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1-methylcyclopropene treatment and storage conditions delay the ripening of plantain fruit while maintaining sensory characteristics of *ampesi,* the boiled food product

[1]Hagan, L.L., [2,4*]Johnson, P. N. T., [3]Sargent, S.A., [3]Huber, D.J. and [3]Berry, A.

[1]Food Research Institute, Council for Scientific and Industrial Research- Box M20, Accra, Ghana
[2]Council for Scientific and Industrial Research, Head Office, Box M.32, Accra, Ghana
[3]University of Florida, IFAS, Horticultural Sciences Department, Gainesville FL, USA
[4]P.N.J. Partners Limited, Box AD 984, Accra, Ghana

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Abstract

The effects of 1-MCP application and storage conditions on the ripening characteristics of mature-green plantains (*Musa paradisiacal* AAB, var. Falsehorn) and the sensory qualities of their boiled Ghanaian plantain pulp product, ampesi, were investigated. Plantain fruit at von Loesecke ripening stage 2-3 were dipped into a 100 µg l-1 aqueous 1-MCP formulation for 1 min and stored at 15^{o}C or 30oC and, 75% relative humidity. Data collected were on the physiological (as CO_2 and ethylene production), physicochemical and shelf-life parameters of the plantain. Sensory parameters assessed on the ampesi were appearance, flavor, taste and overall acceptability. 1-MCP significantly lowered the respiration rate and ethylene production; these effects were more pronounced at 15^{o}C compared with 30^{o}C. 1-MCP treatment significantly reduced the ripening rate as measured by changes in peel colour, soluble solids content and total titratable acidity; keeping quality of the plantain increased 3-fold, from 6 to 21 days without significantly affecting sensory qualities of the ampesi, the boiled plantain pulp product. This work demonstrates that 1-MCP improves the keeping qualities of plantain, significantly reducing postharvest losses, and would be of tremendous assistance to commercial plantain traders in the tropics.

Introduction

Plantains are a perishable starchy crop cultivated mainly in humid tropical zones in Ghana and other countries. They are a valuable staple because it is a rich source of iron and dietary energy (Stover and Simmonds, 1987). In Ghana, plantains are consumed in the processed form at several ripening stages starting from the mature green through yellowish green and finally brownish yellow (1-green, 2-green with a trace of yellow, 3-half-ripe, 4-more yellow than green, 5-ripe, 6-fully ripe and 7-over-ripe). Some of the processed forms popularly consumed in Ghana include *Ampesi* (boiled green plantain pieces), Fufu (boiled pounded plantain) and Kelewele (fried, spiced chips made from over-ripened plantain). Plantain contributes about 13.1% of the Agricultural Gross Domestic Product (AGDP) of Ghana and its per capita annual consumption is 96.4 kg (Ortiz and Vuylsteke, 1996). Plantain production is therefore a major income-generating activity in Ghana. Plantains have high moisture content and high metabolic activity after harvest, leading to high postharvest losses in the region, ranging from 20 to 50% (Demirel and Turhan, 2003). Losses are especially high during the main harvest season when the fruit quickly become overripe. There are therefore major constraints associated with postharvest handling of fresh (green) plantain under the tropical climate of Ghana. These constraints include poor storage conditions, inadequate distribution facilities in the production areas and limited transportation (Sugri and Johnson, 2009). There is need to find appropriate methods to extend the storage life and maintain fruit quality during the 5 to 7 days required for transport to urban markets. Sugri *et al.* (2010) applied a coating of shea butter to extend the shelf life of mature-green plantain from 5 days to 15 days. Shea butter as a coating, however, is not practical because it has to be applied as a thick, 1-mm coating on each plantain fruit to be effective. A number of workers (Olorunda and Aworth, 1984; Sugri and Johnson, 2009; Mangaraj *et al.*, 2009; Kudachikar *et. al.*, 2011) have studied how to extend the shelf life of bananas and plantains beyond one week using technologies such as cold storage, hypobaric storage, irradiation, modified atmosphere and evaporative cooling. However, most of these methods are quite complex and beyond the technical and economic capacities of the small-scale handlers in Ghana.

