HORTSCIENCE 39(3):562–566. 2004.

The Anaerobic Compensation Point for Fresh-cut Watermelon and Implications for Postprocess Handling

Jorge M. Fonseca¹

Clemson University, Horticulture Department, Clemson, SC 29634-0375

James W. Rushing²

Clemson University, Coastal Research and Education Center, Charleston, SC 29414-5332

Robert F. Testin

Clemson University, Packaging Science Department, Clemson, SC 29634-0375

Additional index words. *Citrullus lanatus*, modified atmosphere, quality, minimally processed

Abstract. The influence of temperature and O₂ concentration on respiration and shelf life of fresh-cut watermelon was investigated. Product stored at selected temperatures from 1 to 30 °C showed increasing respiration and reduced shelf life with increasing temperature. Oxygen depletion and CO₂ evolution were measured using a closed system method and rates of O₂ consumption and CO₂ production were computed. A mathematical model found to predict the CO₂ production as function of temperature and O₂ showed an elevated rate of CO₂ production at about 14% O₂ or lower. A modified atmosphere trial that compared product stored at 7 to 9 °C in air with product at either 14% or 8% O₂ revealed increased respiration in the latter treatments, suggesting a relatively high anaerobic compensation point (ACP) at >14% O₂. Our results suggest limited applicability of modified atmosphere packaging (MAP) for this product. Fresh-cut watermelon had extended shelf life and reduced respiration rate when stored at 1 to 3 °C and in >14% O₂ atmospheres.

The consumption of fresh-cut watermelon [*Citrullus lanatus* (Thunb. Matsum. and Nakai)] has increased at a rate of 20% to 30% annually, to the extent that ≈25% of all watermelon produced in U.S. is cut in some fashion for retail sale. Most of this processing is done in the supermarket due to the product's short shelf life (NWPB, 1998). Previously we determined that shock and vibration stress encountered during transportation is a major problem that must be addressed by regional processors. Packaging that diminishes cube-to-cube friction appeared to be a promising solution (Fonseca et al., 1999).

Refrigeration is the primary method for reducing the respiration rate and quality deterioration of fresh fruits and vegetables (Cameron et al., 1994; King and Bolin 1989). Intact watermelon stored below 10 °C may suffer chilling injury, which may be manifested as water-soaked areas in the pulp (Risse and Maynard 1990). The respiration rate of intact watermelon ranges between 10 and 20 mL CO₂ kg⁻¹·h⁻¹ at 18 °C (Elkashif et al., 1989). Watada et al. (1996) and Gorny (1997) reviewed respiration rates and optimum temperatures for storage of fresh-cut products but their reports

lacked information on fresh-cut watermelon.

The respiration rate of fresh fruits and vegetables depends on such factors as the composition of the surrounding gas, the moisture content of the tissue, wounding, morphology, maturity, and temperature of the product (Kays, 1991; Talasila et al., 1992). The effectiveness of temperature management on extending the shelf life of some fresh produce can be enhanced by using modified atmosphere packaging (MAP) (Kader et al., 1989). Using MAP techniques, aerobic respiration may be reduced by decreasing the available O₂, but only to a critical level below which respiration increases due to anaerobic respiration (Knee, 1980). This level was first mentioned as the extinction point (EP) (Platenius, 1942). Since then, four alternative concepts have been proposed, each one determined by a slightly different method. The anaerobic compensation point (ACP) is the O₂ concentration at which CO₂ production is minimal (Boersig et al., 1988). The respiratory quotient breakpoint (RQB) is defined as the partial pressure of O₂ at which the respiratory quotient increases with reduced O₂ content (Beaudry et al., 1992). The maintenance oxygen concentration (MOC) is the oxygen concentration at which ATP production rate is minimal for maintaining cell viability (Peppelenbos and Rabbinge, 1996). Finally, the fermentation threshold (FT) combines the RQB with the O₂ level above which fermentation is extinguished (EP) (Yearsley, et al., 1996).

