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REVIEW

Respiration Properties of Tree-Ripe Mango under CA Condition

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Abstract

Respiration rate is the necessary parameter for designing the storage conditions. In the present investigation, the effects of storage temperatures (5, 10, 15, 20, 25ºC) and gas composition on the O_2 consumption and the CO_2 production have been studied by using the flow through system. The ratio of the respiration rate under controlled atmosphere (CA) conditions (1.6 to 20.7% O_2, 0.2 to 10.2% CO_2, balanced with N_2) were calculated against the values under normal air condition. As a result, it was found that a decrease in O_2 concentration suppressed O_2 uptake at each temperature involving an increase of the respiratory quotient. On the other hand, an increase in CO_2 concentration up to 10% suppressed both O_2 uptake and CO_2 output at 5–15ºC with almost a constant respiratory quotient. Thus, low temperature combined with CA having 5–10% CO_2 will be effective to suppress the respiration rate of tree-ripe 'Irwin' mango fruit, and O_2 should be higher than 5% to avoid anaerobic respiration.

Discipline: Post harvest technology / Food
Additional key words: full ripe mango, oxygen, carbon dioxide, controlled atmosphere, storage

Introduction

Tree-ripe 'Irwin' mango fruit grown under green houses in Japan have excellent quality. However, their harvesting period is very limited with short storage life. Therefore, it is highly required to develop a suitable technology for extending the shelf-life and preserving the fruit quality during storage. Respiratory behavior is one of the most important indexes of physiological activities of fruits and vegetables, which is required to design effective storage conditions. The respiration rate of fruits and vegetables are suppressed by adequate temperature and gas composition. Storage methods for controlling them are known as Controlled Atmosphere (CA) storage and Modified Atmosphere (MA) packaging. Kader summarized major matters about the optimum CA condition, effect of the atmospheric condition and injury symptoms on various crops[9]. Ishikawa et al. made a prediction model of gas composition in packaging[7].

The idea of respiratory suppression under high CO_2 condition has been explained by the fact that CO_2 strongly affects mitochondrial activity[4,11,21]. Inaba et al. developed an automated system for the simultaneous measurement of respiration rate of horticultural products even in atmospheres containing a considerable amount of CO_2[6], and Kubo et al. reported that the respiratory suppression by high CO_2 was observed on certain crops involving C_2H_4 production[12,13].

Meanwhile, the mechanism of respiratory suppression by lowering the O_2 level is not clear enough[1], there is a suggestion to apply Michaelis-Menten enzyme kinetic models, which are based on a theory of enzymatic reaction[14,19]. Additionally, Dan et al. showed the respiratory responses to low O_2 condition were distinct by each crop[2,3]. Shiina et al. reported that the respiratory suppres-

This paper is based primarily on the report[17,18] of our previous studies on the respiration rate of mango fruit carried out by Distribution Engineering Laboratory, National Food Research Institute (2000).

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sion by O_2 is dramatic under higher temperature[23].

However, an extremely low O_2 condition causes damage to the quality of fruits and vegetables by the accumulation of acetaldehyde and ethanol etc.[10], produced by anaerobic respiration with a high value of respiratory quotient. Meanwhile extremely high CO_2 conditions also introduce injuries as typified by softening, off-flavor and discoloration[5]. Hence, the measurements of respiration rates under various atmospheres are considered to lead to information about the storage condition.

In this study, we used tree-ripe mango 'Irwin' cv. According to the report of Kader, the typical recommended CA condition for mango fruits was 10–15ºC, 3–7% O_2 and 5–8% CO_2 [9]. Other reports also indicated similar condition[15,20,24]. However, there are few studies about the storage of tree-ripe mangoes because fruits are usually harvested at green mature stage and force-ripened after storage. In addition, there are very few reports about 'Irwin' cv.[7,8,16,26–28] grown in Japan.

In this present report, we discuss about respiratory behavior of tree-ripe mango 'Irwin' cv. under CA at different storage temperatures (5–25ºC) to determine optimum storage conditions.

