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Respiratory Rate and Vital Heat of Some Specialty Vegetables at Various Storage Temperatures

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ADDITIONAL INDEX WORDS. arugula, banana flower bud, bitter gourd, cassava, chayote, Chinese chive, Chinese water chestnut, drumstick, elephant garlic, giant garlic, guar, hyacinth bean, Jerusalem artichoke, jicama, methi, roquette, salsify, tindora, tomatillo, tumeric

SUMMARY. Respiratory rate was measured and vital heat calculated for 18 specialty vegetables {arugula or roquette [*Eruca sativa* Miller], banana flower bud [*Musa × paradisiaca* L. var. *paradisiaca*], bitter gourd [*Momordica charantia* L.], cassava [*Manihot esculanta* Crantz], chayote [*Sechium edule* (Jacq.) Swartz], Chinese chive [*Allium tuberosum* Rottler ex Sprengel], Chinese water chestnut [*Eleocharis dulcis* (Burm. f.) Trin. ex Henschel], drumstick [*Moringa oleifera* Lam.], giant or elephant garlic [*Allium scorodoprasum* L.], guar [*Cyamopsis tetragonoloba* (L.) Taub.], hyacinth bean [*Lablab purpureus* (L.) Sweet.], Jerusalem artichoke [*Helianthus tuberosus* L.], jicama [*Pachyrhizus erosus* (L.) Urban], methi [*Trigonella foenum-graecum* L.], salsify [*Tragopogon porrifolius* L.], tindora [*Coccinia grandis* (L.) Voigt], tomatillo [*Physalis ixocarpa* Brot. ex Hornem.], and tumeric [*Curcuma longa* L.]} at 0, 5, 10, and 20 °C. Respiration rates increased more or less exponentially with increasing storage temperature in all the vegetables tested, CO₂ varying from 28 to 302 mg·kg⁻¹·h⁻¹ at 20 °C for tumeric and drumstick, respectively. At 0 °C, the same products had the lowest and highest respiration rates of

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the products measured (i.e., CO_2 at 4.5 and 28 $\text{mg}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$, respectively). Among the vegetables tested, above-ground plant parts such as leaves, fruit, and flowers generally had higher respiration rates than subterranean storage organs such as roots, corms, and tubers. Vital heat produced ranged from 49 $\text{J}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$ for tumeric at 0 °C to 3272 $\text{J}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$ for drumstick at 20 °C.

Vegetables make up a major portion of the human diet, providing not only calories but also essential vitamins, fiber, and minerals. Specialty vegetables comprise a small but increasingly significant portion of the vegetables consumed in many areas of the world. In the United States, their increased consumption has been attributed to the expanding ethnic diversity of the population, renewed emphasis on eating healthy foods, and the successful promotion of a greater variety of vegetables (The Packer, 1993). Ethnic diversity, in particular, is a primary contributor to changing food consumption patterns and has increased the availability of and demand for specialty vegetables in the United States (Kays and Silva Dias, 1995). Immigrant populations are known to have food needs that often differ substantially from those of the indigenous population. New immigrants, for example, often have strong emotional attachments to the traditional foods of their country of origin (Bell and Coursey, 1971). In the 1960s, southern Europeans immigrated to work in the northwestern European industrial zone, bringing with them their distinct consumer behavior patterns and vegetable preferences (Smith, 1989).

Available statistics show that within the last two decades there has been a tremendous increase in the volume and variety of specialty vegetables grown and imported into the United States (U.S. Dept. of Agriculture, 1995; Lamberts, 1992; Yamaguchi, 1973). Of 390 vegetable crops grown commercially around the world, ≈ 204 (52%) can be found in the United States. Of these, ≈ 52 are considered minor crops and 85 are relatively rare (Kays and Silva Dias, 1995). In 1980, 666,855 t of specialty vegetables with a value of \$370,700,000 were harvested from 54,941 ha in California alone. By 1993, the area was up to

117,569 ha, yield to 1,702,585 t, and value to \$1,281,300,000 (USDA, 1995).

Information on the postharvest behavior of vegetables is essential to maximize shelf life and to minimize quality losses. The respiration rate is related to product temperature and often is a fairly good indication of the rate of postharvest quality loss. Respiration produces heat, CO_2 , and H_2O , each of which increases with increasing product temperature within the 0 to 35 °C range. While diverse methods such as burying products in soil or moist media, storage in aqueous salt solutions, film wraps, waxing, and controlled-atmosphere storage have been used to extend the shelf life of fresh vegetables (Cooke et al., 1988; Hardenburg et al., 1988; Kays and Sanchez, 1984; Mohammed and Wickham, 1993), temperature management remains the most effective method. Individual crops are known to display a substantial range in respiratory rates and subsequent heat load placed on the cooling system (Hardenburg et al., 1988). Knowledge of the respiratory response of vegetables, therefore, is important in predicting the shelf life and determining storage cooling requirements.

