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Postharvest Attributes of 'Virosa' Tomato Fruit Produced in an Enriched Carbon Dioxide Environment

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Abstract. **The effect of preharvest CO_2 enrichment (1000 μl·liter^{-1}) on postharvest quality of tomato fruit (*Lycopersicon esculentum* Mill. 'Virosa') was studied with an emphasis on soluble sugars, ripening, and mineral composition. High-CO_2 fruit had higher concentrations of sucrose, glucose, fructose, and total soluble solids than ambient-CO_2 fruit. High-CO_2 fruit also ripened more slowly and was characterized by lower respiration and ethylene production rates than ambient-CO_2 fruit. Concentrations of N, P, and K were lower in the high-CO_2 fruit than in the ambient-CO_2 fruit, whereas those of S, Ca, and Mg were the same for both treatments. Preharvest CO_2 enrichment of 'Virosa' tomato enhances fruit desirability in terms of slower postharvest ripening and higher concentrations of soluble sugars and total soluble solids.**

Carbon dioxide enrichment is a common practice in protected cultivation of tomatoes (Nederhoff and De Graaf, 1993). While CO_2 enrichment effects on growth, yield, and physiological attributes of the plant have been researched extensively, fruit quality responses have been neglected, creating a gap in the overall assessment of CO_2 enrichment as a management tool. Slack et al. (1988) found no enrichment effects on the concentration of reducing sugars in extracted tomato fruit juice, and Madsen (1975) reported increases in fruit concentrations of glucose and fructose, a decrease in N, and no effect on P. Our objective was to study the effect of CO_2 enrichment on fruit quality in 'Virosa', a popular glasshouse cultivar in New Zealand, emphasizing ripening and concentration of mineral elements, soluble sugars, and total soluble solids (TSS) in fruit.

Materials and Methods

Five-week-old plants were placed in controlled-environment (CE) rooms at the National Climate Laboratory, HortResearch, Palmerston North, New Zealand. The CE rooms met the following conditions: 22C day/16 ± 0.5C night, relative humidity 70% ± 5%, photosynthetic photon flux 710 μmol·m^{-2}·s^{-1} at plant level, and CO_2 340 μl·liter^{-1} (ambient CO_2) for ambient and 1000 μl·liter^{-1} for the elevated concentration (high CO_2). The photoperiod was from 0900 to 2100 HR. The lighting system for CE rooms consisted of 4× 1000-W Sylvania Metalarc high-pressure discharge lamps (GTE Products Corp., Manchester, N.H.) together with 4× 1000-W Philips tungsten iodide lamps (Philips, Eindhoven, The Netherlands). Carbon dioxide enrichment was achieved by using bottled food-grade CO_2 regulated by a solenoid and controlled to within 50 μl·liter^{-1} of the set point by a Binos-1 infrared gas analyzer (Leybold-Heraeus GmbH, Hanau, Germany). Plants were irrigated at 0600, 1800, and 2400 HR with a mineral nutrient solution supplied by an automatic application system. The solution contained (in ppm) 105 N, 15.5 P, 119 K, 32.1 S, 100 Ca, 2.1 Fe, 24.3 Mg, 0.25 B, 0.25 Mn, 0.01 Cu, 0.02 Zn, 0.005 Mo, 1.8 Cl, and 1.02 Na. Other details of growing conditions and cultural practices are given by Behboudian and Lai (1994). Fruit harvest began when plants were 13 weeks old (from seeding) and had been in CE rooms, receiving CO_2 treatment, for 8 weeks.

Mature-green fruit were harvested and weighed, and the volume was measured by water displacement. Individual fruit were placed in 0.6-liter glass jars with sealed lids fitted with an airtight rubber septum. Jars were kept in a dark growth cabinet at 20C with constant airflow. They were sealed 3 h before measurements of CO_2 and ethylene evolution. One-milliliter duplicate samples were taken from the atmosphere of the sealed jars through the septum and were injected into a gas chromatograph (3400 Varian; Varian Instrument Group, Walnut Creek, Calif.) fitted with a thermal conductivity detector and a CTR-I column (Alltech Associates, Doorfield, Ill.) for CO_2 measurement. Similar injections were made into a gas chromatograph (Pye model 104; Pye Unicam, Cambridge, U.K.) fitted with a flame ionization detector for ethylene determination. These measurements continued until the fruit were table-ripe, i.e., fully red colored.

