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EFFECT OF ELEVATED CARBON DIOXIDE ON NUTRITIONAL QUALITY OF TOMATO

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ABSTRACT

Tomato (*Lycopersicon esculentum* Mill.) cvs. Red Robin (RR) and Reimann Philipp (RP) were grown hydroponically for 105 d with a 12 h photoperiod, 26 °C / 22 °C thermoperiod, and 500 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PPF at either 400, 1200, 5000, or 10,000 $\mu mol \cdot mol^{-1}$ (0.04, 0.12, 0.50, 1.00 kPa) CO_2. Harvested fruits were analyzed for proximate composition, total dietary fiber, nitrate, and elemental composition. No trends were apparent with regard to CO_2 effects on proximate composition, with fruit from all treatments and both cultivars averaging 18.9 % protein, 3.6 % fat, 10.2 % ash, and 67.2 % carbohydrate. In comparison, average values for field-grown fruit are 16.6 % protein, 3.8 % fat, 8.1 % ash, and 71.5 % carbohydrate (Duke and Atchely, 1986). Total dietary fiber was highest at 10,000 $\mu mol \cdot mol^{-1}$ (28.4 % and 22.6 % for RR and RP) and lowest at 1000 $\mu mol \cdot mol^{-1}$ (18.2 % and 15.9 % for RR and RP), but showed no overall trend in response to CO_2 . Nitrate values ranged from 0.19 % to 0.35 % and showed no trend with regard to CO_2 . K, Mg, and P concentrations showed no trend in response to CO_2, but Ca levels increased from 198 and 956 ppm in RR and RP at 400 $\mu mol \cdot mol^{-1}$, to 2537 and 2825 ppm at 10,000 $\mu mol \cdot mol^{-1}$. This increase in Ca caused an increase in fruit Ca/P ratios from 0.07 and 0.37 for RR and RP at 400 $\mu mol \cdot mol^{-1}$ to 0.99 and 1.23 for RR and RP at 10,000 $\mu mol \cdot mol^{-1}$, suggesting that more dietary Ca should be available from high CO_2-grown fruit.
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INTRODUCTION

Information on nutritional quality of plant-produced foods has typically come from field-grown plants exposed to changing meteorological conditions, varying levels of nutrient availability, and nominal ambient CO_2 concentrations of approximately 350 $\mu mol \cdot mol^{-1}$. In addition, crops in the field can experience different degrees of stress from insect herbivory and weed competition. In contrast, food from plants grown in a Controlled Ecological Life-Support System (CELSS) will be maintained under controlled environment conditions free of such stresses. Most likely this would involve the use of electrical lighting, recirculating hydroponic culture (to conserve water and nutrients), and elevated CO_2 concentrations to increase photosynthetic rates and productivity. Indeed, because of the closed nature of a CELSS, CO_2 may even build to levels beyond what is optimal for plants, which typically ranges between 1000 and 2000 $\mu mol \cdot mol^{-1}$ (0.10 to 0.20 kPa) for C_3 plants (Wheeler *et al.*, 1994a; Bugbee *et al.*, 1994).

At NASA's Kennedy Space Center, we have been particularly interested studying the effects of CO_2 concentration on plant growth and composition for a CELSS. The following series of experiments was conducted in plant growth chambers to study to influence of CO_2 concentrations on the nutritional and elemental composition of tomato fruit. Tomatoes have been suggested as a crop for CELSS consideration (Hoff *et al.*, 1982) and have been the focus of extensive CO_2 testing in the past, particularly in greenhouse settings (Madsen, 1974; Hicklenton and

Jolliffe, 1980; Peet and Willits, 1984); however, few data are available on the effects of CO_2 on the nutritional composition of the fruits.

MATERIALS AND METHODS

Tomato (*Lycopersicon esculentum* Mill.) cvs. Red Robin (RR) and Reimann Philipp 75/59 (RP) plants were grown from seed in a walk-in type plant growth chamber. Plants were spaced at 6.7 plants m^{-2} and grown in hydroponic culture trays using a nutrient film technique (Wheeler *et al.*, 1993, 1996). A modified 0.5 x Hoagland nutrient solution (Wheeler *et al.*, 1993, 1996) was circulated through trays at 1.0 to 1.5 $L \cdot min^{-1}$, with solution pH controlled to 5.8 with additions of dilute (0.4 $mol \cdot L^{-1}$) HNO_3, and electrical conductivity adjusted daily to 0.12 $S \cdot m^{-1}$ with additions of a complete stock solution. Lighting was provided by high-pressure sodium lamps and maintained at 500 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PPF with a 12 h photoperiod. Temperatures were cycled between 26 °C (light) and 22 °C (dark), and relative humidity was maintained at 65%. Carbon dioxide levels were controlled to 400, 1200, 5000, 10,000 $\mu mol \cdot mol^{-1}$ (0.04, 0.12, 0.50, and 1.00 kPa) using an infrared gas analyzer and dedicated computer control system. Plants were grown for a total of 105 d, but beginning at 63 d, fruits were harvested weekly as they turned red.

