EFFECTS OF STORAGE OF BANANAS IN CONTROLLED ATMOSPHERE BEFORE ETHYLENE TREATMENTS ON ITS RIPENING AND QUALITY*

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ABSTRACT

The study was conducted in Post Harvest Laboratory, Cranfield University at Silsoe College, UK during 1999. The objective was to investigate whether ripening processes in banana fruits which are depressed in reduced O_2 and increased CO_2 storage for two weeks, could be initiated with ethylene treatment and produce good quality ripe fruit like control. It was observed that ethylene treatment became dominant over the inhibition effect of controlled atmosphere storage when bananas were removed to normal air. All bananas including control reached colour stage 6 after 9 days of ethylene treatment. Bananas exhibited the lowest weight loss at 2 percent O_2 with 8, 6 and 4 percent CO_2 while the control showed higher percentage of weight loss during storage. The trend of weight loss was changed during ripening which was less in storage conditions but it increased with ethylene treatments. The total weight loss (storage + ripening) was greater (5.48%) in control and it was lower (4.71, 4.54 and 4.68%) in storage at 2 percent O_2 with three levels of CO_2. Controlled atmosphere storage showed no effect on total soluble solids. Bananas stored at 2 percent O_2 with 4, 6 and 8 percent CO_2 produced firm bananas (3.48, 5.51 and 3.54 values N/mm). Firm and ripe bananas could be less susceptible to mechanical injury and some fungal diseases.

KEYWORDS: Bananas; controlled atmosphere storage; oxygen; carbon dioxide; chlorothalonil; United Kingdom.

INTRODUCTION

Controlled atmosphere (CA) storage is a technique for maintaining the process quality in an environment that differs from air with respect to the proportion of O_2 and CO_2 (1). Wills *et al.* (16) describe CA storage as the precise control of oxygen and carbon dioxide concentrating usually with a decrease in oxygen and increase in the carbon dioxide to extend the produce storage life. The respiration rate of fresh produce is slowed down with a decrease in oxygen of fresh produce.

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Banana is the most important fruit crop of the world. It was estimated that 100 million people subsist on banana which is their main energy source (11). They are chiefly eaten raw as a dessert fruit, because in the ripe stage they are sweet and easily digestible. They are also useful for patients with peptic ulcers, for the treatment of infant diarrhoea, in celiac disease and colitis.

Commercial ripening of bananas is initiated with exogenous ethylene treatment and these bananas can survive maximum upto one week. In this short period these bananas cannot reach the ultimate consumers so these are over ripened at the outlets and heavy losses occur. CA storage condition inhibits ethylene production and retards the rate of banana ripening (10). However, care has to be taken because low oxygen can cause fermentation/anaerobic respiration. Therefore, it is necessary to formulate different combinations to delay ripening of banana fruit, while allowing there to subsequently ripen to good quality. Liu (6) stored pretreated bananas (ethylene treated) for 28 days in 1 percent oxygen at 14°C. He observed that bananas remained green and firm until the end of storage, but started to ripen almost immediately after these were placed at 21°C in air without addition of ethylene treatment. Acedo and Bautista (2) reported that fruit can be successfully stored under low oxygen conditions without raising the carbon dioxide in the atmosphere. Wills *et al.* (16) found in short term CA storage that addition of carbon dioxide did not improve the effect of low oxygen. Mapson and Robinson (8) claimed that unripe fruit did not synthesize significant amount of ethylene at 18°C unless the oxygen level was above 7.5 – 8.0 percent. Abdullah *et al.* (1) reported that storage in reduced oxygen and increased carbon dioxide reduced the respiratory activity and slowed down the ripening processes. Nair *et al.*(9) observed that oxygen and carbon dioxide quickly equilibrated when bananas were removed from lower oxygen to normal air. Knee (5) reported that the chlorophyll breakdown was reduced clearly in reduced oxygen. However, this effect could not show any significant effectiveness when bananas were ripened in the normal air without ethylene treatment.

This research has been undertaken to explain the effect of reduced oxygen and increased carbon dioxide storage before ethylene treatments on the ripening and quality of banana fruit.

MATERIALS AND METHODS

This study was conducted in Post Harvest Laboratory of Cranfield University at Silsoe College, UK during 1999. Pre-climacteric Cavendish bananas were obtained from C.E. Wilkinson in Bedford. These were uniform in colour.

Undamaged hands with 6-8 fingers were selected and stored at 2, 4 and 6 percent O_2 with 4, 6 and 8 percent CO_2 and compared with the fruits stored at 21 percent O_2 + 0 percent CO_2 (control) for two weeks at 14°C.