*Corresponding author.
Email: *paanii.johnson@gmail.com*

The ethylene inhibitor 1-methylcyclopropene (1-MCP) has been studied on numerous crops and shows promise for delaying ripening and senescence (Huber, 2008). Joyce *et al.* (1999), Golding *et al.* (1998) and Sisler and Serek (2006) demonstrated the ability of gaseous 1-MCP to delay ripening of mature-green, pre-climacteric banana. These authors found that 1-MCP has potential to delay banana ripening. However, the lack of gas-tight cold rooms in Ghana currently limits the use of gaseous 1-MCP. Aqueous 1-MCP formulation has been reported to be an effective postharvest treatment for delaying ripening and senescence in some fruits and vegetables (Choi and Huber, 2008; Zhang *et al.*, 2011). The aqueous formulation is applied directly to the fruit, thus eliminating the need for lengthy exposure in sealed facilities that is required for gaseous 1-MCP treatment. Treatment with aqueous 1-MCP requires only 1 min immersion versus 6 to 24 h exposure for gaseous 1-MCP. 1-MCP has been reported to negatively affect the sensory acceptability of some fruits, notably apple (Manrin *et al*., 2009) and banana (Pinheiro *et al*., 2010). Pereira *et al.* (2013), however, found no effect of 1-MCP treatment on the sensory acceptability of Guatemalan-West Indian hybrid avocado. There are no reports of the influence of aqueous 1-MCP on mature-green plantain (Musa paradisiaca AAB) and the sensory qualities of its boiled pulp *(ampesi)*. The objective of this study was to assess the influence of treatment with aqueous 1-MCP and storage conditions on the physiochemical, physiological and storage life of fresh, mature-green plantain and the sensory qualities of its boiled pulp food *(ampesi)*.

Materials and Methods

Experimental setup

Imported fresh fingers of mature-green plantain (Musa paradisiacal AAB var. Falsehorn) not previously treated with ethylene were obtained from Chiquita Brands LLC (Ft. Lauderdale, Florida). Two groups of plantain replicates (n=15) were immersed in a freshly prepared 100μg l-1 aqueous 1-MCP formulation (AgroFresh, Philadelphia, Pennsylvania) for 1 min and then air-dried for 30 min. One group of the 1-MCP treated samples was stored at 15^{o}C and the second group at 30^{o}C. The third and fourth groups were immersed in diH_2O for 1 min and subsequently stored at 15^o and 30^{o}C, respectively, and approximately 75% relative humidity. Fruit were sampled at 0, 7 and 21 d of storage for chemical analyses, fruit firmness and sensory attributes of boiled pulp of the fruit. Data on fruit peel colour and weight loss were taken every two days until 20 d of storage.

Whole fruit firmness

Firmness was determined as bioyield point on whole plantain fruit with a section of peel removed exposing the fruit equator, using a TA.XT Plus texture analyzer (Texture Technologies Corp, Hamilton Mass.) fitted with a 8mm, convex probe and crosshead speed of 2.0 mm/sec. Firmness was conducted initially, and at 7 and 21 d of storage.

Respiration and ethylene production rates

Respiration (as CO_2 evolution) and ethylene production rates were measured on fruit until they reached ripening stage 4 according to the Von Loesecke (1950) scale. Plantain fingers (n=5) were individually placed in 3-L glass containers and sealed for 30 min, after which 3 ml headspace gas were withdrawn through a rubber septum and analyzed on a gas chromatograph (Varian Inc., Palo Alto, CA) equipped with a thermal conductivity detector (TCD, CO_2) and a pulse discharge helium ionization detector (PDHID, ethylene). The carrier gas (helium) flow rate was 0.33 mLs^{-1}. The injector was set to 220◦C, the oven to 50◦C, the TCD to 175◦C, and the PDHID to 120◦C. CO_2 and C_2H_4 were quantified using standard gas mixtures containing 1.02% CO_2 (19.3 mgL^{-1} CO_2) and 1.1 uL/L C_2H_4, respectively.

Weight loss

Fruit weight loss (fresh weight basis) was monitored during storage until ripeness stage 7 using the formula:

Weight loss (%) = [(initial weight of fruit) – (current weight of fruit) / (initial weight of fruit)] × 100.

Peel colour

A panel of five persons subjectively rated the external peel colour of 5 plantain fingers using the standard Von Loesecke banana colour chart (Lescot, 2008). Peel colour was also determined by reflectance photometry on opposite sides of the equator of each of five plantain fingers using the Minolta Chroma Meter (CR-400, Ramsey, NJ) operating with a D65 illuminant, 0° viewing angle and equipped with a 11-mm diameter light projection tube aperture. Colour parameters L^*, C^* and h° were recorded according to McGuire (1992).

