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Retention of Freshness in Fig Fruit by CO_2-Enriched Atmosphere Treatment or Modified Atmosphere Packaging under Ambient Temperature

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Summary

At 20°C, freshness retention of figs (*Ficus carica* L. cv. Masui Dauphine) by CO_2-enriched atmosphere treatment or modified atmosphere packaging were studied in an attempt to reduce deterioration during transportation. CO_2-enriched atmosphere treatment inhibited ethylene production, delayed the incidence of mold growth and promoted ethanol production. Majority of the figs exposed to 60% or 80% CO_2 for 2 days were still marketable 1 day after transfer to air at 20°C.

Based on mold growth, figs stored in air and in unperforated polyethylene bags deteriorated slightly faster than those stored in perforated bags. A gas mixture of 80% CO_2 + 20% O_2 or 100% CO_2 introduced into the polyethylene bags before sealing were more effective in the control of mold growth compared to air or 100% N_2 and equally effective in reducing ethylene accumulation as 100% N_2. The results suggest that postharvest deterioration of figs can be reduced by either CO_2-enriched atmosphere treatment or through modified atmosphere packaging.

Introduction

Figs (*Ficus carica* L.) are usually limited in their postharvest storage by the high rate at which the fruits soften thereby making storage and/or transportation difficult. This problem is further aggravated by the fact that although figs are classified among the climacteric type of fruits (Marei and Crane, 1971), they are harvested when they are almost fully ripened in order to develop the optimum flavor (Tsantili, 1990). At this stage, however, they become soft and susceptible to bruising and splitting (Tsantili, 1990) thereby providing avenues for microbial molds (Colelli et al., 1991). For this reason the postharvest life of figs is limited to only 1～3 week at 0°C (Snowdon, 1990). Little information is, however, available on the storage and transportation of figs especially without the use of refrigerated facilities.

The use of reduced O_2 and/or elevated CO_2 has been shown to delay fruit ripening, reduce respiration and ethylene production rates, retard softening and suppress decay in several fruits (Zagory and Kader, 1988; Li and Kader, 1989; Colelli et al., 1991). Alternatively, the quality of most fresh fruits and vegetables can be maintained by holding them in modified atmosphere (MA) formed within sealed polymeric films as a result of respiration (Hardenburg, 1971) or intentionally by replacing the package atmosphere with the desired gas mixture (Zagory and Kader, 1988). While the precooling transport system of fruits and vegetables from producer to consumer has greatly been improved in Japan, exposure of these commodities to ambient temperature for a short time during postharvest handling cannot be avoided (Nakamura et al., 1992). For instance, small amounts of figs produced by small-scale farmers are transported under ambient conditions. MA packaging (MAP) can possibly serve as an alternative or a supplement to complete cold chain transport system or use of fungicides to extend the shelf life of fresh

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figs.

This study was therefore undertaken to investigate the postharvest transport potential of figs as influenced by CO_2-enriched atmosphere treatment or MAP at 20°C.

Materials and Methods

1. Plant material and treatments

Figs (*Ficus carica* L. cv. Masui Dauphine) were obtained from a local producer in Okayama Prefecture. The figs were selected for uniformity and lack of defects. The number of fruits per replicate were eight.

In the treatment with various concentrations of CO_2, fruits were placed in 5.5-liter air-tight plastic containers and held at 20°C. The fruits were flushed with humidified air (control) or humidified gas mixture containing the various CO_2 concentrations for 30 min at a flow rate of 100 ml · min^{-1}. The O_2 concentration was maintained at $20 \pm 1\%$, the balance gas being N_2. To obtain the desired gas mixtures, the flow rates of CO_2, O_2 and N_2 from each of the high pressure gas cylinders were regulated using an electrical flow rate controller (SCEU-1, SEC Inc.). The containers were then sealed and ethylene production rates determined at the indicated time points. After each ethylene determination, the containers were flushed with the appropriate gas mixture and sealed. After the CO_2 treatment for 2 days and keeping for 1 day in air at 20°C, the fruits were evaluated for mold infection. In a separate experiment to determine the effects of CO_2-enriched atmosphere treatment on ethanol production, figs were treated with the various concentrations of CO_2 for 5 days. Ethanol production rates were determined daily after flushing the containers with the appropriate gas composition and the ethanol accumulated in 2 hr was determined. No attempt was made to remove the figs which were already showing signs of mold infection.