Information on the postharvest handling of many specialty vegetables is relatively scarce. Improper temperature control is known to be a critical constraint in the successful storage and shipping of many specialty crops (Mohammed, 1992). For most of the products on which we report in our study, little information is available on storage requirements and the effect of temperature on the respiratory rate, although such information is available for the major crops (Hardenburg et al., 1988). Our objective was to determine the rate of respiration of 18 specialty vegetables held at four storage temperatures.

Materials and methods

The following vegetables were procured from the Dekalb Farmers Market, Atlanta: arugula or rocket, banana flower bud, bitter melon, cassava (waxed roots), chayote, Chinese chive, Chinese water chestnuts, drumstick, giant or elephant garlic, guar, hyacinth bean, Jerusalem artichoke, jicama, methi, salsify, tindora, tomatillo, and tumeric. Each vegetable was separated into 16 equal sets, weighed,

and placed in glass containers of suitable size for the sample (e.g., 3.8-L glass jars, 9.0-L desiccators, 1.1-L glass tubes). Samples with four replicates were held in the experimental storage temperature (0, 5, 10, or 20 °C) for ≈ 24 h to bring the product temperature to that of the storage temperature, and after equilibration, the container was flushed with air and was sealed. The number of individual units of product per replication varied among the crops from two to four in large organs (e.g., jicama) and ≤ 80 to 100 in leafy crops. Individual products were purchased twice for analysis. Gas samples were removed at an appropriate interval that varied from 2 to 24 h (i.e., before the CO_2 concentration reached 1.0% within the container) depending on the product, storage temperature, and container volume. Gas samples were analyzed for CO_2 by gas liquid chromatography (Fisher Hamilton Gas Partitioner; 2.0 mm $\times$ 4.8 m column of 42- to 60-mesh Molecular Sieve 13 $\times$ and an 1.8 m $\times$ 6.4 mm column of DEHS on Columnpak, 60 to 80 mesh; 70 °C; Fisher Scientific, Springfield, N.J.). Headspace CO_2 concentration was converted to mass for comparisons among temperatures (Kays, 1991). Vital or respiratory heat expressed as Joules per kilogram per hour was calculated as follows: CO_2 in $\text{mg}\cdot\text{kg}^{-1}\cdot\text{h}^{-1} \times 10.8485 = \text{J}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$.

Results and discussion

In each of the crops, respiratory rates increased with increasing temperature. Cassava, chayote, giant garlic, Jerusalem artichokes, jicama, and tumeric displayed low respiratory rates compared with other products. At 20 °C their CO_2 rates were $< 100 \text{ mg}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$. Banana flower bud, bitter melon, Chinese water chestnuts, methi, salsify, tindora, and tomatillo had respiration CO_2 rates in between 100 to 200 $\text{mg}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$ at 20 °C. Chinese chives, guar, and hyacinth bean had CO_2 rates $> 200 \text{ mg}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$ at 20 °C, and drumstick had the highest respiratory rate (CO_2 at 301.6 $\text{mg}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$ at 20 °C) among the vegetables tested. Vital heat produced by the products at different storage temperatures is given in Table 1 and is indicative of the product heat load that would be placed on a cooling system at the respective storage temperatures.

Respiratory quotients (RQ_{10}) ranged from 1.7 (tumeric) to 4.7 for

Table 1. Respiration rate and vital heat of 18 specialty vegetables at four storage temperatures.

