         | 46.33a | 78.69a | 0.006 | 43.21a | 59.85a | 0.037 |
| **CW2**          | 47.64a | 43.69a | 0.318 | 47.26a | 69.13a | 0.081 |
| **CWS**          | 36.91a | 69.56a | 0.011 | 47.41a | 48.83a | 0.742 |
| **CW10**         | 47.52a | 75.51a | 0.038 | 41.41a | 68.31a | 0.048 |
| **NB**           | 8.83b  | 22.57b | 0.004 | 35.63a | 32.64bc | 0.574 |
| **SB**           | 4.31b  | 18.28b | <0.001 | 10.67b | 47.52a | 0.026 |
| **SL**           | 7.21b  | 16.56b | <0.001 | 19.52b | 12.77c | 0.137 |
| **CTR**          | 4.84b  | 12.45b | 0.021 | 15.85b | 17.45c | 0.558 |
| **p-value**      | <0.001 | 0.402  | 0.352 | 0.051 |

DAH: days after harvest. Means with similar alphabetic superscripts in the same column do not differ from each other (P > 0.05).

Key: **H** = Immersion in hot water, **CD2** = 2 g dry CaC2 for 2 kg FW of banana, **CD5** = 5 g dry CaC2 for 2 kg FW of banana, **CD10** = 10 g dry CaC2 for 2 kg FW of banana, **CW2** = 2 g CaC2/100 ml water for 2 kg FW of banana, **CWS** = 5 g CaC2/100 ml water for 2 kg FW of banana, **NB** = banana wrapped in nylon bag, **SB** = banana wrapped in sack bag, **SL** = banana kept under direct sunlight, **CTR** = Control.

In this study, the use of hot water discolored the bananas. It induced a khaki green color, which was prominent for the whole 9 days and never encouraged induced banana fruit ripening but rather accelerated spoilage effects of both banana species at day 2 and day 3 for M. balbisiana and M. acuminata respectively. The use of hot water treatment raised glutathione, ascorbic acid, free phenolic and flavonoids values during storage and quality parameters including peel color and pulp firmness demonstrated that boiling water treatment postponed banana fruit ripening (Ummarata et al., 2011). This is in line with our observation as hot water treatments delayed ripening of both banana samples. We also observed that as ripening progresses due to induced ripening conditions, it significantly increases total phenol and ascorbic acid contents (Table 5). This is in agreement with the report of Fernando et al. (2014) that the chemical composition of banana including total phenol and ascorbic acid contents increases during ripening. In another study, Vu et al. (2019) noted that the behavior of phytochemicals during ripening of banana subjected to induced ripening condition could be used as a basis of classification for the ripening stage. Although the mechanism for phenol
Table 6. Arsenic concentration in fruit endocarp after exposure to different calcium carbide concentration to induce ripening.

| Ripening method | Raw \( \text{CaC}_2 \) (mg/kg) | \textit{Musa acuminata} (mg/kg) | \textit{Musa balbisiana} (mg/kg) | p-value |
|-----------------|-------------------------------|---------------------------------|---------------------------------|---------|
| Raw \( \text{CaC}_2 \) | 10.12 | - | - | - |
| CD2 | - | 0.058<sup>a</sup> | 0.147<sup>b</sup> | 0.123 |
| CD5 | - | 0.071<sup>a</sup> | 0.155<sup>b</sup> | 0.319 |
| CD10 | - | 0.083<sup>a</sup> | 0.164<sup>b</sup> | 0.069 |
| CW2 | - | 0.026<sup>a</sup> | 0.072<sup>a</sup> | 0.274 |
| CW5 | - | 0.033<sup>a</sup> | 0.084<sup>a</sup> | 0.116 |
| CW10 | - | 0.051<sup>a</sup> | 0.113<sup>a</sup> | 0.046 |
| CTR | - | <0.001<sup>b</sup> | <0.001<sup>b</sup> | NA |
| p-value | - | <0.001 | <0.001 | - |

Means with similar alphabetic superscripts in the same column do not differ from each other (\( P > 0.05 \)).

Key: \( H \) = Immersion in hot water, \( \text{CD2} = 2 \text{ g dry CaC}_2 \) for 2 kg FW of banana, \( \text{CD5} = 5 \text{ g dry CaC}_2 \) for 2 kg FW of banana, \( \text{CD10} = 10 \text{ g dry CaC}_2 \) for 2 kg FW of banana, \( \text{CW2} = 2 \text{ g CaC}_2/100 \text{ ml water} \) for 2 kg FW of banana, \( \text{CW5} = 5 \text{ g CaC}_2/100 \text{ ml water} \) for 2 kg FW of banana, \( \text{CW10} = 10 \text{ g CaC}_2/100 \text{ ml water} \) for 2 kg FW of banana, \( \text{NB} = \text{banana wrapped in nylon bag} \), \( \text{SB} = \text{banana wrapped in sack bag} \), \( \text{SL} = \text{banana kept under direct sunlight} \), \( \text{CTR} = \text{Control} \).

accumulation during ripening in banana is not well understood, it is suggested that the process is regulated by dopamine and senescence cues (Teeranud et al., 2005). Brown colored spots on the skins of bananas is a typical phase of ripening that generally happens when the skin has changed color from green to yellow or completely yellow contingent upon the genotype (Thompson et al., 2019). This concurs with the result on spottiness from this examination as all samples of both banana species developed spots at different days during the investigation.

In conclusion, this study ascertained the extent to which each of the ripening agents used in this study affects banana fruits and found that hot water priming and calcium carbide treatments had more irreversible consequences on the fruits taking cognizance of edibility, appearance, and nutritional value. The presence of arsenic can be used as a tool to detect banana fruits ripened with calcium carbide. In line with Chandel et al. (2018) we recommend the soaking fruits in 2% sodium carbonate solution for 12 hours to remove arsenic from calcium carbide ripened fruit. However, consumers are often unaware of the ripening method used by vendors and vendors are often unaware of the risk associated with using calcium carbide to ripen fruits or uneducated about the safe application of sodium carbonate to reduce the risk of arsenic poisoning from consuming the fruits. Hence, the government through agriculture extension officers and approved task force as well as non-governmental organizations should embark on a public campaign to discourage the use of calcium carbide as a fruit-ripening agent for the protection of human health, sustainable environmental development. From our results, we recommend the use of nylon and sack bags as well as exposure to sunlight because of the longer shelf life, cheaper cost and minimal effects on fruit quality.

**Acknowledgments**

The authors are grateful to Mrs. Ruth Ate-Ebiye, postgraduate student of the Department of Plant Biology and Biotechnology, University of Benin, Nigeria and Mr. Pieter-Jan Loveniers of the Faculty of Bioscience Engineering, University of Ghent, Belgium for their technical assistance during the study.

**Disclosure Statement**

The authors declare there is no competing interest.

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Authors’ Contributions

BI and OO conceived the research questions. BI, OO and MO developed the research plan. OO carried out the experiments. BI and OO analysed the data and interpreted the results. OO wrote the first manuscript draft. BI and MO revised the manuscript. All the authors approved the final version and publication of the work.

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