In the MAP experiment, eight figs were packaged in perforated and unperforated polyethylene (PE) bags (0.03 mm in thickness) or in PE bags and flushed with 100% CO_2, 80% CO_2 + 20% O_2 or 100% N_2 for 1 hr. The packages were sealed and the gas composition in the PE bags was verified by gas chromatography. The packages were then held at 20°C for 3 days and the concentrations of O_2, CO_2 and C_2H_4 in the packages were monitored.

2. Gaseous monitoring

During MA storage, the gas composition of the microclimate within each bag was monitored by gas chromatography. Samples of the internal gas were withdrawn through a self-sealing septum affixed on the surface of the bags using a 2-ml gas-tight syringe. Ethylene was determined by a gas chromatograph equipped with a flame ionization detector (FID) and an activated alumina column. Carbon dioxide and O_2 concentrations were determined in a gas chromatograph equipped with a thermal conductivity detector, Porapak Q and molecular sieve columns, respectively, and with helium as the carrier gas. Ethanol content was determined by a gas chromatograph equipped with an FID and a Porapak Q column. Nitrogen was used as the carrier gas.

3. Assessment of postharvest deterioration

Quality attributes were evaluated initially and thereafter on a daily basis for the presence of molds and external decay. The percentage spoilage was computed by dividing the number of fruits exhibiting visible molds by the number of fruits per treatment. Quality score was based on the degree of mold infection and the overall visual quality of the figs on a scale of 1 to 5 where, 5 = All fruits are highly marketable; 4 = Majority of fruits are very marketable; 3 = Majority of fruits are marketable; 2 = Majority of fruits are edible but not marketable; 1 = Majority of fruits are not marketable and not edible.

Results

1. Effects of CO_2-enriched gas treatment on ethylene and ethanol production

Carbon dioxide treatment caused an immediate reduction in the rate of ethylene production (Fig. 1) with little difference in ethylene production rates among the various CO_2 concentrations during the initial 15 hr of treatment. After 15 hr, figs held in 40% CO_2 or higher, maintained higher ethylene production rates compared to figs held in lower CO_2 concentrations. Upon transfer of figs to air at 20°C for 1 day, ethylene production rates in figs previously held in 40% CO_2 or lower were

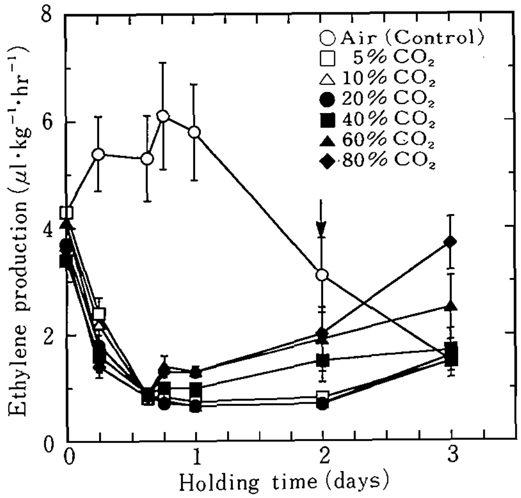

Fig. 1. Effects of various concentrations of carbon dioxide on ethylene production by figs held at 20°C. The arrow indicates the time when the figs were transferred from CO_2-enriched atmospheres to air. Oxygen concentration was maintained at 20 ± 1%, the balance gas being N_2. Vertical bars represent SE of the mean of three replications.

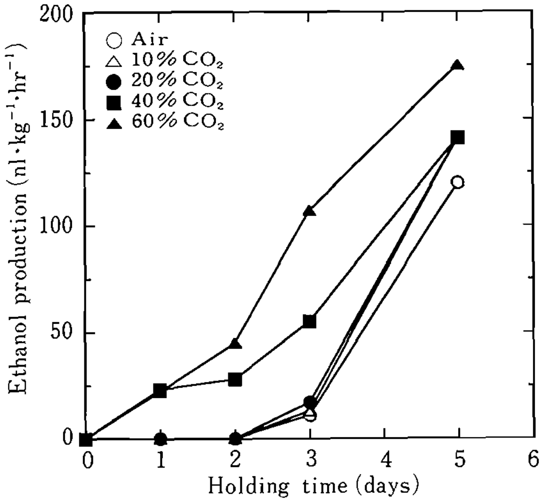

Fig. 2. Effects of various concentrations of carbon dioxide on ethanol production by figs held at 20°C. Oxygen concentration was maintained at 20 ± 1%, the balance gas being N_2.

similar to that of the control figs while the rates in figs previously held in 60% or 80% CO_2 were higher than those of the control figs.