Chemical analyses

Plantain fruit (at initial, stages 2-3 and 7 of ripening) were hand-peeled and the pulp cut into 3 pieces and frozen at -30ºC. Frozen pulp samples (n=3) were later thawed, homogenized and then centrifuged at 17,600 × g for 20 min at 5ºC. The supernatant was filtered through cheesecloth, and the filtrate used to determine the soluble solids content (SSC), pH, and total titratable acidity (TTA, as % malic acid), according to AOAC (1990) methods.

Preparation and sensory analysis of ampesi

Fresh plantain fruit (at stages 2-3 and 7 of ripening) were hand-peeled and the pulp was sliced into cylinders approximately 2 cm thick. DiH_2O was added (2 parts H_2O/1 part pulp in grams) and the samples boiled for 10 min to produce *ampesi*. Sensory analysis was carried out using a panel of 20 individuals who were accustomed to eating *ampesi*. Samples were rated for appearance, colour, aroma, texture, taste, mouthfeel and overall acceptability using a 9-point hedonic scale, where (1= dislike extremely, 2= dislike very much, 3= dislike moderately, 4= dislike slightly, 5= neither like nor dislike, 6= like slightly, 7= like moderately, 8= like very much, and 9= like extremely.

Statistical analysis

SPSS (version 16, SPSS Inc., Chicago, USA) was used to perform analysis of variance and obtain Tukey's test (5%) values for each of the main effects (plantain colour data and sensory attributes of *ampesi*).

Results and Discussion

During storage at 30ºC control plantains became unmarketable after 6 d, while 1-MCP treated fruit remained marketable for 20 d; fruit from both treatments remained marketable for 20 d when stored at 15ºC (Figure 1). Peel colour changes were delayed in 1-MCP treated plantains which had lower L^* values (were darker) during storage at both temperatures compared to control fruit. During storage at 15ºC, the L^* for the 1-MCP treated plantain changed from 65.2 (at storage day 0) to 54.1 (by storage day 20) whilst that of the un-treated plantain decreased to 45.2 (by storage day 20). Similarly, the peel ho decreased (representing a change from green to dark yellow) in both control and 1-MCP-treated plantains kept at 30°C. In control fruit ho decreased from 108.2 to 83.7 by day 6 (limit of marketability), whereas 1-MCP treated fruit decreased from 108.2 to 91.5 by day 6 and to 58.8 by day 20. Fruit from both treatments at 15°C stored for 20 d; ho decreased but at a slower rate and higher final value (108.2 to 70.6 for control and 108.2 to 79.5 for 1-MCP fruit). Golding *et al.* (1998) observed similar results for 1-MCP applied to mature-green banana, in which rates of colour change were slower in 1-MCP-treated fruit compared with fruit not exposed to 1-MCP. Delayed changes in peel colour have been associated with disrupted or incomplete and uneven yellowing, the magnitude being dependent on the temperature at which the plantains were stored (Golding *et al*, 1999). Pelayo *et al.* (2003) observed similar results when gaseous 1-MCP was applied to banana at different concentrations (100, 300 and 1000 nl L^{-1}).

The plantains softened significantly during the first 7 d of storage. Firmness of control fruit stored at either 15°C or 30°C decreased by 70%, while 1-MCP-treated fruit decreased approximately 40% and 55% at 15°C or 30°C, respectively. Thereafter, the reduction in firmness remained fairly constant until day 21. These results are in agreement with the reductions in respiration rate, ethylene production

Figure 1. 1-MCP-treated and untreated plantain appearance after 21days of storage at 30°C or 15°C

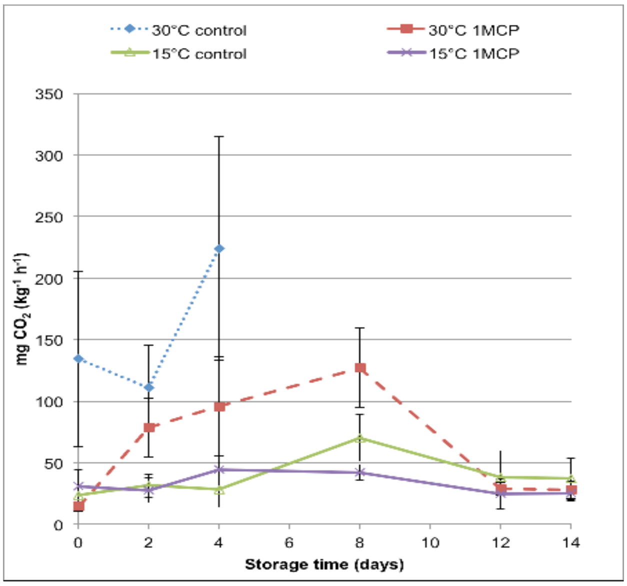

Figure 2. Respiration rate of 1-MCP pretreated and untreated plantain samples stored at 15º and 30ºC and 75% RH. Vertical bars represent standard deviation