Vegetable	Plant part	Respiration rate and vital heat $\pm$ SE CO ₂ at mg·kg ⁻¹ ·h ⁻¹ (J·kg ⁻¹ ·h ⁻¹)			
		Storage temp (°C)			
		0	5	10	20
Arugula	Leaves	21.1 $\pm$ 5.3 (229 $\pm$ 57)	58.1 $\pm$ 12.3 (630 $\pm$ 133)	106.6 $\pm$ 12.4 (1156 $\pm$ 135)	198.1 $\pm$ 11.7 (2149 $\pm$ 127)
Banana flower bud	Unopened flower bud	15.8 $\pm$ 0.4 (171 $\pm$ 4)	20.9 $\pm$ 2.7 (227 $\pm$ 29)	42.2 $\pm$ 1.3 (458 $\pm$ 14)	107.4 $\pm$ 1.4 (1165 $\pm$ 15)
Bitter Melon	Unripe fruit	25.2 $\pm$ 2.8 (273 $\pm$ 30)	60.6 $\pm$ 1.6 (657 $\pm$ 17)	70.8 $\pm$ 4.6 (768 $\pm$ 50)	175.2 $\pm$ 5.1 (1885 $\pm$ 55)
Cassava	Storage root	5.0 $\pm$ 0.2 (54 $\pm$ 2)	7.0 $\pm$ 1.1 (75 $\pm$ 12)	12.7 $\pm$ 1.3 (136 $\pm$ 14)	45.1 $\pm$ 6.7 (485 $\pm$ 72)
Chayote	Mature fruit	4.9 $\pm$ 0.1 (53 $\pm$ 1)	9.0 $\pm$ 1.4 (98 $\pm$ 15)	16.1 $\pm$ 0.8 (175 $\pm$ 9)	50.4 $\pm$ 2.7 (547 $\pm$ 29)
Chinese chives	Leaves	27.0 $\pm$ 3.2 (293 $\pm$ 35)	44.7 $\pm$ 3.4 (485 $\pm$ 37)	51.6 $\pm$ 1.9 (560 $\pm$ 21)	240.2 $\pm$ 12.5 (2605 $\pm$ 135)
Chinese water chestnut	Corm	10.1 $\pm$ 1.6 (109 $\pm$ 17)	25.4 $\pm$ 1.9 (277 $\pm$ 21)	41.7 $\pm$ 5.0 (452 $\pm$ 54)	114.5 $\pm$ 4.8 (1245 $\pm$ 52)
Drumstick	Immature pod and seed	28.0 $\pm$ 2.8 (304 $\pm$ 30)	58.9 $\pm$ 2.5 (639 $\pm$ 27)	141.0 $\pm$ 9.5 (1529 $\pm$ 103)	301.6 $\pm$ 14.3 (3271 $\pm$ 155)
Giant garlic	Cloves	13.3 $\pm$ 0.5 (144 $\pm$ 5)	28.5 $\pm$ 5.7 (309 $\pm$ 62)	50.0 $\pm$ 3.1 (542 $\pm$ 33)	96.8 $\pm$ 1.2 (1050 $\pm$ 13)
Guar	Immature pod and seed	16.2 $\pm$ 0.4 (176 $\pm$ 4)	59.5 $\pm$ 5.5 (645 $\pm$ 60)	67.5 $\pm$ 5.4 (732 $\pm$ 58)	254.8 $\pm$ 4.6 (2764 $\pm$ 50)
Hyacinth bean	Immature pods and seed	25.0 $\pm$ 1.5 (271 $\pm$ 16)	74.6 $\pm$ 11.4 (809 $\pm$ 124)	79.2 $\pm$ 2.6 (859 $\pm$ 28)	255.3 $\pm$ 5.9 (2769 $\pm$ 64)
Jerusalem artichoke	Tuber	10.2 $\pm$ 0.5 (111 $\pm$ 5)	12.3 $\pm$ 0.4 (134 $\pm$ 4)	19.4 $\pm$ 0.7 (211 $\pm$ 7)	49.5 $\pm$ 6.5 (537 $\pm$ 70)
Jicama	Storage root	8.7 $\pm$ 0.2 (95 $\pm$ 2)	11.4 $\pm$ 0.2 (124 $\pm$ 2)	19.4 $\pm$ 0.7 (211 $\pm$ 7)	53.8 $\pm$ 5.0 (584 $\pm$ 54)
Methi	Leaves and tender shoots	23.1 $\pm$ 0.2 (251 $\pm$ 16)	47.0 $\pm$ 3.8 (510 $\pm$ 41)	63.5 $\pm$ 2.4 (689 $\pm$ 26)	194.6 $\pm$ 9.8 (2111 $\pm$ 106)
Salsify	Root	12.9 $\pm$ 1.9 (140 $\pm$ 21)	22.0 $\pm$ 5.4 (239 $\pm$ 58)	25.2 $\pm$ 4.4 (273 $\pm$ 48)	107.0 $\pm$ 0.5 (1160 $\pm$ 5)
Tindora	Young fruit	21.3 $\pm$ 0.8 (231 $\pm$ 97)	28.9 $\pm$ 4.4 (313 $\pm$ 48)	47.3 $\pm$ 0.8 (513 $\pm$ 9)	168.7 $\pm$ 9.4 (1830 $\pm$ 102)
Tomatillo	Fruit	6.0 $\pm$ 1.0 (65 $\pm$ 11)	15.2 $\pm$ 2.6 (165 $\pm$ 28)	27.7 $\pm$ 3.6 (301 $\pm$ 39)	67.9 $\pm$ 11.7 (737 $\pm$ 127)
Turmeric	Rhizome	4.5 $\pm$ 0.3 (49 $\pm$ 3)	9.4 $\pm$ 1.3 (102 $\pm$ 14)	16.5 $\pm$ 1.6 (179 $\pm$ 17)	27.8 $\pm$ 2.9 (302 $\pm$ 32)