The rate of ethanol production increased with increase in treatment time and CO_2 concentration (Fig. 2). Ethanol production in figs held in 40% or 60% CO_2 began to increase immediately after initiation of the gas treatment, while production in figs held in air, 10% or 20% CO_2 started to increase after 3 days of treatment and in a similar pattern.

2. Changes in O_2, CO_2 and C_2H_4 concentrations in the polyethylene bags

During storage of air-packed figs, the levels of O_2 and CO_2 in the microclimate of the figs decreased and increased, respectively (Fig. 3A). The MA development included an initial rapid change within the initial 24 hr followed by a semi-equilibrium (so called 'steady state') concentrations of O_2 and CO_2.

The CO_2 concentration in the PE bags containing figs that had been initially sealed in 100% CO_2 decreased to about 15% during the storage period (Fig. 3B). In the 80% CO_2 + 20% O_2 treatment, a similar pattern of change in CO_2 concentration within the PE bags was observed. In PE bags initially flushed with 100% N_2, CO_2 accumulated to 3.8% within 1 day and thereafter remained constant.

Ethylene concentration in the bags which had been flushed with the various gases decreased during the initial 6 hr and increased steadily thereafter and remained lower than the concentration in air-packed PE bags in which ethylene concentration increased steadily during the entire treatment time (Fig. 3C).

3. Effects of CO_2 treatment and MA packaging on spoilage of figs

Figs held in CO_2-enriched atmospheres for 2 days were still within the limits of marketability (Table 1). Upon transfer of figs to air for 1 day, more than 50% of the figs previously held in 20% CO_2 or below were infected by molds. Most of the figs previously held in 60% or 80% CO_2 were still marketable 1 day after transfer to air. Majority of the figs held in PE bags initially flushed with 100% CO_2 or 80% CO_2 + 20% O_2 were still marketable after 3 days of holding at 20°C (Table 2). About 50% of the figs in PE bags initially

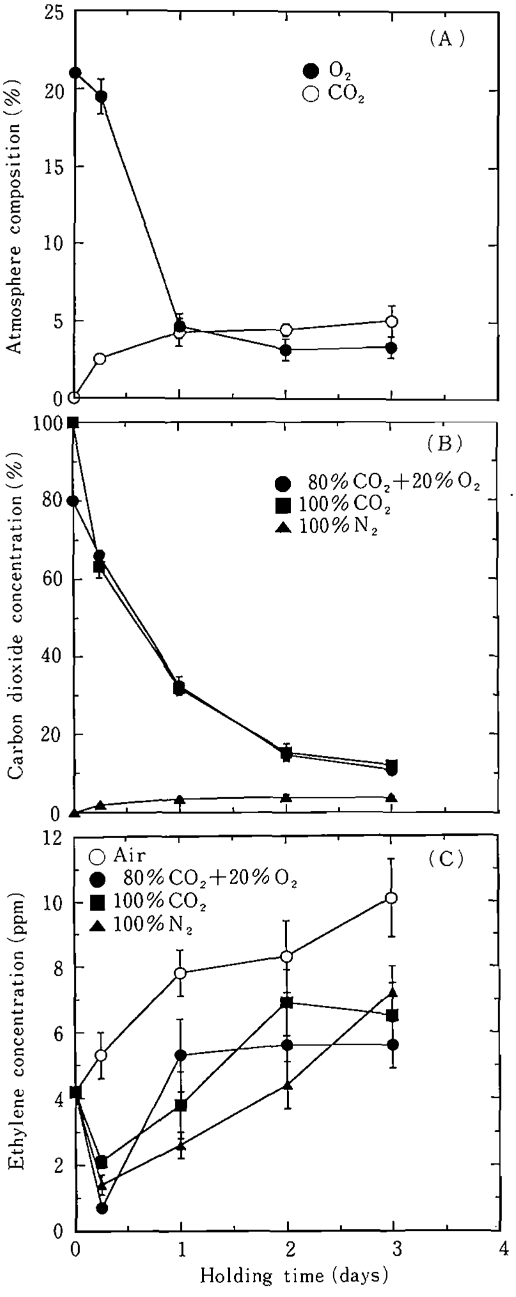

Fig. 3. Changes in oxygen and carbon dioxide (A), carbon dioxide (B) and ethylene (C) concentrations within fig packages held at 20°C. Vertical bars represent SE of the mean of three replications.

flushed with 100% N_2 were infected by molds after holding for 3 days at 20°C, while majority of figs kept in unperforated PE bags were infected by molds compared to 50% of those kept in perforated PE bags.