TSS concentration of the juice was measured for table-ripe fruit with a refractometer (Abbe 60; Bellingham and Stanley, London) maintained at 20C. Pieces of pericarp and placental tissues were freeze-dried and homogenized in 95% ethanol for determination of fructose, glucose, and sucrose. Samples were left for 2 weeks in ethanol, then solids were removed by filtering, and ethanol was evaporated through rotary evaporators. The residue was taken up in water and, after being filtered (using 0.02-μm filters), was injected into a high-performance liquid chromatography system (Waters, Millipore Corp., Milford, Mass.) using a Biorad Aminex HPX87C column with Biorad de-ashing guard columns (Bio-Rad Laboratories, Hercules, Calif.). A refractive index detector (Optilab 5922; Tecator AB, Höganäs, Sweden) was employed with water as the mobile phase and column and detector temperatures at 80 and 40C, respectively.

Fruit were dried at 65C before they were ground for measurement of macronutrient concentration. Nitrogen was analyzed by Kjeldahl digestion and colorimetry; P by sulfuric acid digestion and colorimetry; K, Mg, and Ca by nitric acid digestion and either atomic absorption or emission spectrophotometry; and S by sodium hypobromite digestion followed by hydrogen sulfide reduction and colorimetry.

Ten replicate fruit from 10 replicate plants were used for each of the above measurements. A *t* test was used to compare means.

Results and Discussion

Fruit were harvested on the basis of color, but size also was the same for both CO_2 treatments. Individual fruit from ambient CO_2, from the first truss (oldest truss), weighed 64.2 ± 3.5 g (mean ± SE) and 64.8 ± 3.3 g from elevated CO_2. Ambient-CO_2 fruit reached climacteric respiration earlier than did high-CO_2 fruit (Fig. 1A); this response was paralleled by higher ethylene production (Fig. 1B). The effect might have been imparted through lower ethylene production as a result of lower concentrations of ethylene precursors in fruit grown under high CO_2 relative to those under ambient CO_2. Postharvest exposure of tomato fruit to high CO_2 limits ethylene production or action (Zamponi et al., 1990). The aftereffect of preharvest high CO_2 on fruit ethylene relations apparently has not been studied. The postharvest studies by Zamponi et al. (1990) involved much higher CO_2 concentrations (up to 20%) than used by us.

Quality was also improved in high-CO_2 fruit, compared to ambient-CO_2 fruit, in terms of increased concentration of soluble sugars and TSS (Table 1). These results for sugars are similar to those of Madsen (1975), who measured increases in fruit fructose and glucose with preharvest exposure of plants to 1000 μl CO_2/liter. Since sugars are major components of TSS (Davies and Hobson, 1981), an increase of TSS along with higher sugars would be expected for the high-CO_2 fruit.

Foliar concentration of macronutrients was

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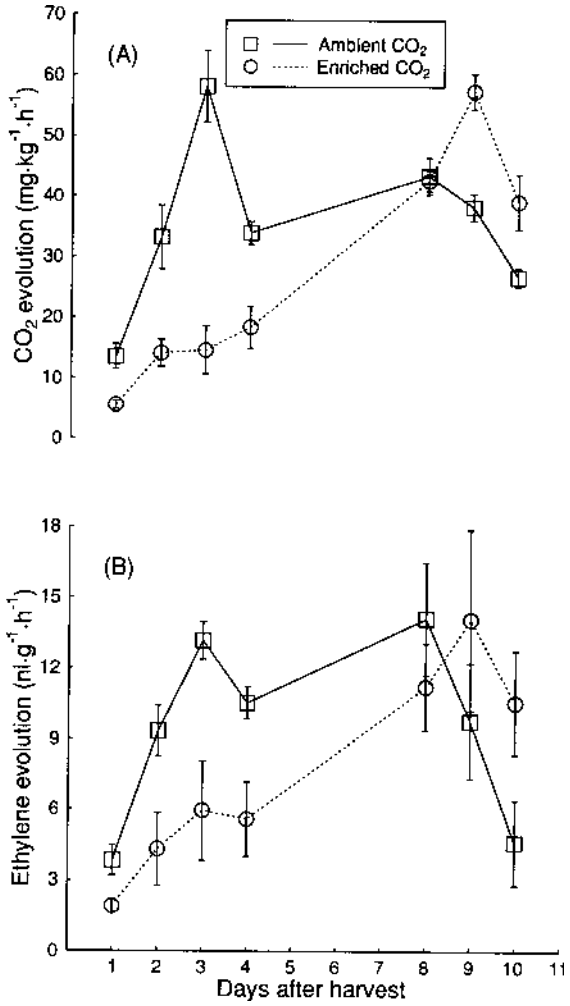