CA System

The fruits used for controlled atmosphere were tested with required gas mixture of CO_2 and O_2 in closed system inside the controlled temperature rooms. The closed system consisted of air tight plastic containers (Model C217, Mailbox International Ltd, Cheshire, UK) having 75 liter capacity each. Each container had one inlet and one outlet tube. The tip of the outlets was immersed in water to prevent back flow into the container. The inlet tubes were connected to channel the gas distributor (Mercury, UK Serial No. SS13306) by PVC tubing of 6.5 mm internal diameter. The gas distributor was connected to a computer programmed gas blender (Signal Instrument Co. Ltd. Srrey, UK 850 series) which was connected to compressed oxygen and carbon dioxide with a nitrogen generator (Bolton 75-72). Times and intervals used in each particular controlled atmosphere are specified in each experiment.

Controlled atmosphere combination between oxygen and carbon dioxide were made according to gas concentration needed in each experiment. The gas output from the gas blender and controlled atmosphere storage containers was analyzed regularly for oxygen and carbon dioxide levels using an Oxystate 2 Fruit Store Analyzer fitted with an Infra Red Gas Analyzer and a paramagnetic Oxygen Analyzer (David Biship Instrument Sussex, UK type 770).

The inlet and outlet gases were analysed each day to check the O_2 and CO_2 levels. The actual mean gases mixtures in the experiment were as follows:-

O_2 (%)		CO_2(%)
2.2	+	4.5
2.2	+	6.5
2.2	+	8.4
4.3	+	4.6
4.3	+	6.5
4.3	+	8.2
6.5	+	4.6
6.5	+	6.6
6.5	+	8.5
21.5	+	0.0

After two weeks fruits were removed from the storage and treated with 1000 ppm ethylene for 24 hours to initiate the ripening and then stored at 16°C in normal air for ripening. This experiment was conducted with four replications. Fruits were analyzed when these reached colour score 6 (ripened)

Assessment of fruit ripening and quality

Ripening of banana fruit was assessed according to peel colour changes compared with a colour chart as described by Stover and Simmonds (13). The quality of ripe fruit was assessed by the following two methods.

Objective method: The peel colour was measured by colorimeter (Minolta Model CR-200/CR-200b). Results were recorded in a* and b* values. A positive a* representing the degree of redness, negative value corresponds to the degree of greenness. A positive b* value represents the degree of yellowness and negative one represents the degree of blueness. Peel firmness was measured using an Instron Universal Testing Machine (Model 2211) with an 8 mm cylindrical probe.Total soluble solids percentage was measured using a refractometer (Atago Co-Ltd refractometer PR-1). Starch percentage was measured by using a technique recommended by Blankinship *et al.* (3).

Individual fruits were weighed using a digital balance (precisa 6000 D) just before storage, then reweighed at score 6 (fully ripe) and cumulative weight loss percentage was calculated as follows:

$$\textit{Weight loss} = \frac{W_o - W_1}{W_o} \times 100$$

where W_0 = Original weight and W1 = Weight at sampling (when banana reached colour score 6)

Weight loss percentage per day was calculated as follows:

$$\textit{Weight loss percentage per day} = \frac{TWP}{SL}$$

where TWP = Total weight loss percentage at colour stage 6,
SL= Storage life (total days when bananas reached colour stage 6 from pre-climacteric stage)

Pulp and peel were separated when banana reached colour stage 6. Peel and pulp were weighed individually and expressed as pulp peel ratio as follows:

$$\text{Pulp/peel ratio} = \frac{\text{Pulp weight}}{\text{Peel weight}}$$

Sensory evaluation: The fruits were removed from the storage when these were at colour score 6. A panel of eight judges was selected from the college and the tests involved individual in isolated tasting conditions under a standard light source. Judges were asked to assess pulp flavour, sweetness, off flavour, astringency and acceptance on the five pointed scale as follows:

1 = Low
2 = Moderate
3 = Moderate to high
4 = Good/high
5 = Very good/very high

The scores marked by panelists were collected and an average was calculated for each parameter and sub-parameters. These averages were calculated and presented in the form of tables.

Statistical analysis

Data were processed using analysis of variances (ANOVA) techniques based on completely randomized designs (CRD) using MSTAT, a PC based programme. LSD at P = 0.05 was used to test for significant differences of results where applicable.

RESULTS AND DISCUSSION

Storage life (speed of ripening)

The results (Table 1) indicated no variation in speed of ripening after ethylene treatment. The bananas of all treatments including control ripened at the same time after nine days of ethylene treatment. The ripening of bananas at the same time after CA storage with ethylene treatment indicated that ethylene effect on ripening was dominant over the residual inhibiting effect of CA storage when bananas were removed to normal air. It can be safely assumed that decreased O_2 and increased CO_2 storage had an ethylene inhibitor effect, but it may fail to exert a long lived influence when withdrawn. Such type of effect was previously observed by Abdullah *et al.* (1). However,

if cause of inhibition is withdrawn, normal ripening will proceed on the return of fruits to normal atmosphere.