Materials and methods

1. Materials

Tree-ripe 'Irwin' mangoes used for this study were produced under greenhouse conditions in Miyazaki Prefecture. Mango fruits were harvested on July 13, 2001, and then reached our institute on July 15 by cool delivery service at about 5ºC. In the laboratory, fruits were kept for 2 days at 5ºC and thereafter divided into five groups and shifted to 5, 10, 15, 20 or 25ºC for 1 day.

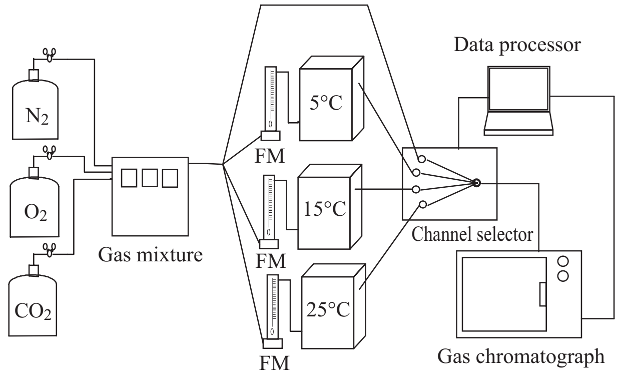

Fig. 1. The schematic of flow through system
FM: Flow meter.

2. Flow through system for respiration measurement

For respiration measurements, we used a flow through system[23] designed by ourselves referring to the report of Inaba et al.[6]. Fig. 1 shows the schematic diagram of the respiration measurement system. This equipment consists of CA gas generator controlled by mass flow controller, flow meter with a needle valve, acrylic chambers for samples, channel selector, gas chromatograph, and the data processor. Mixed gas was divided into four lines; one of them was used as the inlet gas measurement. The other 3 lines were led to the sample chambers, and then outlet gases were measured. Respiration rate was calculated from sample mass, flow rate of CA gas to the sample chamber and the difference in the gas concentration between inlet and outlet. A channel selector controlled by the data processor selects the line to be analyzed. Gas composition was measured by gas chromatograph (Shimadzu, GC-8A) equipped with a thermal conductivity detector.

Table 1. Experimental conditions and gas compositions

Inlet		Outlet									
		5ºC		10ºC		15ºC		20ºC		25ºC	
O_2	CO_2	O_2	CO_2	O_2	CO_2	O_2	CO_2	O_2	CO_2	O_2	CO_2
1.64	0.00	1.57	0.28	–	–	–	–	–	–	–	–
5.88	0.00	5.59	0.30	5.53	0.48	5.61	0.55	5.81	0.20	5.82	0.27
10.44	0.00	10.09	0.34	9.95	0.49	10.02	0.51	10.15	0.42	10.22	0.48
15.06	0.00	14.70	0.32	14.54	0.46	14.49	0.56	14.46	0.66	14.52	0.88
20.40	0.00	20.04	0.32	19.86	0.47	19.71	0.60	19.65	0.72	19.68	0.92
21.04	0.00	20.76	0.31	20.58	0.46	20.91	0.51	20.91	0.19	20.94	0.29
21.06	1.77	20.77	2.05	20.71	2.11	20.73	2.14	20.73	1.76	20.64	1.99
21.07	4.72	20.79	5.00	20.74	5.04	20.75	5.06	20.75	5.12	20.61	5.39
21.15	9.60	20.95	9.81	20.83	9.93	20.95	9.91	–	–	20.90	10.21

3. Measurement of the respiration rate under CA condition

Respiration rate of mango fruits was measured under CA conditions (5.5 to 21.0% O_2, 0.3 to 10.2% CO_2, balanced with N_2) at each temperature, as shown in Table 1. Outlet gas concentrations were used as the storage gas concentration, since gas concentration within the respiratory chamber should be equal to that of the outlet gas on the flow through system with perfect mixing. Gas flow rate of 300 mL min^{-1} was employed as in the pilot study.

