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Respiratory Activity and Mitochondrial Oxidative Capacity of Bell Pepper Fruit following Storage under Low-oxygen Atmosphere

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Abstract. **Bell pepper *(Capsicum annuum* L., var. 'Jupiter') fruit stored in 1.5%, 5%, or 10% O_2, or in air at 20C for24 hours were compared to determine the residual effect of low-O, storage on respiration after transfer to air. The lowest O_2 concentration (1.5%) exerted the greatest residual effect on bell pepper fruit CO_2 production and O_2, uptake. No ethanol was detected in the headspace gas of fruit stored in 1.5% O_2. Carbon dioxide production continued to be suppressed for ≈ 24 hours after transfer from 1.5% O_2 to air. Exposure to 5% O_2, for 24 hours resulted in less suppression of CO, production and O_2 uptake upon transfer to air, while 10% O_2 exerted no residual effect. Extending the storage period in 1.5% O_2 to 72 hours extended the residual effect from 24 to 48 hours. Ethylene production was not affected by storage in 1.5% or 4% O_2 for 24 or 72 hours. The residual effect exhibited in whole fruit was not apparent in mitochondria isolated from bell pepper stored in 1.5% or 4% O_2.**

The benefits of controlled-atmosphere (CA) storage of fresh fruits and vegetables include extended storage life and maintenance of quality. Reduced O_2 and elevated CO_2 in CA storage can reduce respiration and ethylene production rates, reduce tissue sensitivity to ethylene, delay ripening and softening, and slow down biochemical changes associated with ripening (Kader, 1986).

Concentrations of O_2 and CO_2, duration of exposure, and storage temperature are some important criteria for successful CA storage of fresh fruits and vegetables. Tolerance to low-O, levels varies with commodity. Kader (1986) indicated that, for most commodities, a minimum of 1% to 3% O_2 in the storage environment is required to avoid a shift to anaerobic metabolism. Oxygen concentrations as low as 0.2% within the plant cell may result in anaerobic respiration. Anaerobiosis normally results in the accumulation of ethanol and acetaldehyde (Patterson and Nichols, 1988), and increased activity of pyruvic decarboxylase (EC 4.1.1.1) and alcohol dehydrogenase (EC 1.1.1.1) (Davis et al., 1973).

Changes in physiological properties and quality attributes following short-term exposure to low O_2 have been elucidated for various commodities, including tree fruits (Ke and Kader, 1990; Ke et al., 1991) and strawberry *(Fragaria* × *ananassa* Duch.) fruits (Aharoni et al., 1979). In some commodities, the respiration and ethylene production rates continue to be suppressed even after transfer from a low-O_2 environment to air. Li and Kader (1989) have termed this phenomenon the "residual effect" of low-O_2 storage. These authors demonstrated that 'Selva' strawberry fruit stored in 0.5% to 2.0% O_2 at 2C for 7 days exhibited reduced respiration and ethylene production rates and maintained flesh firmness and color after removal to air. The residual effect was more pronounced following storage at lower O_2 concentrations.

Mitochondria are the cellular sites of oxidative phosphorylation, where respiratory enzymes are located. Low O_2 and high CO_2 may influence the activity of these enzymes, depending on the concentration and duration of exposure. Burton (1978) and Solomos (1982) have pointed out, however, that the decrease in respiration rate in response to low O_2 levels may not be due to a reduction in the activity of cytochrome oxidase (EC 1.9.3.1), a high-affinity, low-Km oxidase, but rather to the diminished activities of low-affinity oxidases, such as polyphenol oxidase (EC 1.14.18. I), lipoxygenase (EC 1.13.11.12), and ascorbic acid oxidase (EC 1.10.3.3).

The primary objective of this study was to determine whether low O_2 exerts residual effects on respiration of bell pepper fruit. This included an evaluation of whether mitochondrial oxidative capacity was reduced after storage in low pO_2.

Materials and Methods

Plant material. Cauliflower (*Brassica oleracea*, Botrytis Group) florets, mature green tomato *(Lycopersicon esculentum* Mill.) fruit, and bell pepper fruit were examined in initial studies of low-O_2-imposed residual respiratory effects. For the reasons described in the Discussion section. this paper is limited to the results obtained with bell pepper.

Bell pepper fruit (var. 'Jupiter') were hand harvested at commercial maturity (green) and transported to the laboratory on the same day. Fruit were selected for uniform size and shape and freedom from defects. The fruit were wiped with paper towels moistened with 0.25% (v/v) sodium hypochlorite (1:20 dilution of 5% commercial bleach). Individual fruit were placed into 1.7-liter glass jars and kept in a 20C room for 24 h to allow handling-induced respiration to subside. Jars were sealed for 1 h, and 0.5 ml of headspace gas was removed for CO_2 measurement. About 80% of the total fruit samples having CO_2 production rates of 25 ± 0.5 $ml \cdot kg^{-1} \cdot h^{-1}$ and an average weight of 160 g were selected for the experiments.