Table 1. Effect of reduced O_2 and increased CO_2 on the ripening and quality of banana fruit.

Treatment	Storage life (days)	Peel colour a* values	Peel colour b* values	Peel firmness (N/mm*)	Pulp firmness (N/mm)	TSS (%)	Starch (%)
T_1 (2% O_2 + 4% CO_2)	9.0	-4.57b	+49.27	3.48a	2.26a	21.0	6
T_2 (2%O_2 +6%CO_2)	9.0	-4.61b	+49.59	3.51a	2.01bc	21.4	7
T_3 (2%O_2+8%CO_2)	9.0	-4.98a	+48.91	3.54a	2.35a	21.2	7
T_4(4%O_2+4%CO_2)	9.0	-4.00cd	+50.25	3.09bc	1.72cd	22.5	6
T_5(4%O_2+6%CO_2)	9.0	-4.09cd	+50.00	3.17bc	1.92bc	23.1	6
T_6(4%O_2+8%CO_2)	9.0	-3.87cd	+50.09	3.22bc	1.74cd	21.8	5
T_7(6%O_2+4%CO_2)	9.0	-3.75cd	+50.74	2.64de	1.74cd	21.9	5
T_8(6%O_2+6%CO_2)	9.0	-3.87cd	+51.04	2.82bc	1.54de	22.6	5
T_9(6%O_2+8%CO_2)	9.0	-4.06cd	+49.84	2.83bc	1.50de	22.4	5
T_{10}(21%O_2+0%CO_2)	9.0	-4.02cd	+50.99	2.32ef	1.44de	22.4	5
LSD	N.S	0.29	NS	0.14	0.15	NS	NS
CV		14.7%	3.2%	8.1%	8.2%	8.4%	18.0%
Initial reading		-19.17	+53.37	28.8	17.07	9.4	90-95%

NS = Non-significant, NA = No Analysis

Weight loss percentage

Weight loss percentage during storage, ripening and total weight loss showed significant results at P = 0.05 level (Table 2). Banana exhibited the lowest weight loss at 2 percent O_2 with 8, 6 and 4 percent CO_2 while control fruits (21% O_2 + 0% CO_2) showed higher percentage of weight loss during storage. Weight loss was less in storage but it increased during ripening. During ripening, control fruit exhibited reduced weight loss but fruit stored at 2 percent O_2 with different combinations of CO_2 showed greater weight loss than those stored at other treatments. The total weight loss (storage + ripening) was greater in fruits stored in control and lower in those stored at 2 percent O_2 with different levels of CO_2. The levels of CO_2 showed interesting results as in storage higher concentrations gave lower weight loss than lower concentrations, but weight loss increased when removed to normal air after ethylene treatment. The reduced weight loss during storage and increased weight loss during ripening could be due to the reduced respiration and greater respiration, respectively. It was concluded that reduced O_2 and increased CO_2 decreased the respiration rate of banana fruit but when the fruits were treated with ethylene and moved to normal air these started respiration at faster rate than control, because O_2 and CO_2 levels equilibrated in the air. This effect has also been reported by Nair *et al.* (9). The greater weight loss during ripening at low O_2 could be due to longer life as total weight loss increased with the length of storage.

Table 2. Effect of reduced O_2 and increased CO_2 on weight loss (%) of banana fruit.

Treatment	Weight loss during storage	Weight loss/day during storage	Weight loss during ripening	Weight loss/day during ripening	Total weight loss	Total weight loss/day
T_1 (2% O_2 + 4% CO_2)	2.19bc	0.15de	2.52b	0.28b	4.71cd	0.20de
T_2 (2%O_2 +6%CO_2)	2.07cd	0.14ef	2.47bc	0.27cd	4.54de	0.19ef
T_3 (2%O_2+8%CO_2)	2.00cd	0.14ef	2.66a	0.29a	4.68cd	0.20de
T_4(4%O_2+4%CO_2)	2.34	0.16cd	2.53b	0.27cd	4.84bc	0.21cd
T_5(4%O_2+6%CO_2)	2.30bc	0.16cd	2.49bc	0.27cd	4.79bc	0.22bc
T_6(4%O_2+8%CO_2)	2.24bc	0.16cd	2.57b	0.28b	4.83bc	0.21cd
T_7(6%O_2+4%CO_2)	2.50b	0.17b	2.43bc	0.27cd	4.95b	0.23a
T_8(6%O_2+6%CO_2)	2.38bc	0.14b	2.52b	0.28b	4.90b	0.21cd
T_9(6%O_2+8%CO_2)	2.47b	0.17b	2.35cd	0.26de	4.86bc	0.21cd
T_{10}(21%O_2+0%CO_2)	3.19a	0.22a	2.29cd	0.25ef	5.48a	0.23a
LSD (P = 0.05)	0.09	0.001	0.07	0.001	0.06	0.001
CV	8.7%	1.3%	6.5%	2.9%	2.8%	4.5%