Chinese chives in the 10 to 20 °C range. The mean RQ₁₀ across all crops between 10 and 20 °C was 2.9. Typically Q₁₀ values are considered valid in the 5 to 25 °C range; at lower temperatures the values are commonly substantially higher, a situation aggravated by crops that display chilling injury. To our knowledge, for most products tested, no information is available on the chilling sensitivity to low-temperature storage. Thus, this area requires further research. Such information is important in determining the optimum temperatures for storage to minimize quality losses.

In the few examples where respiratory data were available, reported

results are comparable, with differences among tests within what might be anticipated with varying cultivar, age, degree of ripeness, and other factors. For example, the respiratory rates for jicama are in close agreement with that reported by Bergsma and Brecht (1992). Greater differences were apparent with bitter melon, a climacteric fruit, and tomatillo, a crop that has been altered significantly in the past few years through plant breeding. Zong et al. (1992) reported CO₂ at 4, 8, 15 and 34 mL·kg⁻¹·h⁻¹ for bitter melon at 0, 5, 10 and 20 °C, respectively, whereas our values were significantly higher (i.e., CO₂ at 25, 61, 71, and 175 mg·kg⁻¹·h⁻¹ at 0, 5, 10, and 20 °C,

respectively). The respiratory rate of bitter melon varies greatly (CO₂ at 25 to 250 mg·kg⁻¹·h⁻¹) with proximity to the respiratory climacteric (Kays and Hayes, 1978) and due to the substantial genetic diversity found in the crop (unpublished data). Likewise, our results for tomatillo (CO₂ at 68 mg·kg⁻¹·h⁻¹ at 20 °C), were higher than those reported by Cantwell et al. (1992) (i.e., CO₂ at 33 to 46 mg·kg⁻¹·h⁻¹) but were well within what might be expected due to cultivar and maturity differences. For example, Hirots et al. (1984) found a 2-fold difference in respiratory rate between the cassava cultivars 'Golden Yellow' and 'Kadabao'. Production environment and preharvest

crop management practices have affected the respiratory behavior of harvested products (Alban et al., 1940; Bramlage et al., 1974; Mellenthin and Wang, 1976).

In general, belowground storage organs such as rhizomes (turmeric), roots (cassava, jicama, and salsify), and tubers (Jerusalem artichoke) had lower respiratory rates than aboveground parts such as leaves (arugula, Chinese chives, and methi), inflorescences (banana flower buds), and immature fruit (drumstick, guar, hyacinth bean, and tindora).

These results provide reasonable estimates of respiratory rates that would be expected from these crops, although individual crops should be expected to vary somewhat due to maturity, cultivar, growing and handling conditions, and other factors. Respiratory rate should not be used as an indicator of the optimum storage temperature. A number of the crops included in this study are chilling sensitive, and as a consequence, the lower temperatures may be well below the threshold for injury.

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Geographical Characterization of Greenhouse Irrigation Water

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ADDITIONAL INDEX WORDS. alkalinity, B, Ca, Cl, electrical conductivity, Mg, pH, Na, sodium adsorption ratio, SO_4

SUMMARY. Chemical analyses of 4306 randomly selected greenhouse water samples for 1995 from the United States and Canada were obtained from four analytical laboratories and graphically characterized using a distribution analysis. For pH, electrical conductivity (EC), and nutrient concentrations, a mean and median value and the percentage of samples with concentrations above or below those generally considered acceptable are presented for all samples and the 10 leading states in floricultural production. The median nutrient concentrations were more representative of the type of water found throughout the United States and Canada than that of the mean values because of the unequal distribution of the data. The overall median water source had a pH of 7.1; an EC of 0.4 dS·m⁻¹; an alkalinity of CaCO₃ at 130 mg·L⁻¹; (in mg·L⁻¹) 40 Ca, 11 Mg, 8 SO₄-S, 13 Na, 14 Cl, 0.02 B, and <0.01 F; a Ca : Mg ratio of 3.2, and a sodium adsorption ratio (SAR) of 0.7. The information presented characterizes irrigation water and may assist in developing more refined fertilizer recommendations for greenhouse crop production.

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