Gas treatments. Fruit were sealed individually in 1.7-liter glass jars and exposed to 1.5%, 5%, or 10% O_2 in N_2 for 24 h at 20C. The control consisted of fruit exposed to air. Fruit also were stored in 1.5% O_2 for 72 h to determine the influence of prolonged exposure to low O_2 on the extent of the residual effect. There were three fruit

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for each treatment, and each fruit constituted a replicate. The humidified O_2 mixtures or air were introduced by means of a continuous flow-through system, and the flow rates were adjusted to keep CO_2 levels <0.3%. After treatment in low O_2 or air, all fruit were transferred to air and ventilated with humidified air at 20C. Gas measurements and ethanol content from the headspace gas were determined at various intervals during this subsequent storage in air.

In a separate experiment, bell pepper fruit were exposed to 4% O_2 or air for 24 or 72 hat 20C and then transferred to air at the same temperature.

Gas measurements. The rates of CO_2 and C_2H_4 production and O_2 uptake were measured within 10 min after 24 h of exposure to the various O_2 mixtures or air. Subsequent measurements were taken after 2 h and again at intervals following transfer of the fruit to air. For determining CO_2 production and O_2 uptake, 0.5 ml of the headspace gas (1.7-liter jars sealed for 1 h) was injected into a Fisher Model 1200 gas partitioner (Pittsburgh) equipped with a thermal conductivity detector, and Column Pak and molecular sieve columns at 60C. Ethylene in 0.5-ml samples of headspace gas was measured using a Photovac Model 10A 10 gas chromatograph (Thomhill, Ont., Canada) fitted with a photoionization detector and activated alumina column at ambient temperature.

Ethanol was determined using the Kentville Method (Lidster et al., 1985) following transfer to air by injecting 0.2 ml headspace gas into a gas chromatograph equipped with a flame ionization detectorand 5% carbowax (80/120mesh) column operated at 80C. The detector and injector settings were at 100C. Peak heights were compared to a standard curve prepared from the headspace of a series of ethanol dilutions in double-distilled water kept at 20C. This method was able to detect ethanol concentrations as low as 0.01% in the headspace gas.

Mitochondria isolation. Pericarp tissue (100 g fresh weight), obtained from the equatorial region of pepper fruit, was diced (≈ 2 × 2 mm) and the sections immersed in 150 ml of ice-cold grinding buffer containing 0.4 M sucrose, 0.05 M Trizma base (Sigma Chemical Co.), 1 mM ethylene glycol-bis (ß-aminoethyl ether N,N,N',N'-tetraacetic acid (EGTA), 10 mM KH_2PO_4, 4 mM cysteine, and 1% (w/v) bovine serum albumin (BSA), adjusted to pH 7.6 with HCl. The tissue was disrupted with a Polytron homogenizer (Brinkmann Instruments, Rexdale, Ont., Canada) for 2 to 3 sec at a speed setting of seven, followed by filtration through two layers of Miracloth (Calbiochem, La Jolla, Calif.). The filtrate was centrifuged at 1 to 4C for 10 min at 1000× *g* to remove cell debris, followed by centrifugation of the supernatant for another 10 min at 1000× *g* to remove the remaining cell debris and other denser particles. Crude mitochondrial pellets were obtained by centrifugation of the supernatant at 16,000× *g* for 10 min. The pellets were resuspended in ice-cold medium containing 0.4 M mannitol, 10 mM KH_2PO_4, and 0.5% (w/v) BSA adjusted to pH 7.2 with KOH, and the crude mitochondrial suspension was brought to a volume of 8 ml.

Four milliliters of the mitochondrial suspension were layered onto a step gradient of Percoll (Sigma) following the methods of Moreau and Romani (1982), Duncan and Spencer (1987), and Phelps and McDonald (1990). with the following modifications: The gradient consisted of two steps of 20% and 45% Percoll with 0.25 M mannitol, 10 mM KH_2PO_4, and 0.5% (w/v) BSA, pH 7.2. Centrifugation of the gradients was at 26,000× *g* for 15 min. The mitochondria banded at a density of ≈ 1.06 as determined with density marker beads (Sigma), and were collected with a pasteur pipette. The mitochondria fraction was diluted to 20 ml and washed with resuspension buffer without BSA and centrifuged at 26,000× *g* for 20 min. Final washing was in resuspension buffer without BSA at 16,000× *g* for 20 min. The pellet was resuspended in a reaction medium containing 0.25 M sucrose, 10 mM KH_2PO_4, 10 mM Tris HCl, 0.5 mM ethylenediaminetetraacetic acid (EDTA), 4 mM $MgCl_2$, and 0.05% (w/v) BSA, pH 7.2. All steps involved in isolating Percoll gradient-purified mitochondria were conducted at 1 to 4C.