Table 1. Soluble solids content, total titratable acidity and SSC/TTA for I-MCP treated and untreated plantains during 21 d of storage at 15°C or 30°C

	Treatments			
Storage Time (d)	30°C		15°C	
SSC	Control	1-MCP	Control	1-MCP
Day 0	8.6a	8.6a	8.6a	8.6a
Day7	29.1c	14.5a	17.9ab	13.5a
Day21	-[1]	24.2b	18.8b	13.5a
TTA				
Day 0	0.12a	0.12a	0.12a	0.12a
Day7	0.23b	0.17a	0.20a	0.16a
Day21	-	0.20a	0.23b	0.17a
SSC/TTA				
Day 0	71.6a	71.6a	71.6a	71.6a
Day7	126.5b	85.3a	89.5a	84.4a
Day21	-	121.0b	81.7a	79.4a

[1]Fruit from this treatment were unmarketable on Day 21
[2]Values in the same row within storage temperature with different small letters are significantly different at p<0.05 according to Tukey's test

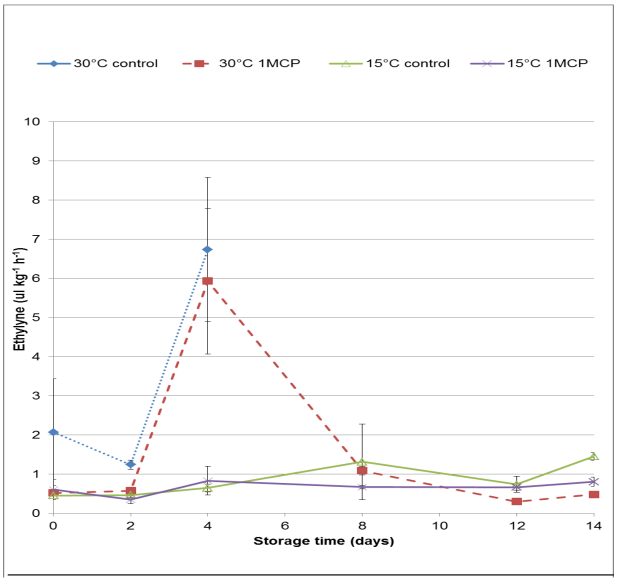

Figure 3. Ethylene production of 1-MCP treated and untreated plantain fruit stored at 15° or 30°C and 75% RH. Vertical bars represent standard deviation

and weight loss (Figures 3) due to treatment with 1-MCP. Lower storage temperature was associated with delayed breakdown of the cell wall, degradation of polysaccharides (Cutillas-Hurralde *et al*., 2006), solubilization of the cell wall and conversion of starch into sugars causing cell turgor changes (Arpaia *et al*., 1987).

Application of 1-MCP suppressed respiration rate (Figure 2) and ethylene production (Figure 3). These effects were considerably more pronounced for fruit stored at 15°C, especially after 6 d of storage. These results are similar to those obtained by Golding *et al.* (1998) and Pelayo *et al.* (2003) who speculated that ethylene-dependent events that are part of normal ripening biochemistry are suppressed by 1-MCP. Golding *et al.* (1999) and Huber (2008) also argued that 1-MCP blocks the normal feedback regulation of ethylene production thereby delaying the ripening rate. Weight loss during storage was affected by storage temperature but not by exposure to 1-MCP. After 20 d of storage, fruit stored at 15°C lost 6.1% weight (mean daily weight loss of 0.3%), compared to 24.7% (mean daily weight loss of 1.2%) for plantain stored at 30°C. Thus, refrigerated storage reduced weight loss by as much as 75%, a significant savings in salable product for farmers and retailers.