Generally, in comparison to intact fruit, the fresh-cut products can be stored at lower O₂ levels such as 1% to 3% (Gorny, 1997; Kays, 1991) in part because they have less cuticle

or skin to restrict gas diffusion (Watada, 1999). However, there are several exceptions: orange slices, for example, undergo anaerobic respiration below 14% O₂ (Gorny, 1997), and sweetpotatoes may shift to anaerobic conditions at external oxygen concentrations below 7% (Chang and Kays, 1981). Little has been reported addressing the effect of O₂ and CO₂ on fresh-cut watermelon physiology. Cartaxo et al. (1997) observed unsatisfactory quality of watermelon cubes stored in 3% O₂ atmospheres, but higher O₂ concentrations were not tested in that study. Perkins-Veazie et al. (1998) measured respiration of watermelon slices (flesh and rind) stored in jars at 10 °C, observing an increase in rate from storage day 1 to 5; these results, however, were not associated with any physiological or environmental factor.

Several models have been used to predict aerobic respiration of produce under closed systems. A linear model (Hayakawa et al., 1975) and an enzymatic model (Lee et al., 1991), both based on O₂ concentration as an inhibitor of fermentative CO₂ production, are noted. Another model uses the ATP concentration as an inhibitor of fermentative CO₂ production (Peppelenbos et al., 1996). However, our interest was to find a model that could predict the CO₂ production (KCO₂) as a function of two factors—temperature and O₂. Such a model could be useful to define the ACP and thus predict the onset of anaerobic respiration in products stored at different temperatures.

The objective of this work was to determine the influence of temperature and oxygen on the respiration and shelf life of fresh-cut watermelon. We provide evidence for defining the anaerobic compensation point and discuss implications for postprocess handling.

Materials and Methods

Fruit source. Seeded 'Royal Sweet' watermelon was used for the gas sampling and storage temperature components of the study and seedless cultivar 5244 was used to test the effects of initial O₂ concentrations. The fruit originated from Mexico and were procured from a local Ingles Supermarket in Clemson, S.C.

Processing protocol and storage temperatures. Intact watermelon fruit were dipped for 1 min in a 200 mg·L⁻¹ chlorine solution. The peel was removed with a sharp knife and pulp cubes (≈2.5 cm each dimension) were cut.

Shelf life determination. Cubes (250 g) were placed into a polypropylene (PP) cup-and-lid packages (340 g capacity, Fabri-Kal Corporation, Kalamazoo, Mich.), currently used commercially for fresh-cut watermelon. The packages were filled with air. To avoid contamination, the packages were previously irradiated with UV light (250 nm) for 3 min (420 mJ·cm⁻²) using a bulb-lamp (Germicidal lamp, American Ultraviolet Co., Beaufort, S.C.) placed 15 cm above the containers. The treatments consisted of experimental units of two packages of product with five replicates placed at six different storage temperatures: 1, 3, 7, 11, 15, and 30 °C. Each day, the stored product was evaluated for color fading, dark-

Received for publication 13 Nov. 2002. Accepted for publication 25 June 2003. South Carolina Agricultural Experiment Station Technical Contribution No. 4872. This work was partially supported by the South Carolina Agricultural Society, Charleston, SC, the Wade Stackhouse Foundation, Clemson, SC and CONICIT-MICIT, Costa Rica.

¹Current address: The University of Arizona-Yuma Agricultural Center, Yuma, AZ 85346.