Mitochondrial oxygen uptake. Oxygen consumption was measured at 20C with an oxygen electrode (Model 53, Yellow Springs Instruments Co., Yellow Springs, Ohio), standardized against air-saturated deionized water. Aliquots of 1.5 ml of the mitochondrial suspension were placed into a sample chamber containing 2 mM succinate and 150 µM adenosine 5'-diphosphate (ADP) to initiate state-3 respiration. The final volume of the solution in the reaction chamber was 3 ml. Oxygen consumption rate was expressed as nmol O_2/mg mitochondrial protein per min, and was calculated from steady state O_2 consumption values attained within 5 min after addition of succinate and ADP. Protein was determined following the method of Smith et al. (1985) using Pierce bicinchoninic acid (BCA) protein assay reagents (Sigma) and BSA as standard.

Enzyme assays. Cytochrome c oxidase (EC 1.9.3.1), a mitochondrial marker (Quail, 1979). was assayed by measuring the absorbance reduction of reduced cytochrome c at 550 nm (Storrie and Madden, 1990) using a Beckman spectrophotometer (Model DU-20, Irvine, Calif.). Catalase (EC 1.11.1.6). a peroxisome marker (Quail, 1979), was assayed by measuring the absorbance reduction of H_2O_2 at 240 nm (Luck, 1965).

Mitochondrial integrity. The intactness of purified mitochondria was evaluated according to Storrie and Madden (1990) by measuring the activity of cytochrome c oxidase in the presence or absence of nonionic detergent (Lubrol, Sigma).

Results

The magnitude of reduction in CO_2 production after low O_2 storage was greatest in fruit stored in 1.5% O_2 relative to 5% or 10% O_2, and air (Fig. 1). The CO_2 production rate of fruit measured after 24 h in 1.5% O_2 was 53% lower than that of the air-stored fruit when measured within 10 min of return to air. Preliminary experiments indicated that ≈ 2 h were required for the atmosphere inside the locules of fruit from the 1.5% O_2 treatment to equilibrate with an atmosphere of 21% (data not shown). Oxygen concentrations were measured in the fruit locule after 24 h in 1.5% O_2 and at 30 min intervals following transfer to air until an equilibrium was reached. The CO_2 production rate of fruit stored in 1.5% O_2 continued to be suppressed, and attained values similar to the air-stored fruit only after 24 h in air (Fig. 1). Treatment with 5% or 10% O_2 had no consistent effect on the CO, production rate upon transfer of bell pepper fruit to air. Within several hours in air, the CO_2 production rates of fruit previously stored in 5% or 10% O_2 reached values similar to those of fruit stored continuously in air. Extending the storage period of bell pepper fruit in 1.5% O_2 from 24 to 72 h suppressed CO_2 production for 48 h following transfer to air (Fig. 2). Ethanol was not detected in the headspace gas obtained from fruit after storage in 1.5% O_2 for 24 or 72 h.

The O_2 consumption rate of bell pepper fruit stored in 1.5% or 5% O_2 for 24 h was reduced by ≈ 80% or 40%, respectively, compared to the air-stored fruit (Fig. 3). While there was about a 35% recovery in the O_2 consumption rate 24 h after transfer from 1.5% O_2 to air, the O_2 consumption rate recovered by ≈ 50% following storage in 5% O_2. The O_2 consumption rates of fruit stored in 10% O_2 or after 24 h transfer to air were not significantly

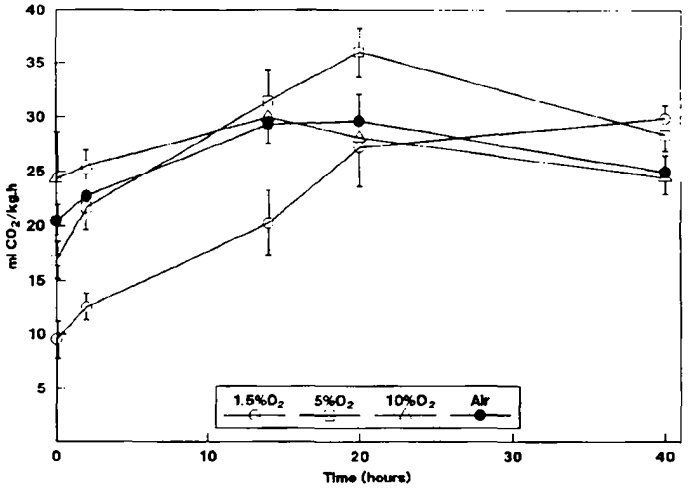

Fig. 1. Carbon dioxide production rates of bell pepper fruit in air following storage in 1.5%, 5%, or 10% O_2, or in air for 24 h at 20C. Vertical lines represent SD of the mean. Values are the means of three replications.

