CONTROLLED ATMOSPHERE STORAGE AFFECTS QUALITY AND CHILLING SUSCEPTIBILITY OF CUCUMBERS

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ABSTRACT

Controlled atmospheres (CA) maintained the quality of cucumbers better than conventional refrigerated storage at 5C. Elevated levels of CO_2 (3%) and decreased concentrations of O_2 (1 and 15%) also increased the tolerance of cucumbers to chilling exposure. The content of sugars, including fructose and glucose; and organic acids, particularly malic acid, were maintained at higher levels in CA-stored cucumbers than in air-stored samples. The respiration rates (measured as CO_2 production) of cucumber fruit during storage at 5C were markedly suppressed under CA conditions. Contrary to reports in the literature, CA storage was found to be beneficial in reducing chilling injury and maintaining cucumber quality.

INTRODUCTION

Controlled atmosphere (CA) storage has been shown to affect the respiration, ethylene production and action, enzyme synthesis and activity, ripening process, and senescence of various horticultural products (Calderon and Barkai-Golan 1990; Kader 1986). Most fresh fruits and vegetables respond favorably to CA treatment in maintaining sensory and nutritional quality and in extending storage life (Blanpied *et al.* 1993). However, CA is not always beneficial in reducing chilling injury of chilling-sensitive horticultural crops (Forney and Lipton 1990). The effectiveness of chilling injury reduction often depends on the type of commodity, the concentrations of O_2 and CO_2, and the temperature and duration of storage (Wang 1993).

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A decrease in O_2 level and/or an increase in CO_2 concentration in the storage atmospheres have been shown to alleviate chilling injury of avocados, grapefruit, apricots, nectarines, okra, peaches, pears, pineapples, potatoes, and zucchini squash (Wang 1993). However, an atmosphere of 3 or 5% CO_2 combined with a 20% O_2 was found to increase the symptoms of chilling injury in cucumbers at chilling temperature (Eaks 1956). Elevated concentrations of CO_2 induced injury symptoms in tomatoes similar to those of chilling injury (Kader and Morris 1975). Unfavorable results in ameliorating chilling exposure by CA have also been reported in asparagus spears (Lipton 1965), lime fruit (Spalding and Reeder 1983), sweet peppers (Cappellini *et al.* 1984), and grapefruit (Hatton *et al.* 1972).

In a recent study, we found that cucumber fruit packaged in perforated or sealed low density polyethylene bags had significantly less chilling injury than nonwrapped fruit when stored at a chilling temperature of 5C (Wang and Qi unpublished). One of the effects of film packaging is the modification of in-package atmosphere with raised CO_2 levels and decreased O_2 concentrations. This result prompted us to initiate a study to evaluate the effect of CA on quality and chilling susceptibility of cucumbers during refrigerated storage.

MATERIALS AND METHODS

Cucumber fruit (*Cucumis sativus* L., cv. Thunder) used in this study were grown on a farm in southern Maryland. Fruit that were uniform in size (18-22 cm in length) and free from blemishes were chosen for the research. Samples were washed with tap water to remove any loose soil, then were randomly divided into three lots and used for three CA treatments: air, 15% O_2 + 3% CO_2, and 1% O_2 + 3% CO_2.

Three cucumber fruit were placed in each 3.8 L glass respirometer jar and stored at 5C. Humidified gas mixtures of air, 15% O_2 + 3% CO_2, or 1% O_2 + 3% CO_2 were passed through the respective jars at a rate of 50 mL min^{-1}. Air, CO_2 and nitrogen from a liquid nitrogen supply or from a nitrogen generator (AVIR and NA 100H5, A/G Technology Corporation) were metered and combined to obtain the desired gas mixtures. Respiration rates, based on CO_2 production from the effluents of the respirometer jars, were determined every four hours by an automated system. Respiration data were reported after each 24-h period. CO_2 was analyzed with a carbon dioxide analyzer (AMETEX Applied Electrochemistry, Model CD-3A).

Three jars in each treatment were removed from the respirometer at 3-day intervals for the evaluation of chilling injury and chemical analyses. The severity of chilling injury was evaluated 24 h after cucumbers were transferred to 20C.