Fruits were macerated in a kitchen blender and then freeze dried for analysis. Dried tissue was analyzed for proximate composition, total dietary fiber (TDF), and nitrate by a commercial laboratory (Nutrition International, Dayton, NJ, USA) following standard AOAC (1990) procedures: moisture by vacuum oven (AOAC method 934-01); ash by muffle furnace (AOAC method 900.02); protein by Kjeldahl nitrogen with 6.25 conversion factor (AOAC method 981.10); fat by acid hydrolysis and ether extraction (AOAC methods 920.39 and 922.06); carbohydrate by difference [100% - (% ash + % fat + % protein)]; nitrate-nitrogen by xylenol method (AOAC method 935.48); and total dietary fiber by enzymatic-gravimetric method (AOAC method 985.29). Tissue elemental composition was analyzed using DC arc inductively-coupled plasma (ICP) spectroscopy (Alexander and McAnulty, 1981).

RESULTS AND DISCUSSION

Analysis of proximate composition and TDF showed no trends with regard to CO_2 concentration (Table 1). (Note, only single samples of pooled tissue from different plants were analyzed in triplicate, hence no statistical analyses were performed). Red Robin (RR) fruit had higher fat and TDF levels than Reimann Philipp (RP) at all CO_2 levels. However, fat levels are low in tomato fruit (Duke and Atchely, 1986) and hence this difference is likely inconsequential for dietary considerations. The higher TDF in RR fruit may be a result of RR having smaller fruit than RP, resulting in proportionately more epidermis (skin) tissue in the samples. In related studies with soybean and potato grown at different CO_2 concentrations, soybean seed showed increased crude fiber with increased CO_2 , but no other difference were noted (Wheeler *et al.*, 1994b). McKeehen *et al.* (1996a) reported decreased ash in lettuce and radish tissue grown at increased CO_2 , but as with soybean and potato, no other trends were apparent.

If proximate composition data for both cultivars and all CO_2 treatments are combined and compared to the average of six entries for field-grown tomato reported by Duke and Atchely (1986), results show that the controlled environment-grown fruits were slightly higher in protein and ash than field-grown fruits (Fig. 1). This trend is consistent with previous analyses of crops grown in NASA's biomass production chamber (Wheeler *et al.*, 1996), yet the distributions of observations (shown as bars on Fig. 1) overlap for all measurements, suggesting that there were no significant differences between fruits from our studies and field-grown tomatoes.

A comparison of elemental analysis showed no trend in response to CO_2 for tissue levels of potassium (K), magnesium (Mg), phosphorus (P), or nitrate-nitrogen (NO_3 -N) (Table 1). However, fruit calcium content showed a clear increase with CO_2 . The increase in fruit Ca levels with increased CO_2 resulted in a similar increase in tissue Ca/P ratio (Fig. 2). The ratio of Ca/P in the diet is known to affect the absorption and retention of calcium in humans (McKeehen *et al.*, 1996a). Except for leafy vegetables, Ca/P ratios are typically low in plant foods, particularly for hydroponically-grown plants that are given plentiful phosphorus in the nutrient solution (McKeehen *et al.*, 1996a). Calcium uptake by plants is known to be closely linked with water movement within the tissue (Wiebe *et al.*, 1977) , and extreme CO_2 levels (*e.g.*, 5000 and 10,000 $\mu mol \cdot mol^{-1}$) have been shown to