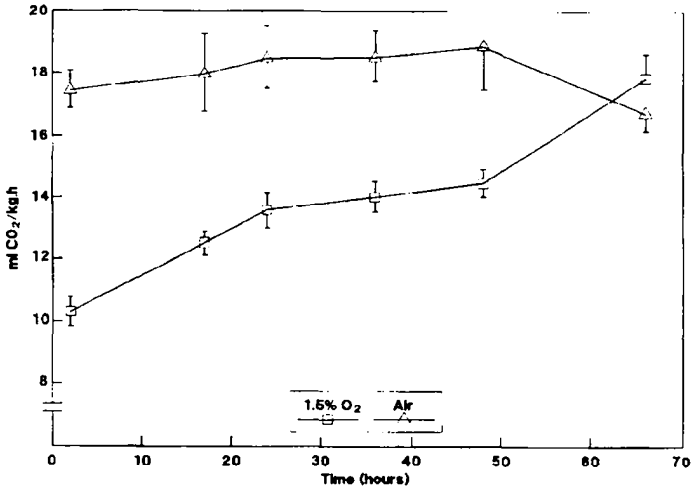

Fig. 2. Carbon dioxide production rates of bell pepper fruit in air after storage in 1.5% O_2, or in air for 72 h at 20C. Vertical lines represent SD of the mean. Values are the means of three replications.

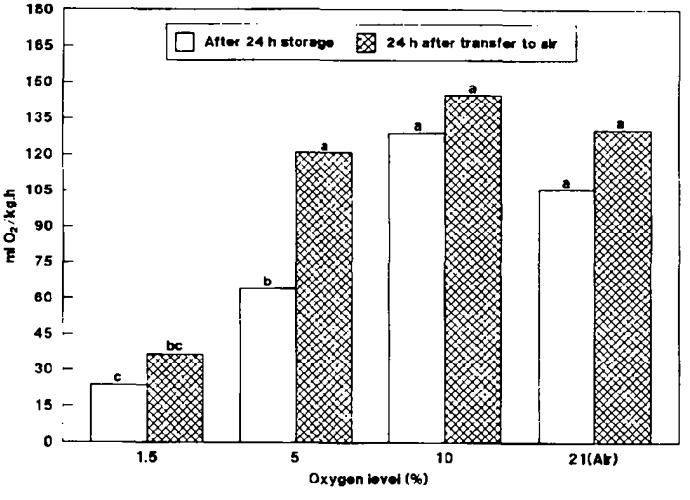

Fig. 3. Oxygen consumption rates of bell pepper fruit after storage in 1.5%, 5%, or 10% O_2, or in air for 24 h at 20C, and 24 h after transfer to air. Values are the means of three replications. Mean separation at $P = 0.01$ by Duncan's Multiple Range Test.

different ($P \leq 0.01$) from those of fruit stored continuously in air.

Fruit stored for 24 h in 1.5% O_2 had a respiratory quotient (RQ) of ≈ 1.15, which had decreased to 0.95 24 h after transfer to air.

The CO_2 production rate of bell pepper fruit that had been stored in 4% O_2 for 24 h was ≈ 25% lower than that of air-stored fruit measured within 10 min of transfer to air (Fig. 4A). The reduced CO_2 production was highly apparent during the first 6 h after transfer to air. After ≈ 24 h in air, the CO_2 production rate was similar to that of the air-stored fruit. There was no difference in the C_2H_4 production rates between fruit stored in 4% O_2 and air (Fig. 4B).

Carbon dioxide production rates measured within 10 min after 72 h of storage in 4% O_2 were 38% lower than the air-stored sample (Fig. 5A). Later. the values generally were not significantly different from fruit stored continuously in air. The C_2H_4 production rates of fruit previously stored in 4% O_2 for 72 h and then transferred to air were similar to those stored continuously in air (Fig. 5B).

Mitochondria were isolated from the fruit to determine whether the low O_2-induced residual respiratory effect could be explained by limitations in mitochondrial oxidative capacity. Purification of