Measurement of respiration rate at each temperature under various CA conditions was done by using the same samples from beginning to the end. We realize that gas concentration before measurement may cause some effects on respiration rate. Therefore CA gas and normal air (21% O_2, 79% N_2 and 0% CO_2) were flowed alternately at 2 day intervals to eliminate the effect. In order to evaluate the respiration rate under CA conditions, we adopted relative respiration rate (RR), which was the ratio of the rate under different CA conditions to that under normal air.

Results and discussion

1. Gas exchange property of sample chamber

Data in Fig. 2 show the changes in dimensionless O_2 concentration (O_d) inside the chamber, when N_2 was flowed at constant flow rate (300 mL min^{-1}) into the chamber after being enclosed with normal air. O_d was calculated by the following equation:

$$O_d = (O_t - O_\infty) / (O_O - O_\infty)$$

where the variables are, O_t : O_2 concentration at time t ; O_∞ : Final O_2 concentration; and O_O : Initial O_2 concentration, respectively.

The dimensionless concentration of O_2 decreased to approximately 1/100, 1/1,000 and 3/10,000 after 5, 7 and 10 h, respectively. The respiration rate is calculated by the difference of inlet and outlet gas concentration as mentioned above with an expected minimum difference of 0.1%. In order to have less than 10% error in the respiration rate throughout this experiment, the dimensionless gas concentration should be below 1/2,000, and it should take about 8.5 h for the change in the gas concentration.

2. Respiration rate under normal air condition

Respiration rate of mango under normal air on the first day of this experiment is given in Fig. 3. The relationships between respiration rate and storage temperature for O_2 and CO_2 were expressed by the following equations: $Qo = 8.28 \times 10^{0.0297T}$ and $Qc = 8.56 \times 10^{0.0370T}$, respectively. Where, Qo is O_2 uptake; Qc is CO_2 output; and T is storage temperature, respectively. Respiration rate was highly affected by lowering temperature. Temperature coefficients (Q_{10}) were 1.98 for O_2, and 2.34 for CO_2.

Data in Fig. 4 show that there was less variation in

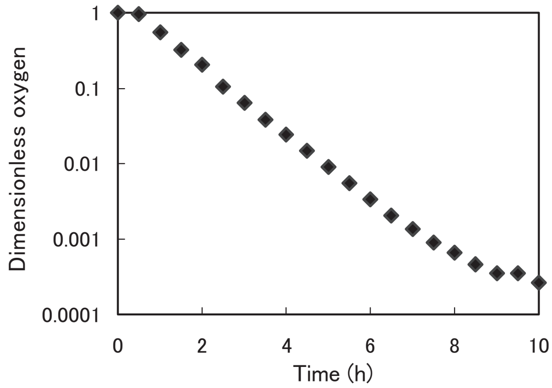

Fig. 2. The characteristic of gas exchange of the chamber
Flow rate : 300 mL min^{-1}.

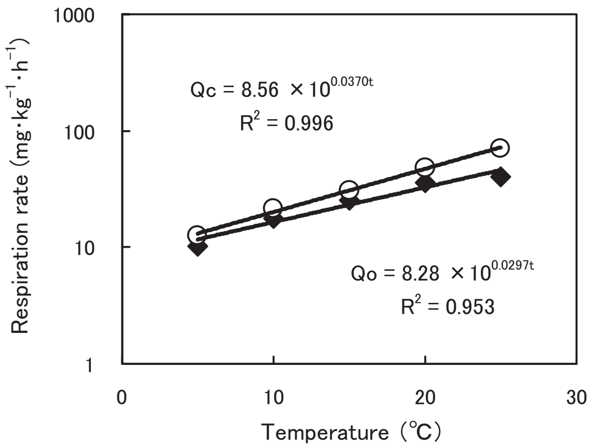

Fig. 3. Effect of storage temperature on the respiration rate in mango
◆ : O_2 , ○ : CO_2.