Table 1. Effect of CO_2 on Proximate and Elemental Composition of Tomato Fruit

CO_2	cv.	Protein	Fat	Ash	CHO	TDF	K	Ca	Mg	P	NO_3-N
(μmol · mol^{-1})		(%)	(%)	(%)	(%)	(%)	(ppm)	(ppm)	(ppm)	(ppm)	(%)
400	RR	17.7	2.8	10.0	69.5	20.9	33016	198	3056	2752	0.32
	RP	18.2	1.6	5.8	74.4	16.6	39476	956	3201	2558	0.19
1200	RR	17.2	6.2	10.1	66.4	18.2	45491	771	2486	2580	0.14
	RP	17.6	1.4	10.8	70.3	15.9	46127	1714	2813	2518	0.24
5000	RR	21.3	5.7	11.3	61.6	21.5	45575	1662	2072	2328	0.15
	RP	19.1	2.5	12.9	65.5	16.3	55444	2308	2843	2277	0.35
10,000	RR	20.4	5.0	10.4	64.2	28.4	46512	2537	2927	2574	0.25
	RP	20.1	4.0	10.2	65.7	22.6	42540	2825	3087	2294	0.21

cv. = Cultivar; CHO = Carbohydrate; TDF = Total Dietary Fiber; RR = Red Robin; RP = Reimann Philipp.

increase water flow through soybean and potato plants (Wheeler *et al.*, 1993, 1994a). Transpiration and water uptake by tomatoes in these tests were highest at the 5000 and 10,000 treatments as well (Mackowiak *et al.*, unpublished), suggesting that more calcium might have been moved to growing tissues in these treatments. However, related studies by McKeehen *et al.* (1996b) noted no effect of increased CO_2 on Ca content of lettuce leaves. Thus the increase in Ca from CO_2 enrichment may occur only in organs where transpiration rates are typically low (*e.g.*, fruits and tubers).

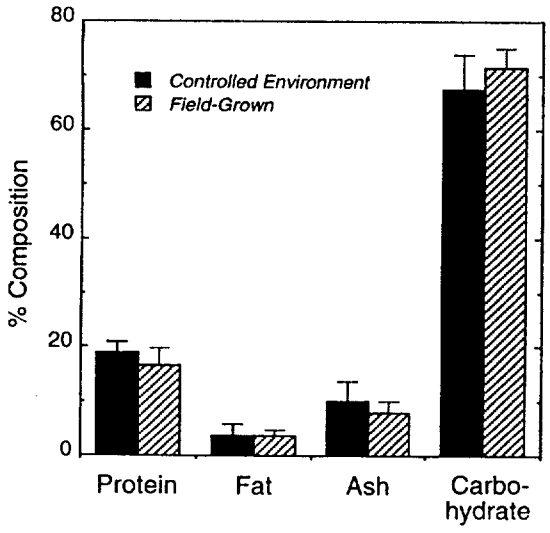

Fig. 1. Proximate composition of controlled environment and field-grown tomato fruit. Bars indicate distribution ranges for observations.

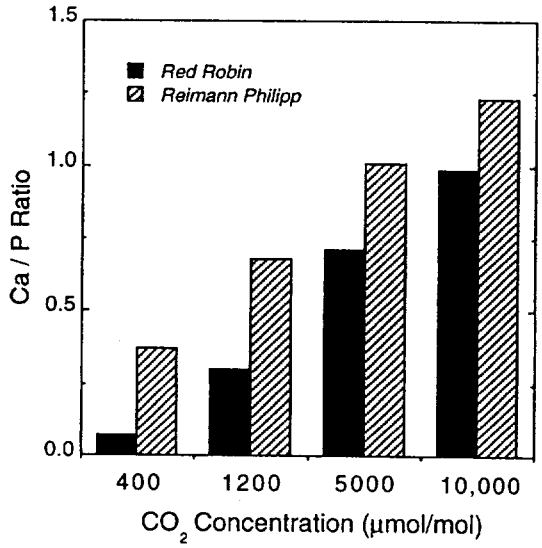

Fig. 2. Carbon dioxide effect on calcium to phosphorus ratio in tomato fruit from cvs. Red Robin and Reimann Philipp 75/59.

CONCLUSION

Growing tomato cultivars Red Robin and Reimann Philipp 75/59 at different CO_2 concentrations had little effect on proximate and elemental composition of their fruit, with the exception of tissue calcium concentration, which increased with increased CO_2 . Red Robin tended to be higher than Reimann Philipp in total dietary fiber, but this may be related to the smaller size of the fruits and the higher proportion of epidermis (skin) in the fruit mass. When all treatments were averaged and compared with field-grown tomatoes, ash and protein were slightly higher than field data, but differences were not significant, suggesting that tomatoes should do well in controlled environment settings that might be used for a CELSS.

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