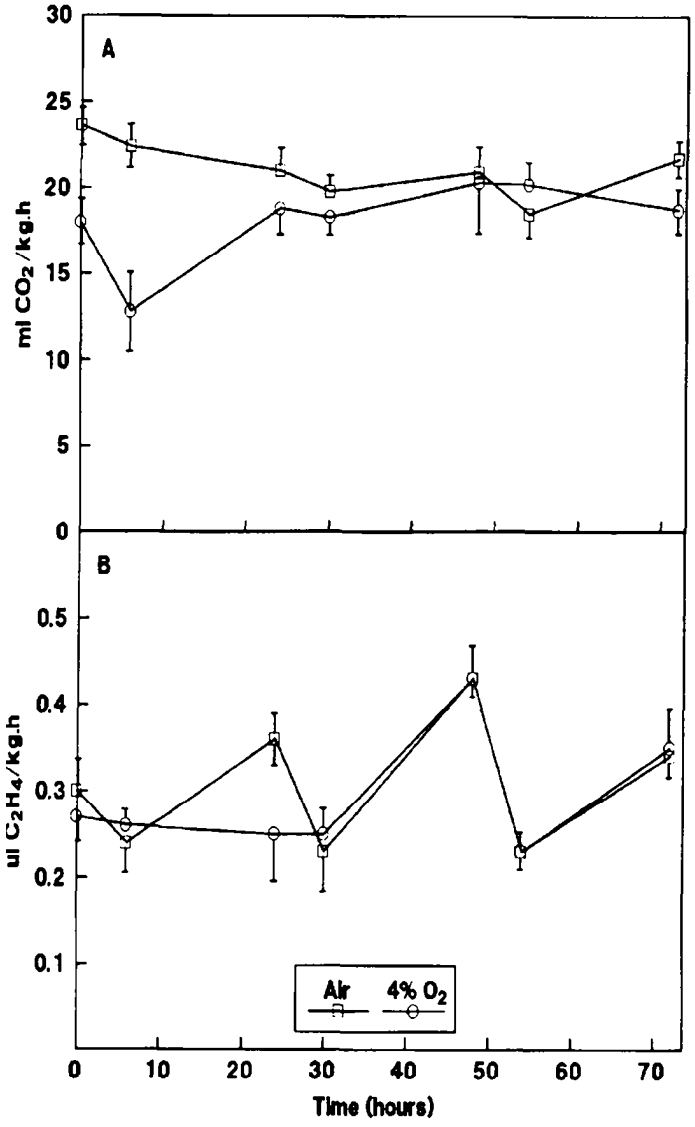

Fig 4. Carbon dioxide (**A**) and ethylene (**B**) production rates of bell pepper fruit in air after 24 h of storage in 4% O_2, and of continuously air-stored samples at 20C. Vertical lines represent SD of the mean. Values are the means of three replications.

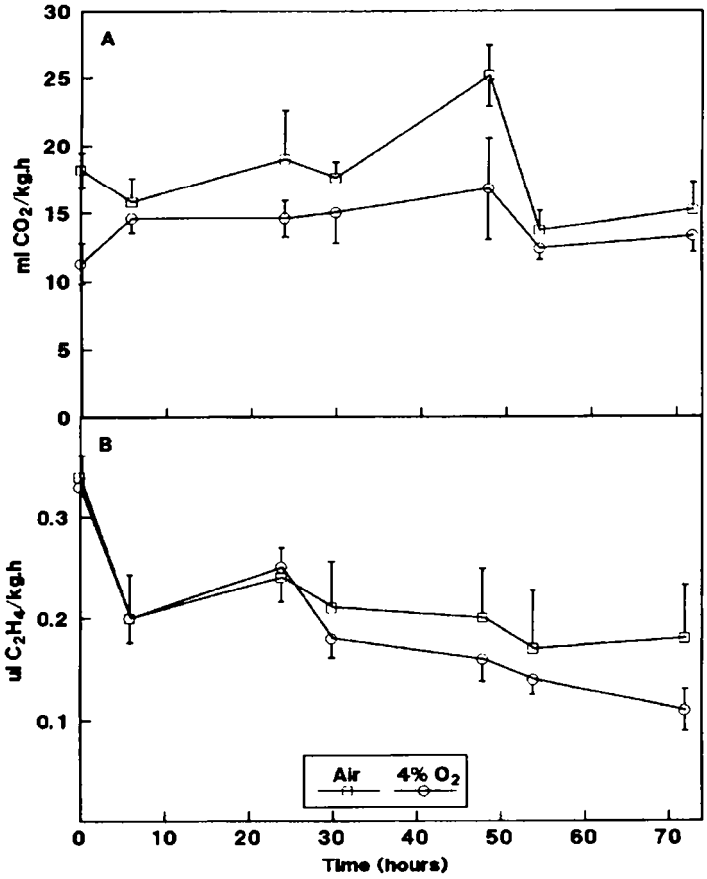

Fig. 5. Carbon dioxide (A) and ethylene (B) production rates of bell pepper fruit in air after 72 h of storage in 4% O_2, and of continuously air-stored samples at 20C. Vertical lines represent SD of the mean. Values are the means of three replications.

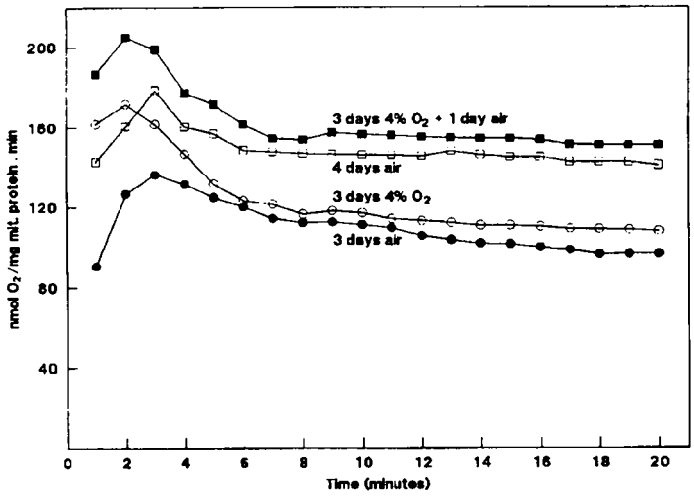

Fig. 6. Oxygen uptake capacity of isolated mitochondria from bell pepper fruit stored for 3 days in 4% O_2, 3 days in air, 4 days in air, or 3 days in 4% O_2 plus 1 day in air. Values are the means of two replications.