The quality of cucumber fruit as affected by controlled atmosphere storage was elevated by changes in sugar and organic acids. Sugar analysis consisted of cutting mesocarp tissue; (2.0 g) cucumber fruit was cut into small sections and homogenized with a Polytron homogenizer (Brinkmann) in imidazole buffer (20 mM, pH 7.0). The extracts were centrifuged and supernatants were dried *in vacuo* in derivatizing vials. Derivatization of the sugars was carried out according to procedures described by Li and Schuhmann (1980). One μL of the derivatized samples was injected for gas chromatographic separation and quantification. A Hewlett Packard 5890 gas chromatograph equipped with a flame ionization detector was used. A known amount of β-phenyl-D-glucopyranoside was included in all samples as an internal standard. A 12.5 m dimethyl silicon fluid capillary column (0.2 mm ID, 0.33 μm film thickness) was used. Chromatograph temperatures were as follows: injector 250C, detector 275C, and column 160 to 250C programmed at 10C/min.

Organic acids were analyzed after extraction with imidazole buffer and purification with a Baker-10 solid phase extraction system. Supernatants from the extracts were passed through quaternary amine column which were previously conditioned with hexane and methanol. The samples were then eluted from the columns with 0.1 N HCl. The eluates were concentrated to dryness *in vacuo* in derivatized vials. Procedures of derivatization and chromatography for organic acids were the same as those for sugars except that column temperatures were programmed from 100 to 230C at 4C/min. Separated sugars and organic acids were compared with derivatized standards for qualitative and quantitative determinations. Data were analyzed by analysis of variance and the variance components were used to calculate the expected standard errors of the means.

RESULTS AND DISCUSSION

Respiratory rates of cucumbers were markedly suppressed by CA treatments throughout storage at 5C (Fig. 1). Reduction of respiration by low O_2 and/or high CO_2 atmospheres has been reported previously (Wang 1990). Lowering the O_2 concentration or raising the CO_2 level has been shown to delay the onset of climacteric rise in some fruits and retard the CO_2 production in nonclimacteric type of fruits and vegetables (Biale 1960; Kader 1986). In our study, cucumbers from both CA treatments (1% O_2 + 3% CO_2 and 15% O_2 + 3% CO_2) had lower rates of respiration than the air control.

One of the most significant benefits of 1% O_2 + 3% CO_2 treatment was the inhibition of mold growth in cucumber fruit during storage at 5C. Cucumbers from other treatments, particularly the air control developed decay at the chilling temperature. The 1% O_2 + 3% CO_2 and 15% O_2 + 3% CO_2 treatments showed no difference in the degree of chilling injury. Both CA treatments

delayed the onset and reduced the severity of pitting in the chilled cucumbers. Cucumbers stored under an elevated CO_2 atmosphere (3 or 5%) combined with an ambient O_2 concentration were previously reported to have high pitting incidence at a chilling temperature (Eaks 1956). The present research indicates that low O_2 concentration is important in alleviating chilling injury in cucumbers.

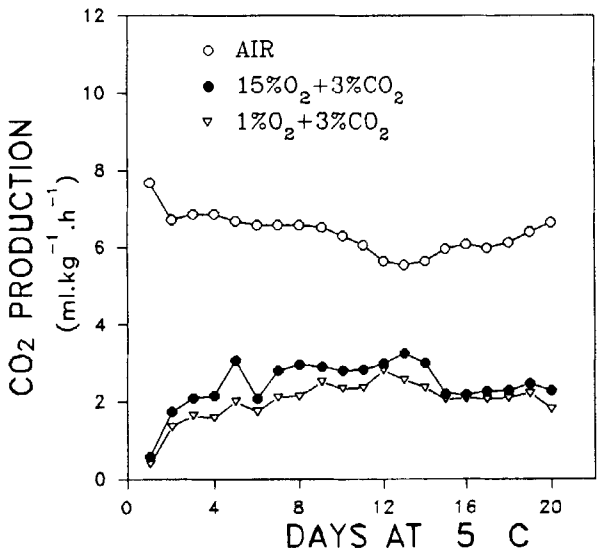

FIG. 1. EFFECT OF CONTROLLED ATMOSPHERES ON RESPIRATORY RATES OF CUCUMBERS STORED AT 5C

Fructose and glucose were the major sugars in cucumber with trace amounts of sucrose. Fructose increased during storage at 5C for 3 or 6 days, then declined gradually (Fig. 2). Cucumbers kept in CA conditions (1% O_2 + 3% CO_2 or 15% O_2 + 3% CO_2 maintained higher fructose concentrations than those in air storage. Glucose concentrations decreased during the first 3 or 6 days of storage, then leveled off (Fig 3.). The low O_2 and elevated CO_2 atmospheres reduced glucose loss at the beginning of the 5C storage.