²Corresponding author; email: jrushing@clemson.edu.

ening, off-odor, and overall visual quality by a group of 10 untrained panelists simulating typical retail customers. The quality of each watermelon cube was rated according to the following criteria: 10 = excellent; 7 = lowest point of salability; 5 = definite consumer rejection point; and 0 = extremely poor. The maximum shelf life of cubes in each container was defined as the period of time before the overall quality fell below level 7 according to its hedonic scale. Aerobic total count (ATC), using Petrifilm aerobic count plates (3M Co., St Paul, Minn.), was monitored on additional samples stored at temperatures 7 °C and below, to estimate any effect of microbial population on quality judging and respiration results. A sample of 25 g of the product was prepared according to the film manufacturer's recommendations. Dilutions from 10^1 to 10^7 per 1 g of sample were incubated at 30 °C for 72 h. Two cubes from each of three containers were sampled on the second, fifth and seventh day of the trial.

Respiration rate in a closed system. Watermelon cubes (200 g) processed as previously described were placed into 480-mL glass jars with tight-fitting lids equipped with a rubber sampling port. The jars had been cleaned with 500 mg·L⁻¹ chlorine and irradiated with UV light as described. For each treatment, three fruit were used, each to fill five jars (replicates). The jars were stored at five different temperatures: 3, 7, 11, 15, and 30 °C. A closed system method was used for the measurement of O₂ and CO₂ concentration (Yam and Lee, 1995; Zhu et al., 2001), with jars being sealed until the CO₂ level reached above 20%, as this was reported to be a safe level for fresh-cut watermelon (Cartaxo et al., 1997). At least twice per day, 1-mL samples were withdrawn from the headspace of each jar. Samples were analyzed for O₂ and CO₂ with a Tracor 540 capillary gas chromatograph fitted with a double column Altech CTR-1 and thermal conductivity detector. The first sample was taken within the first hour after cutting. Respiration rate, as CO₂ production (KCO₂) in mL·kg⁻¹·h⁻¹ at a given O₂ level and CO₂ level, was then calculated according to Kays (1991):

$$KCO_2 = (\% CO_2 \times 10) V / (W t) \quad [1]$$

where % CO₂ = change in carbon dioxide concentration (%), V = free space volume of container (L), W = product weight (kg), and t = time container was closed (h). The trial was repeated 14 d later.

Respiration with different initial levels of oxygen. An experiment was conducted to compare the effects of different initial levels of O₂ to further verify the interpretation of results of the preceding study. Watermelon cubes (100 g) processed as previously described were placed into 300-mL pouches with zero permeability to gases during short-term storage. Four pouches, each with cubes from a different fruit, were used per treatment. For the reduced O₂ treatments, the pouches were internally vacuumed and filled with the predetermined gas mix. The treatments consisted of 1) 14% O₂ (balance N₂), 2) 8% O₂ (balance N₂), and 3) air. In addition, control pouches containing the gas mix but without product were maintained

throughout the study to monitor leakage of the pouches. The pouches were then stored at 7 to 9 °C. Gases in the pouches were sampled at least daily and analyzed until headspace O₂ was below 1% in treatments.

Statistical analysis. Statistical analysis to assess the effect of temperature on shelf life was computed by nonlinear regression procedures using the SAS 6.2 General Linear Model (SAS Institute, Cary, N.C.). ANOVA at $P \leq 0.05$ was used for determining differences in microbial population. The gas concentration against time data were plotted with MS-Excel 2000 (Microsoft Co., Seattle, Wash.) and SAS 6.2 response surface regression analysis was used to determine the mathematical function that best characterized respiration as function of temperature and gas concentration.