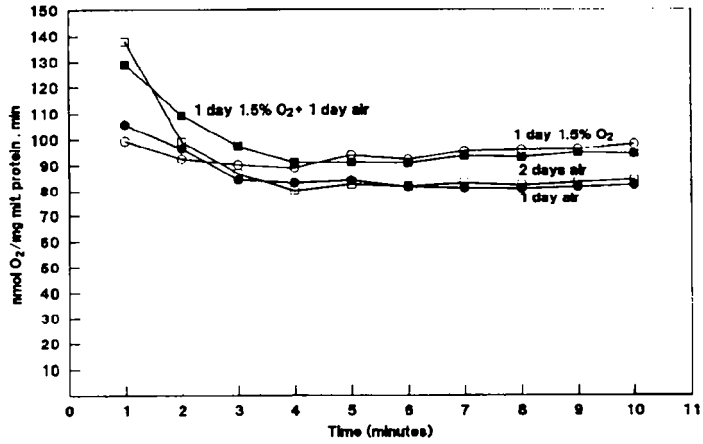

Fig. 7. Oxygen uptake capacity of isolated mitochondria from bell pepper fruit stored for 1 day in 1.5% O_2, 1 day in air, 2 days in air, or 1 day in 1.5% O_2 plus 1 day in air. Values are the means of two replications.

crude mitochondrial extracts on Percoll gradients yielded mitochondria free from contaminating peroxisomes, microsomal membranes, and thylakoid fragments, with ≈ 90% intact. The steady-state oxidative capacity of mitochondria isolated from bell pepper fruit stored in 4% O_2 for 3 days showed no marked difference from the mitochondria of air-stored fruit (Fig. 6). Steady state O_2 uptake rates were maintained for periods up to 20 min, at which time dissolved O_2 was nearly depleted. Mitochondria from fruit stored for 4 days in air or 3 days in 4% O_2 plus 1 day in air had higher rates of O_2 uptake than mitochondria from fruit stored only 3 days. The O_2 uptake capacity of mitochondrial isolates obtained from fruit stored in 1.5% O_2 for 1 day was also similar to those isolated from air-stored samples (Fig. 7).

Discussion

Several criteria were employed in selecting an appropriate commodity for the present study. The commodity 1) should exhibit a poststorage, residual respiratory response to low O_2, with "respiration" defined as the organ's net exchange of CO_2 or O_2 without regard to the cellular sites of production or consumption; 2) should not exhibit rapid developmental changes during the experimental period; and 3) should allow the isolation of relatively pure, high-integrity mitochondria. Among three commodities initially examined (bell pepper fruit, tomato fruit, and cauliflower florets), bell pepper best satisfied the above criteria. Comparisons of the residual effects of low O_2 imposed on tomato fruit respiration were confounded by the differential influence of low O_2 and air on the onset of ripening and the associated respiratory climacteric. Cauliflower florets. however, exhibited no apparent residual response of net gas exchange to low-O_2 storage.

The rationale for investigating the poststorage residual effect of low O_2 on respiratory activity is 2-fold. First, practical postharvest benefits may be derived from such a "plastic" response to low O_2. For example, Li and Kader (1989) indicated that exposing strawberries to an atmosphere containing 1% to 2% O_2 for at least 3 days at 2C could maintain quality during transport or temporary storage, and that such a low-O_2 exposure reduced deterioration during subsequent handling in air. Second, the maintenance of presumed low O_2-imposed metabolism upon transfer to air presents the opportunity for experimental elucidation, under ambient conditions, of the effects of low-O_2 storage.

These studies demonstrate that the respiration of bell pepper fruit is affected by prior storage under reduced O_2 levels. Kader (1992) indicated that the recommended level of O_2 for CA or MA storage of bell pepper is between 3% and 5%. The results of the present study demonstrate that 1.5% O_2 is more effective in reducing the respiration rate of bell pepper fruit than are higher O_2 levels. Additionally, the continued suppression of CO_2 production or O_2 consumption after return of the pepper fruit to air indicates

the presence of a residual effect as a consequence of prior exposure to low O_2. The residual effect exhibited by bell pepper fruit stored in 1.5% O_2 was apparent for almost 24 h after transfer to air. Thereafter, the pepper fruit recovered and attained respiration rates similar to those of continuously air-stored fruit. A residual effect of low O_2 on respiration and C_2H_4 production rates has been demonstrated in 'Selva' strawberries by Li and Kader (1989). They indicated that low O_2 (0.5% to 2%) reduced respiration and ethylene production rates during CA storage and after subsequent holding in air for 7 days at 2C. Ke and Kader (1990) reported that 'Valencia' oranges (*Citrus sinensis* Osb.) tolerated up to 20 days of exposure to 0.5%, 0.25%, or 0.02% O_2 at SC or 10C, followed by holding in air at 5C for 7 days without any detrimental effects on external or internal appearance.