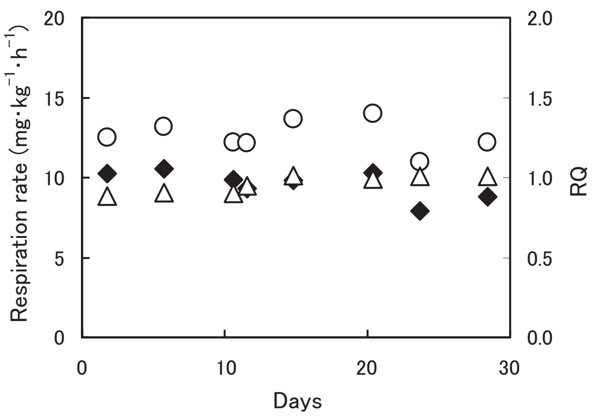

Fig. 4. Changes in the respiration rate under air condition during storage (5°C)
◆ : O_2 , ○ : CO_2 , △ : RQ.

respiration rate at 5ºC under normal air conditions throughout the experiment. In a previous experiment in 2000, output of CO_2 under normal air was affected by CO_2 concentration of the previous CA, due to the higher CO_2 concentration of the previous CA, there was higher output of CO_2 under normal air conditions (data not shown). This seems to be caused by CO_2 accumulated in the fruit flesh maintained in CA at the higher CO_2 levels.

Ueda et al. studied the effects of storage on the respiration of tree-ripe 'Irwin' mango fruit[27,28] and reported that in comparison to the respiration rate of freshly harvested fruits, there was a 35% decrease in respiration rate in the fruits after 3 days storage at 25ºC. However, in the present investigation we did not observe any change in the respiration rate of mango fruits up to 10 days of storage at 5, 10 and 15ºC under normal air conditions. There was an increase in CO_2 output and respiratory quotient (RQ) after 10 days at 10 and 15ºC. These findings indicate that the quality changes are suppressed by low temperature storage. On the other hand, we observed a gradual decrease in respiration rate at 20ºC and 25ºC, but it was non-significant as the measurement of respiration rate was started after 3 days of the fruit harvest.

3. Respiration rate under CA condition

Data on relative respiration rate (RR), O_2 uptake or CO_2 output, and respiratory quotient (RQ) of mango under CA conditions at each temperature are given in Fig. 5.

(1) Effects of O_2 concentration

A close perusal of the data indicates that RRs of O_2 uptake were apparently suppressed by lowering O_2 concentration, except for 10% or more O_2 at 5ºC. However, RRs of CO_2 showed slight changes. Results obtained in this study agree with the reports[22,25] which indicated that O_2 concentration has more effect on O_2 uptake and less effect on CO_2 output. Therefore, an increase of RQ was observed by lowering O_2 concentration at 15, 20 and 25ºC. This increasing tendency of RQ was most apparent at 25ºC. This high increase of RQ indicates anaerobic respiration of fruits. Hence, it is not suitable to store mango fruits in CA below 5% O_2 at 5 and 10ºC, below 10% O_2 at 15 and 20ºC, and below 15% O_2 at 25ºC, because anaerobic respiration sometimes induces skin discoloration and off-flavor development[29].

(2) Effects of CO_2 concentration

It was found that the increase in CO_2 concentration suppresses both the relative O_2 uptake and CO_2 output, and RRs are more suppressed at 5ºC than at higher temperature (not clear at 25ºC), but there was an increase in the RQ at 10% CO_2 (Fig. 5). However, we are not sure whether these variations in the results may be caused due to a change in fruit quality.