There were dramatic increases in soluble solids content (SSC) for both control and 1-MCP-treated fruit during storage. SSC for 30°C control fruit increased from 8.6% to 29.1% by 7d of storage compared to SSC for 30°C 1-MCP fruit that increased from 8.6% to 14.5% by 7 d and to 24.2% by 21 d of storage (Table 1). Biale (1960) reported that increase in SSC during fruit ripening was attributed to the increased activity of enzymes responsible for the hydrolysis of starch to soluble sugars. Similar findings were observed in papaya (Hofman *et al*., 2001) and apples (Fan *et al*., 1999). Similarly, there was an increase in TTA for both 1-MCP-treated and control fruit although there were no significant differences among treatments (Table 1). Fan *et al.* (1999) showed that 1-MCP treatments prevented ethylene-induced acidity loss in carrots and delayed or inhibited TTA loss in tomatoes (Wills and Ku, 2002) and plums (Dong *et al*., 2002). However, Dong *et al.* (2002) and Porat *et al*. (1999) found that application of 1-MCP

Table 2. Sensory attribute ratings for ampesi (boiled plantain pulp) prepared after 7 or 21d of storage at 15°C or 30°C

	Sensory Attributes[1]						
Storage Time	Appearance	Color	Aroma	Texture	Taste	Mouth feel	Overall Acceptability
7 days							
30°C Control	7.71b	7.76b	7.76a	7.71a	8.18b	8.06b	8.00b
30°C 1-MCP	6.18a	6.24a	6.65a	6.71a	6.59a	6.59a	6.71a
15°C Control	7.41b	7.65b	7.00a	7.35a	7.29ab	7.59ab	7.47ab
15°C 1-MCP	7.65b	7.47b	7.00a	7.53a	7.24ab	7.47ab	7.47ab
21 days							
30°C 1-MCP	7.30a	7.45a	7.05a	7.50a	7.35a	7.55a	7.50a
15°C Control	7.05a	6.95a	7.10a	7.10a	7.30a	7.25a	7.20a
15°C 1-MCP	6.95a	6.85a	6.65a	7.10a	6.80a	6.95a	7.10a

[1] For each evaluation time values in the same column by storage time with different small letters are significantly different at $p<0.05$ according to Tukey's test

[2] Sensory attributes were evaluated on a 9-point hedonic scale as follows: 1-dislike extremely, 9-like extremely

did not affect TTA in apricot or Shamouti orange. Thus, the effects of 1-MCP on TTA may vary due to fruit cultivars and storage conditions. In practical terms and usually in commercial situations, the ratio of the SSC to TTA is used as an indicator of flavor quality for many fruits (Kader, 1997). In this study SSC/TTA was higher for fruit stored at 30°C than for those stored at 15°C (Table 2). In control fruit at 30°C, SSC/TTA increased from 71.4 to 126.5 by day 7, while 1-MCP treated fruit increased from 71.4 to 85.3 by day 7 and to 121.0 by day 21. For fruit from both treatments stored at 15°C, SSC/TTA increased but at a slower rate (71.4 to 89.5 for control and 71.4 to 84.4 for 1-MCP fruit) at day 7 and remained constant at day 21.

Sensory quality of boiled plantain (ampesi)

After 21 d of storage sensory attributes for all *ampesi* samples were rated higher than 5 (neither like nor dislike) on the hedonic scale (Table 2). After 7 d *ampesi* prepared from control plantains stored at 30°C were rated higher in Overall Acceptability (8.00), Mouthfeel (8.06) and Taste (8.18) than 1-MCP-treated fruit (6.71, 6.59 and 6.59, respectively). *Ampesi* made from fruit from both treatments after 7 d at 15°C were not rated as different from the other treatments at 30°C. *Ampesi* made from the 1-MCP-treated fruit stored at 30°C was consistently rated lower for Appearance (6.18) and Colour (6.24) than the other treatments. Panelists rated aroma and texture as acceptable, and there were no differences due to treatment, where means ranged from 6.65 to 7.76. *Ampesi* made after 21 d storage was rated as acceptable for all attributes (6.65 to 7.55), and there were no significant differences between treatments (Table 2). Several studies on plantain have established that overall consumer acceptability is positively correlated with texture, flavour, taste and colour (Baiyeri *et al*., 2011 and Baiyeri, 2001).

Conclusions

This study established that untreated mature-green plantain (cv. Falsehorn) maintained acceptable quality for 20 d at 15°C or at 30°C when treated with aqueous 1-MCP formulation (100 ug l^{-1}). These fruits exhibited delayed changes in peel colour and reduced pulp softening during storage. Sensory panelists rated the *ampesi* produced from 1-MCP treated plantains after 7 and 21 d storage at 15 °C as having acceptable quality. This study has therefore shown the potential of extending the postharvest keeping qualities of plantain fruit during handling and distribution stages through the use of aqueous 1- MCP and refrigeration.

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