Storage of fresh fruits and vegetables under excessively low levels of O_2 may induce the accumulation of ethanol, which results in off-flavors (Ke et al., 1990). The absence of detectable levels (<0.01%) of ethanol in the headspace gas from bell pepper fruit stored in 1.5% O_2 indicates that the residual influence on respiration rate was not due to anaerobiosis induced by low-O_2 storage. While ethanol evaporates into the headspace gas, a considerable fraction may be retained in the fruit tissues. 'Bartlett' pears (*Pyrus communis* L.) stored in 0.5% or 1.0% O_2 for 10 days at 0, 5, or 10C had almost the same levels of ethanol as the pears stored continuously in air, while 0.25% O_2 caused a slight increase (Ke et al., 1990).

The reduction in CO_2 production of bell pepper transferred from low O_2 to air persisted for ≈ 24 h, but was not significantly different after 72 h in 4% O_2. In contrast, storage of fruit in 1.5% O_2 for 72 h suppressed CO_2 production for ≈ 48 h. The residual effect likely is prolonged as the storage period under 1.5% O_2 is extended.

The RQ values of about one exhibited by fruit stored in 1.5% O_2 for 24 h or after transfer to air indicates that anaerobiosis is not occurring in the fruit tissues. According to Hole et al. (1992), the RQ under aerobic conditions is about one when glucose or other hexose sugars are used as the predominant C source in glycolysis. When a hypoxic condition was induced in highbush blueberry *(Vaccinium corymbosum* L.) fruit sealed in low-density polyethylene packages at 25C, an RQ of ≈ 3 was measured (Beaudry et al., 1992).

In nonclimacteric bell pepper fruit, the C_2H_4 production rates were not affected by prior exposure to 1.5% (data not shown) or 4% O_2 (Saltveit, 1977). Therefore, there is no residual effect of low O_2 on the C_2H_4 production rate of bell peppers. In contrast, low O_2 often delays the onset of the rise in C_2H_4 and other changes associated with ripening in climacteric fruits (Hesselman and Freebaim, 1969).

The O_2 consumption rate was affected to a greater extent than the CO_2 production rate in fruit exposed to low O_2. An O_2 level of 1.5% exerted a greater residual effect than intermediate levels. The continued suppression of O_2 consumption rate upon transfer to air clearly demonstrates the pronounced residual effect from prior exposure to this low oxygen level. Earlier studies indicated that gas diffusion through fruit tissues is quite rapid. Hence, it is unlikely that the residual effect following storage of fruit in 1.5% O_2 results from resistance to gas diffusion through the fruit tissues.

The biochemical basis of the residual gas-exchange response is not known. In terms of cellular O_2 consumption, relevant enzymes have been categorized as low-affinity (high Km) or high-affinity (low Km) oxidases. Low-affinity oxidases include polyphenol oxidase, lipoxygenase, and ascorbic acid oxidase, whereas the primary high-affinity oxidase is cytochrome oxidase (Malmstrom, 1990). Studies by Burton (1982) on potato (*Solanum tuberosum* L.) tubers indicated that 1% gas phase O_2 would result in steady-state, cellular sap O_2 levels of 1.2×10^{-5} M. Under this condition, O_2 consumption by cytochrome oxidase was inhibited <1% relative to values observed in air. In agreement with these considerations, our studies revealed no residual influence of low O_2 (1.5% or 4.0%) on the oxidative capacity of mitochondria isolated from bell pepper fruit. While the residual respiratory response of intact bell pepper possibly is due, in part, to indirect effects on cytochrome oxidase (e.g., reduced carbon flux), our data reveal no residual impairment in the capacity of isolated mitochondria to oxidize exogenously added substrates.

We speculate that the residual respiratory responses may be explained as the suppression of extramitochondrial, low-affinity oxidases. Under gas phase O_2 of 1%, dissolved O_2 levels would result in a nearly 95% inhibition of these enzymes (Burton, 1982). Studies by Mapson and Burton (1962). indicated that ≈ 70% of the respiration of potato tuber in air occurred through cytochrome oxidase, and 30% through the low-affinity oxidases. The proportion of respiration passing through the low-affinity oxidases in 100% O_2 was increased to ≈ 50%.

In summary, reducing the O_2 concentration to 1.5% and prolonging the exposure period to 72 h resulted in a longer poststorage residual effect on the CO_2 production and O_2 consumption. Ethylene production rate was not affected by storage in 1.5% or 4% O_2 for 24 or 72 h. The absence of ethanol indicates that the residual effect induced by 1.5% O_2 is not injurious to the fruit tissue. Additionally, the residual effect of low O_2 on the respiratory activity of intact fruit is not apparent in isolated mitochondria.