Discussion

Carbon dioxide-enriched atmosphere treatment markedly inhibited ethylene production. The high ethylene production rates observed in figs held in above 40% CO_2 is presumably due to CO_2-induced stress. Carbon dioxide levels of 15% or 20% inhibit ethylene production in 'Mission' figs (Colelli et al., 1991) and CO_2 levels of 50% and 80% have been shown to induce stress in 'Bartlett' pears (Ke et al., 1990) and in strawberries (Ke et al., 1991). The recovery of the inhibition of ethylene production indicates that in figs CO_2 does not cause permanent impairment of the ethylene producing system. A similar reversibility of ethylene production following high CO_2 treatment has been reported in other fruits (Li and Kader, 1989; Kubo et al., 1990; Lurie and Pesis, 1992).

The induction of ethanol production by CO_2 indicates an increased anaerobic respiration under these conditions. Elevated CO_2 levels even at low temperatures increase ethanol production in 'Mission' figs (Colelli et al., 1991), 'Bartlett' pears (Ke et al., 1990) and in strawberries (Ke et al., 1991). This indicates that the potential of off-flavor development resulting from ethanol accumulation over prolonged period may negate the other benefits of CO_2-enriched atmosphere treatment of figs. During the short-term MAP storage used in this study and based on sensory evaluation of the figs after the treatment, there was no indication that the treatment had any adverse effect on the fruit quality in relation to off-flavor development. However, such treatment should not be prolonged since during long-term MAP storage, accumulation of ethanol and acetaldehyde and hence development of off-flavors has been shown to limit the storage life of other fruits including persimmons (Ben-Arie et al., 1991).

In the MAP treatment, the O_2 and CO_2 levels in the air-packed PE bags decreased and increased, respectively, thereby creating a microclimate in the package. It has been shown that within 24 hr after package sealing, the levels of O_2 and CO_2 in the package reach a steady state and remain constant as long as the storage environment does not change (Forney et al., 1989). Similar observations

Table 1. Effect of CO_2-enriched atmosphere treatment on deterioration of figs held at 20℃ for 2 days and subsequently transferred to air for 1 day[z].

CO_2 concentration (%)	After 2 days treatment		1 day after transfer	
	Fruits infected by molds (%)	Quality score[y]	Fruits infected by molds (%)	Quality score
Air (control)	57	2	100	1
5	29	3	71	1
10	38	2	50	2
20	22	3	55	2
40	22	3	44	2
60	20	3	38	2
80	13	3	13	3

[z] Figs were put in air-tight containers and treated with humidified air or gas mixture containing the various concentratrations of CO_2. The O_2 concentration was maintained at $20 \pm 1\%$, the balance gas being N_2. The containers were flushed for 30 min with the appropriate gas composition after every sampling for ethylene determination. Figs were evaluated for mold infection and overall quality after 2 days of CO_2-enriched atmosphere storage and 1 day after transfer to air.

[y] Quality score was estimated in relation to degree of mold infection and overall visual quality based on a subjective scale of 1 to 5 where, 5 = All fruits are highly marketable; 4 = Majority of fruits are very marketable; 3 = Majority of fruits are marketable ; 2 = Majority of fruits are edible but not marketable; 1 = Majority of fruits are not marketable and not edible.

Table 2. Deteriorative changes of figs under modified atmosphere packaging at 20℃[z].

Days at 20℃	Treatment	Fruits infected by molds (%)	Quality score[y]
1	Air (perforated)	0	5
	Air (unperforated)	5	4
	80% CO_2+20% O_2	0	5
	100% CO_2	0	5
	100% N_2	5	4
2	Air (perforated)	7	4
	Air (unperforated)	14	4
	80% CO_2+20% O_2	0	5
	100% CO_2	5	4
	100% N_2	19	4
3	Air (perforated)	57	2
	Air (unperforated)	86	1
	80% CO_2+20% O_2	24	3
	100% CO_2	24	3
	100% N_2	43	2

[z] Eight figs per replicate were packaged in polyethylene bags (0.03 mm in thickness) and stored at 20℃. The figs were evaluated for mold infection initially and thereafter every day for three days.