NS = Non-significant, NA = No Analysis

Peel colour

There was no significant variation between peel colour as measured by a* (greenness) and b* (yellowness) at P = 0.05 level (Table 1). There was an indication that bananas stored at lower O_2 levels were slightly greener than those which were stored at higher O_2 levels. However, statistically bananas stored in CA before ethylene treatment did not show any effect on peel colour when these were ripened in normal air with ethylene treatment. It means that CA storage did not show any residual effect on peel colour development, therefore bananas completed their ripening processes normally in normal air.

Peel firmness and pulp firmness

Analysis of variances showed significant results for peel firmness at P = 0.05 level (Table 1). The firmness showed a negative correlation with O_2 levels. Firmness decreased when O_2 level increased. Bananas stored at 2 percent O_2 with 4, 6 and 8 percent CO_2 exhibited greater firmness when compared to other combinations. The bananas stored at control and at higher levels of O_2 were significantly softer than stored at lower levels of O_2. Pulp firmness showed significant differences at P = 0.05 level. The pulp of control fruits was significantly softer than thos stored at 2 and 4 percent O_2 with different levels of CO_2. No significant difference was found in the pulp of fruits stored in control and 6 percent O_2 with 6 and 8 percent CO_2.

The control of ripening is important to reduce mechanical damage and in maintaining fruit quality. Firm banana fruits with similar total soluble solids

(TSS) as in control indicated that bananas had completed ripening processes normally when removed from the storage to normal air. This could be due to the reduced weight loss resulting from reduced respiration or lower enzyme activity. The same effect of low O_2 has been found in tomatoes and apples by Kim and Hall (4) but they could not find the specific reason for this phenomenon. It has previously been reported by Salunkhe and Desai (12) that controlled atmosphere with high CO_2 inhibits the breakdown of peptic substances, retains fruit texture and remains firmer for a longer period. In current research this effect was most dominant at reduced O_2 levels but effect of low O_2 cannot be separated from the effect of increased CO_2 (14). However, firmer ripe fruit is considered one of the benefits of CA storage to reduce the mechanical damage, avoid fungal infection and to increase the shelf life of ripe banana fruit.

TSS and starch percent

Analysis of variances showed non-significant results for TSS at P = 0.05 level (Table 1). There were no significant differences between TSS in all bananas including the control. Starch percentages showed non-significant results at P = 0.05 levels (Table 1). In this investigation some treatments showed TSS similar to control but the fruits were firmer than control. This indicates that softening of bananas is not completely caused by starch hydrolysis. Therefore, in these cases some other mechanism must have been involved as mentioned in peel pulp firmness.

Sensory evaluation

Analysis of variances showed non-significant differences for all parameters (Table 3). Panelists could not differentiate between bananas regarding flavour, sweetness, astringency and off odour. Bananas of all treatments including the control showed the same eating quality at colour stage 6. Sensory evaluation indicated that bananas in normal air ripened normally without any significant difference in eating quality. Madrid and Lee (7) supported the present investigation observing that controlled atmosphere stored bananas had higher firmness and lower soluble solids content for the first three days during subsequent ripening with no effect on peel colour. All differences disappeared when fruit reached to eatable ripeness.

Table 3. Effect of reduced O_2 and increased CO_2 on sensory evaluation of banana fruit (5 = Maximum score (very good or high), 1 = minimum score (very low or nil)].

Treatment	Flavour	Sweetness	Astringency	Off-odour	Acceptance
T_1 (2% O_2 + 4% CO_2)	3.5	4.0	1.0	1.0	4.0
T_2 (2%O_2 +6%CO_2)	3.5	4.0	1.0	1.0	4.0
T_3 (2%O_2+8%CO_2)	3.4	4.0	1.0	1.0	3.9
T_4(4%O_2+4%CO_2)	3.7	4.1	1.0	1.0	4.1
T_5(4%O_2+6%CO_2)	3.9	4.2	1.0	1.0	4.2
T_6(4%O_2+8%CO_2)	3.5	4.1	1.0	1.0	4.1
T_7(6%O_2+4%CO_2)	3.9	4.1	1.0	1.0	4.2
T_8(6%O_2+6%CO_2)	3.8	4.4	1.0	1.0	4.3
T_9(6%O_2+8%CO_2)	3.5	4.2	1.0	1.0	4.2
T_{10}(21%O_2+0%CO_2)	3.7	4.2	1.0	1.0	4.1
LSD (P = 0.05)	NS	NS	NA	NA	NS
CV	8.8%	11.0%			13.1%

NS = Non-significant, NA = No Analysis

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