The observations were continued for 4 weeks with

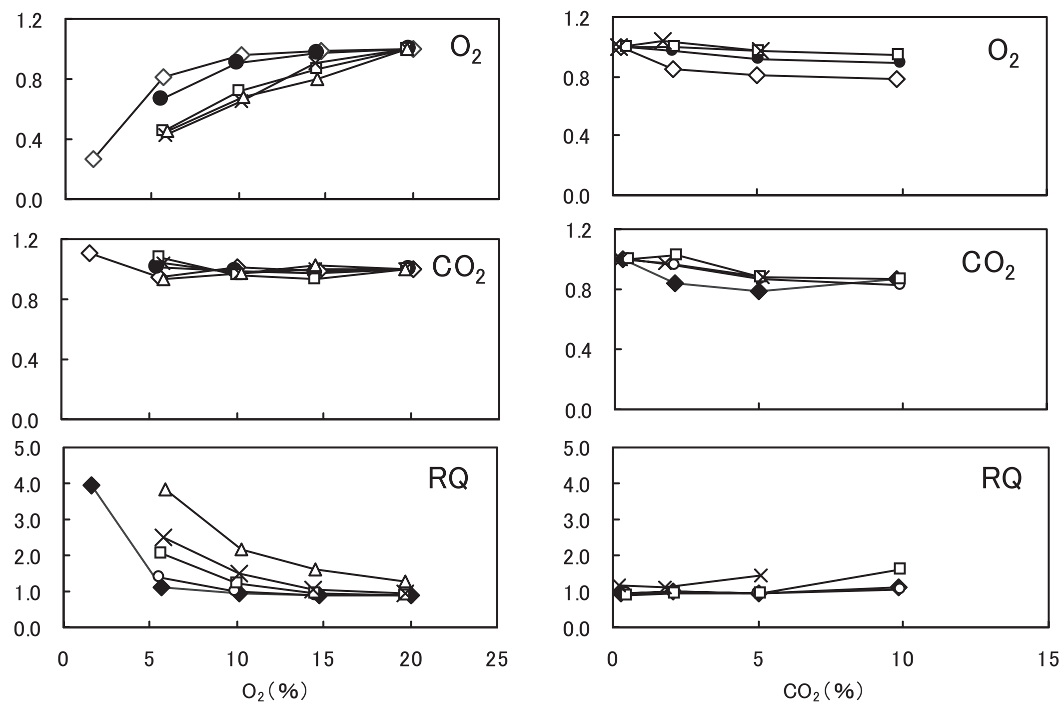

Fig. 5. Effect of O_2 and CO_2 concentration on relative respiration rate (RR) and respiratory quotient (RQ) in mango
◇ : 5ºC, ◆ : 10ºC, □ : 15ºC, × : 20ºC, △ : 25ºC.
Refer to Table 1 for gas concentration.

removing or changing samples in which we observed obvious deteriorations such as changes of pericarp color, development of fungus, etc. On the other hand, the quality was well maintained for one month at 5ºC without symptoms of chilling injury. However, black spots caused by Anthracnose were observed on the skin of mango fruit after one month of storage.

These results indicate that it is effective to keep mango fruits at a temperature of about 5ºC and a CO_2 concentration of about 5–10%, with 5% or more O_2. It is reported that high concentrations of CO_2 over 10% cause CO_2 injury, i. e. development of off-flavor, softening, and grayish flesh coloring[9]. Therefore a level of CO_2 above 10% is considered to be injurious for mango fruits. More investigations on the injurious level of CO_2 will give the best storage condition of mango fruit.

Conclusion

The respiration behavior of tree-ripe 'Irwin' mango under CA conditions was observed to determine the optimum storage condition. Results obtained are as follows:

- Relationship between respiration rate and temperature was linear in semi-log.
- There was no symptom of chilling injury during one month of storage at 5ºC.
- A decrease in O_2 concentration suppressed O_2 uptake, and slightly affected CO_2 output, and consequently the respiratory quotient increased.
- An increase in CO_2 concentration up to 10% suppressed both O_2 uptake and CO_2 output at 5, 10 and 15ºC. Therefore the respiratory quotient was almost constant.

The results obtained on the respiration rate and the respiratory quotient suggest that low temperature in combination with CA gas composition of carbon dioxide at 5–10% will be effective to suppress the respiration rate of tree-ripe 'Irwin' mango fruit, and oxygen should be higher than 5% to avoid anaerobic respiration.

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