Malic acid was the predominant organic acid in cucumber fruit. Malic acid decreased markedly in air storage at 5C (Fig. 4). Cucumbers stored under CA conditions also lost malic acid in storage but to a lesser extent than fruit from

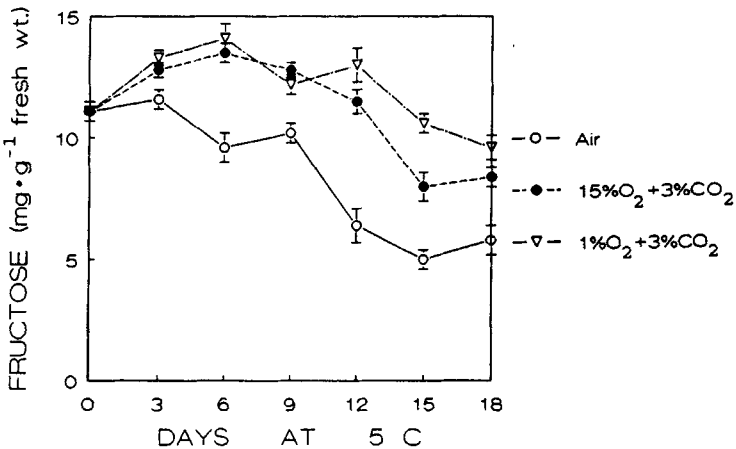

FIG. 2. EFFECT OF CONTROLLED ATMOSPHERES ON CHANGES OF FRUCTOSE CONTENT IN CUCUMBERS DURING STORAGE AT 5C
Error bars represent ± SE.

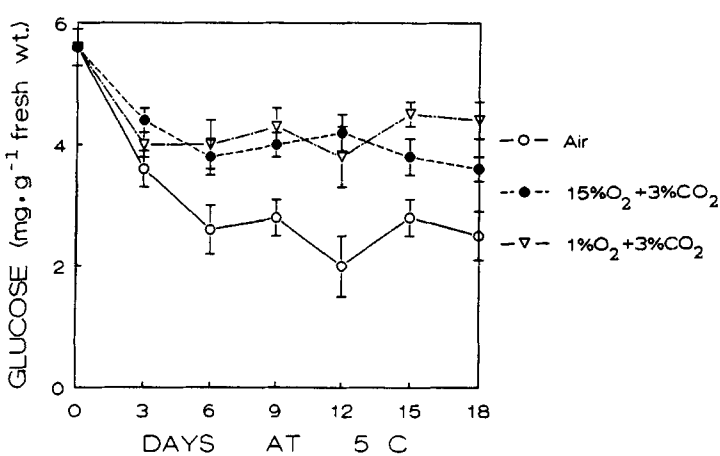

FIG. 3. EFFECT OF CONTROLLED ATMOSPHERES ON CHANGES OF GLUCOSE CONTENT IN CUCUMBERS DURING STORAGE AT 5C
Error bars represent ± SE.

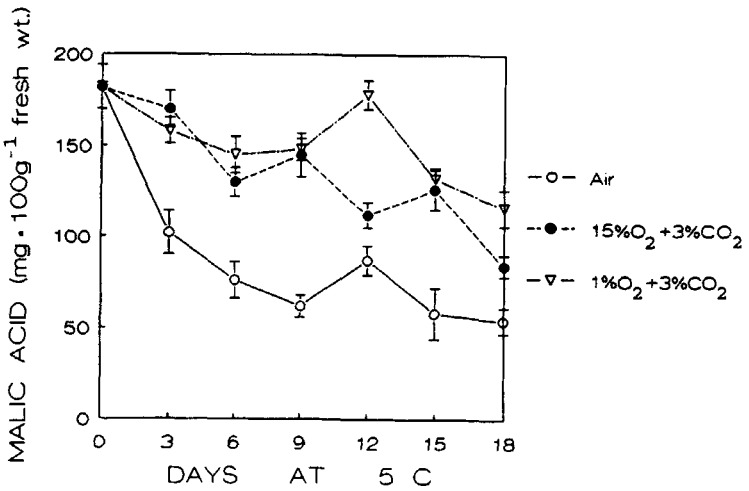

FIG. 4. EFFECT OF CONTROLLED ATMOSPHERES ON CHANGES OF MALIC ACID CONTENT IN CUCUMBERS DURING STORAGE AT 5C
Error bars represent ± SE.

air storage. Citric acid was present in cucumber tissue at a much lower level than malic acid. During storage at 5C, citric acid increased gradually in cucumber fruit; however, due to low levels and large variations, no significant differences were detected between air and CA stored fruit. Other organic acids detected in cucumbers included succinic acid and tartaric acid. These organic acids were present in minute amounts.