[y] Quality score is as described in the footnotes of Table 1.

have been made previously during MAP storage of other highly perishable fruits such as strawberry (Mawele et al., 1992) and tomato (Nakhasi et al., 1991). In the PE bags initially flushed with 80% CO_2 + 20% O_2 and 100% CO_2, CO_2 levels decreased and reached about 15% in 3 days while in PE bags initially flushed with 100% N_2, CO_2 level increased to 3.8% (Fig. 3B). Pesis et al. (1988) observed that CO_2 decreased to about 12% in PE bags containing astringent persimmon fruits that had been sealed following 100% CO_2 flushing and increased to 15% in PE bags that had been sealed following 100% N_2 flushing. Ethylene concentration increased in all treatments and was lower in the PE bags that had been flushed with the various gases.

One of the most important effect of keeping figs in CO_2-enriched atmospheres was a reduction in mold growth. Carbon dioxide is effective in preventing decay in strawberries and blueberries (Ke et al., 1991; Dostal-Lange and Beaudry, 1992; Smith, 1992) and therefore could be recommended for the transportation of figs. After transfer of the figs from CO_2-enriched atmospheres to air for 1 day, the percentage of figs infected by molds was low in batches that had been treated with 10% CO_2 or more (Table 1). Colelli et al. (1991) observed that after 24 hr at 20°C 'Mission' figs from 15% or 20% CO_2 treatments remained above the limit of marketability. In MAP treatment, mold growth was evident within 1 day of storage in figs packaged in air or in PE bags initially flushed with 100% N_2. Mold growth in figs packaged in PE bags initially flushed with 100% CO_2 or 80% CO_2+20% O_2 was evident after 2 and 3 days, respectively. Modified atmosphere packaging reduces spoilage of tomato fruits (Nakhasi et al., 1991; Bhowmik and Pan, 1992) presumably due to the presence of high CO_2 and low O_2 levels (Mawele et al., 1992). Although the percentage of figs infected by molds decreased as the CO_2 concentration in the storage atmosphere increased, there is need to reintroduce the gas frequently thereby making the operation expensive. On the other hand, comparison of figs stored in MAP and CO_2-enriched atmospheres for 2 days indicates that the overall visual quality score of figs from MAP treatment was higher than for those from CO_2-enriched atmosphere treatment. This could, at least in part, be due to the permeability of the PE bags to the various gases, such as CO_2 and O_2.

The results presented here indicate that the marketing period of figs can be improved by holding in CO_2-enriched or modified atmospheres. However, in short-term marketing of figs, MAP, whether the atmosphere is generated through respiration of the figs or introduced artificially, may be cheaper than controlled atmospheres in which the gas composition has to be maintained at a regular interval. Although our experiments were not designed to study the effects of a combination of low temperature and CO_2-enriched atmospheres or MA storage, further improvement of MAP, for example, a combination with low temperature or chemicals such as ethylene absorbers or selection of PE bags and the amount of figs packaged might be one of the ultimate solutions in the marketing of figs in order to extend their postharvest life for both export and domestic consumption.

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常温下での高濃度 CO_2 および MA 環境によるイチジク果実の鮮度保持

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摘　要

20 °C 下での高濃度 CO_2 および MA (Modified Atmosphere) 環境によるイチジク (*Ficus carica* L. cv. Masui Dauphine) 果実の鮮度保持効果を検討した. 5～80% CO_2 環境はイチジク果実のエチレン生成を抑制し, 果実軟化及びカビの発生を遅らせたが, エタノール生成を促進した. 60 または 80% CO_2 (20% O_2) 下で 2 日間保持した果実は, 大気下に移した 1 日後でも商品性を維持していた. 密封ポリ袋に保持した果実は, 有孔ポリ袋の果実に比較して, カビ発生が促進された. 密封前にポリ袋に 80% CO_2 または 100% CO_2 を導入すると, 空気または 100% N_2 を入れた場合と比較して, カビの発生が抑制され, 袋中のエチレン濃度もやや低く推移した.

これらの結果から, 高濃度 CO_2 を封入した密封ポリ袋包装はイチジクの流通中の鮮度保持技術として利用できる可能性が示された.