Literature Cited

Aharoni, Y., P. Hartsell, J.K. Stewart, and D.K. Young. 1979. Control of western flower thrips on harvested strawberries with acetaldehyde in air, 50% CO_2 or 1% O_2. J. Econ. Entomol. 72:819.

Beaudry, R.M., A.C. Cameron, A. Shirazi, and D.L. Dostal-Lange. 1992. Modified-atmosphere packaging of blueberry fruit: Effect of temperature on package O_2 and CO_2. J. Amer. Soc. Hort. Sci. 117:436-441.

Burton, W.G. 1978. Biochemical and physiological effects of modified atmospheres and their role in quality maintenance, p. 97. In: H.O. Hultin and M. Milner (eds.). Postharvest biology and biotechnology. Food and Nutrition Press, Westport, Conn.

Burton, W.G. 1982. Post-harvest physiology of food crops. Longman, New York.

Davis, P.L., B. Roe, and J.H. Bruemmer. 1973. Biochemical changes in citrus fruits during controlled atmosphere storage. J. Food Sci. 38:225-229.

Duncan, I. and M. Spencer. 1987. Changes in respiration of mitochondria isolated from cotyledons of ethylene-treated pea seedlings. Planta 170:44-48.

Hesselman, C.W. and H.T. Freebaim. 1969. Rate of ripening of initiated bananas as influenced by oxygen and ethylene. J. Amer. Soc. Hort. Sci. 94:635-637.

Hole, D.J., B.C. Cobb, P.S. Hole, and M.C. Drew. 1992. Enhancement of anaerobic respiration in root tips of *Zea mays* following low-oxygen (hypoxic) acclimation. Plant Physiol. 99:213-218.

Kader, A.A. 1986. Biochemical and biophysical basis for effects of controlled and modified atmospheres on fruits and vegetables. Food Technol. 40:99-104.

Kader, A.A. 1992. Modified atmospheres during transport and storage, p. 88. In: A.A. Kader (ed.). Postharvest technology of horticultural crops, 2nd ed. Div. of Agr. and Natural Resources, Univ. of California, Davis.

Ke, D. and A.A. Kader. 1990. Tolerance of 'Valencia' oranges to controlled atmosphere as determined by physiological responses and quality attributes. J. Amer. Soc. Hort. Sci. 115:779-783.

Ke, D., L. Rodriguez-Sinobas, and A.A. Kader. 1991. Physiology and

prediction of fruit tolerance to low oxygen atmospheres. J. Amer. Soc. Hort. Sci. 116:253-260.
Ke, D., H. van Gorsel, and A.A. Kader. 1990. Physiological and quality responses of 'Bartlett' pears to reduced O_2 and enhanced CO, levels and storage temperature. J. Amer. Soc. Hort. Sci. 115:435-439.
Li, C. and A.A. Kader. 1989. Residual effects of controlled atmospheres on postharvest physiology and quality of strawberries. J. Amer. Soc. Hort. Sci. 114:629-634.
Luck, H. 1965. Catalase, p. 885-894. In: H.U. Bergmeyer (cd.). Methods of enzymatic analysis. Academic, New York.
Malmstrom, B.G. 1990. Cytochrome oxidase: Some unsolved problems and controversial issues. Arch. Biochem. Biophys. 280(2):233-241.
Mapson, L.W. and W.G. Burton. 1962. The terminal oxidases of the potato tuber. Biochem. J. 82:19-25.
Moreau, F. and R. Romani. 1982. Preparation of avocado mitochondria using self-generated percoll gradients and changes in buoyant density during ripening. Plant Physiol. 70:1380-1384.
Patterson, M.E. and W.C. Nichols. 1988. Metabolic responses of 'Delicious' apple to carbon dioxide in anoxic and low-oxygen environments. HortScience 23:866-868.
Phelps, DC. and R.E. McDonald. 1990. Inhibition of electron transport activities in mitochondria from avocado and pepper fruit by naturally occurring polyamines. Physiol. Plant. 78:15-21.
Quail, P.H. 1979. Plant cell fractionation. Annu. Rev. Plant Physiol. 30:425-471.
Saltveit, M.E. 1977. Carbon dioxide, ethylene, and color development in ripening mature green bell peppers. J. Amer. Soc. Hort. Sci. 102:523-525.
Smith, P.K., R.I. Krohn, G.T. Hermanson, A.K. Mallia, F.H. Gartner, M.D. Provenzano, E.K. Fujimoto, N.M. Geoke, B.J. Olson, and D.C. Klenk. 1985. Measurements of protein using bicinchoninic acid. Anal. Biochem. 150:76-85.
So1omos, T. 1982. Effect of low oxygen concentration on fruit respiration: Nature of respiratory diminution, p. 161. In: D.G. Richardson and M. Meheriuk (eds.). Controlled atmosphere for storage and transport of perishable agricultural commodities. Timber Press, Beaver&on, Ore.
Storrie, B. and E.A. Madden. 1990. Isolation of subcellular organelles, 182:214-215. In: M.P. Deutsher (ed.). Guide to protein purification. Academic, San Diego.