The reduction of losses of sugars and organic acids by CA has been reported in various fruits and vegetables (Blanpied *et al.* 1993; Kader 1986; Wang 1990). Sugars and organic acids are utilized as substrates and as sources of energy for respiratory metabolism. Preservation of these substances tends to maintain the desirable quality of fruits and vegetables. The keeping quality of chilling-sensitive commodities is adversely affected by the exposure to temperatures below 10C. Abnormal utilization of sugars and organic acids in the Krebs cycle were reported to take place in the fruit of eggplant during storage at a chilling temperature (Kozukue *et al.* 1978). In the present study, we have also found that losses of fructose, glucose, and malic acid occurred in cucumber fruit during storage at 5C. However, CA storage minimized these losses. Susceptibility to chilling injury and the incidence of decay were also reduced by the elevated CO_2 levels and low O_2 concentrations. The overall quality of cucumbers was better maintained when the fruit were kept in CA storage.

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REFERENCES

BIALE, J.B. 1960. Respiration of fruits. In *Encyclopedia of Plant Physiology,* Vol. 12, Part 2, (W. Ruhland, ed.) pp. 536–586, Springer-Verlag, Berlin.

BLANPIED, G.D., BARTSCH, J.A. and HICKS, J.R. 1993. *Proceedings from the Sixth International Controlled Atmosphere Research Conference.* Northern Regional Agr. Eng. Ser. 71, pp. 887, Ithaca, New York.

CALDERON, M. and BARKAI-GOLAN, R. 1990. *Food Preservation by Modified Atmospheres.* pp. 402, CRC Press, Boca Raton, FL.

CAPPELLINI, M.C., LACHANCE, P.A. and HUDSON, D.E. 1984. Effect of temperature and carbon dioxide atmospheres on the market quality of green bell peppers. J. Food Quality *7,* 17–25.

EAKS, I.L. 1956. Effect of modified atmospheres on cucumbers at chilling and nonchilling temperatures. Proc. Amer. Soc. Hort. Sci. *67,* 473–478.

FORNEY, C.F. and LIPTON, W.J. 1990. Influence of controlled atmospheres and packaging on chilling sensitivity. In *Chilling Injury of Horticultural Crops.* (C.Y. Wang, ed.) pp. 257–267, CRC Press, Boca Raton, FL.

HATTON, T.T., SMOOT, J.J. and CUBBEDGE, R.H. 1972. Influence of carbon dioxide exposure on stored mid- and late-season 'Marsh' grapefruit. Proc. Trop. Reg. Amer. Soc. Hort. Sci. *16,* 49–58.

KADER, A.A. 1986. Biochemical and physiological basis for effects of controlled and modified atmospheres on fruits and vegetables. Food Technol. *40*(5), 99–104.

KADER, A.A. and MORRIS, L.L. 1975. Amelioration of chilling injury symptoms on tomato fruits. HortSci. *10,* 324.

KOZUKUE, N., KOZUKUE, E., KISHIGUCHI, M. and LEE, S.W. 1978. Studies on keeping quality of vegetables and fruits. III. Changes in sugar and organic acid contents accompanying the chilling injury of eggplant fruits. Sci. Hort. *8,* 19–26.

LI, B.W. and SCHUHMANN, P.J. 1980. Gas-liquid chromatographic analysis of sugars in ready-to-eat breakfast cereals. J. Food Sci. *45,* 138–141.

LIPTON, W.J. 1965. Postharvest responses of asparagus spears to high carbon dioxide and low oxygen atmospheres. Proc. Amer. Soc. Hort. Sci. *86,* 347–356.

SPALDING, D.H. and REEDER, W.F. 1983. Conditioning 'Tahiti' limes to reduce chilling injury. Proc. Fla. State Hort. Soc. *96,* 231–232.

WANG, C.Y. 1990. Physiological and biochemical effects of controlled atmosphere on fruits and vegetables. In *Food Preservation by Modified Atmospheres*. (M. Calderon and R. Barkai-Golan, eds.) pp. 197–223, CRC Press, Boca Raton, FL.

WANG, C.Y. 1993. Approaches to reduce chilling injury of fruits and vegetables. Hort. Rev. *15*, 63–95.