Fig. 1. (**A**) Fruit respiration and (**B**) ethylene production in 'Virosa' tomato fruit grown at ambient (340 µl·liter^{-1}) or at elevated (1000 µl·liter^{-1}) CO_2. The bar on each mean represents twice the standard error of the mean.

Table 1. Concentration of soluble sugars and total soluble solids (TSS) in tomato fruit grown at ambient and at high CO_2.

CO_2 concn	Concn				
	Soluble sugars (mg/100 g fresh wt)				
(µl·liter^{-1})	Sucrose	Fructose	Glucose	Total	TSS (%)
340	15	508	565	1087	4.30
1000[z]	21	598	692	1311	4.76
$P \leq$	NS	0.05	0.01	0.01	0.01

[z]Enrichment was for 8 weeks of a 13-week growth period.
[NS]Nonsignificant.

Table 2. Concentration of N, P, K, S, Ca, and Mg in tomato fruit grown at ambient and at enriched CO_2.

CO_2 concn	Concn (mg/100 g fresh wt)					
(µl·liter^{-1})	N	P	K	S	Ca	Mg
340	154	26	267	12	6	9
1000[z]	131	22	245	11	7	9
$P \leq$	0.01	0.01	0.05	NS	NS	NS

[z]Enrichment was for 8 weeks of a 13-week growth period.
[NS]Nonsignificant.

lower in high-CO_2 plants (Table 2), which had a lower transpiration rate than the ambient-CO_2 plants (Behboudian and Lai, 1994). Except for early in the season, almost all sap flowing into the tomato fruit is through the phloem (Ho et al., 1987). Therefore, the ratio of phloem-mobile elements, such as K, to phloem-immobile elements, such as Ca, would be expected to be higher in fruit than in leaves. Based on the data of Table 2, the K : Ca ratios for the ambient-CO_2 and high-CO_2 fruit are 44.5 and 35.0, respectively . The corresponding values for leaves are 1.6 and 1.4 (Behboudian and Lai, 1994; Table 4). Because the phloem sap originated from a nutritionally more depressed plant from high CO_2, the fruit had lower concentrations of N, P, and K than did the ambient-CO_2 fruit (Table 2). The experimental resolution might have been inadequate to demonstrate this effect in the case of the less abundant S, Ca, and Mg. Fruit concentrations of macronutrients (Table 2) were within the healthy range (Mahler, 1976) for both treatments and no deficiency symptoms were evident. Carbon dioxide enrichment therefore did not result in any micronutrient excess or deficiency that could have negative effects on fruit quality (Adams, 1986).

The experiments reported here were part of a research program assessing the overall effects of CO_2 enrichment on 'Virosa'. Although CO_2 enrichment did not improve growth and yield (Behboudian and Lai, 1994), or fruit size, fruit desirability was enhanced by slower ripening and higher concentration of soluble sugars and TSS. The slower ripening, which was characterized by lower respiration rate and lower ethylene production, should be of potential benefit to tomato growers, especially those shipping to distant markets. Since CO_2 enrichment is practiced widely in protected cultivation of tomatoes, its aftereffects on slower fruit ripening require further studies to delineate underlying mechanisms.

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