Results and Discussion

Shelf life determination. The shelf life of fresh-cut watermelon decreased with increasing temperatures (Fig. 1). The cubes stored at 1 or 3 °C had significantly longer shelf life (≈ 10 d) than cubes stored at or above 7 °C (< 6 d). Moreover, the predicted data yielded by a nonlinear regression ($r^2 = 0.96$) revealed a maximum inflection between 4 and 6 °C, supporting the importance of storing this product below this range. Microbial population, which was monitored for temperatures 7 °C and below, increased from $\approx 3 \text{ Log}_{10} \text{ CFU/g}$ on the second day to near $6 \text{ Log}_{10} \text{ CFU/g}$ on the seventh day. The results comparing each temperature, however, were statistically non significant (data not shown). Within this temperature range, the microbial count did not appear to be affecting the judging of quality of the product. Quality parameters, including color fading and darkening, off-odor, and juice leakage also confirmed the benefits of storage at the lower temperatures (data not shown). In all cases, rejection of cubes was associated with unpleasant off-odor. Occurrence of random water-soaked cubes was observed in the 1 to 7 °C range. In other studies, this had been associated with the section of the fruit from which cubes were cut (Fonseca, 2000).

Although the rigid plastic containers used

in retail stores and in the previous experiments are not designed for MAP due to leakage, we observed in a separate study that the headspace oxygen in some filled containers did decrease to as low as 15.8% O₂ after 5 d of storage at 2.8 °C (Fonseca, 2000). Due to variability in container leakage rates the internal atmospheric modification was not consistent and these containers were not considered to be suitable for MAP studies.

Respiration rate in a closed system. The temporal pattern of CO₂ production of fresh-cut watermelon obtained using Eq. [1] was similar to those of other fresh-cut products such as broccoli florets (Rushing, 1990) and cut iceberg lettuce (Smyth et al., 1998). The rate was initially higher immediately after cutting, ranging between 25 to 50 mL CO₂ per kg⁻¹·h⁻¹, an apparent result of wound metabolism, then dropping to a plateau of about one-eighth the initial level in < 10 h when stored at temperatures below 15 °C (Fig. 2). The rate at this stable stage was higher at higher temperatures. An increase in CO₂ evolution was observed at all temperatures after a period of time, but the delay in the increased CO₂ was longer and the increased level was lower at lower temperatures.

Considerable variability was noted in respiration rate during the first 6 h after processing (Fig. 2). This likely was due to the stress caused by cutting the product (Smyth et al., 1998). The resulting respiration data had a quadratic shape. Thus, we fitted the respiration data initiating with the 6-h sample into the following quadratic model:

$$KCO_2 = b + m_1 (O_2) + m_2 (T) + m_3 (O_2)^2 + m_4 (T)^2 \quad [2]$$

where T = temperature (°C).

The data adequately fit the proposed quadratic model ($r^2 = 0.94$). The constant b and the parameters m_1 , m_2 , m_3 and m_4 in the Eq. [2] were $KCO_2 = 7.507 - 0.871 (O_2) - 0.056 (T) + 0.026 (O_2)^2 + 0.028 (T)^2$.

Excluding data from the first 5 h, the model allowed the prediction of CO₂ production as a function of O₂ and temperature, indicating a distinct increase in respiration rate at a relatively high O₂ concentration. The model predicted the minimal KCO₂ at exactly 16.7% O₂ for all temperatures evaluated. The measured increase

Fig. 1. Shelf life of fresh-cut watermelon as influenced by storage temperatures. Predicted data was estimated

in respiration rate, however, was not substantial until $\approx 14\%$ (Fig 3.). A similar ACP, which has been suggested as a minimum for the storage of orange slices at 0 to 5 °C, was accompanied by an increase in the evolution of ethanol and acetaldehyde (Gorny, 1997).

Respiration rate with different initial levels of Oxygen. The trial we conducted with different initial O_2 levels in barrier pouches at 7 to 9 °C revealed an increased CO_2 production and O_2 consumption for the treatments having

Fig. 2. Respiration rate of fresh-cut watermelon stored at five different air temperatures in a closed system: (A) 3, (B) 7, (C) 11, (D) 15, and (E) 30 °C. Vertical bars indicate $\pm$ SE. When bars are absent the SE is smaller than the symbol.

either 14% or 8% O_2 (Fig 4). Although the air treatment had a higher respiration rate for the first sampling (2 h), this dropped to a stable level as was observed in previous experiments, maintaining a level of 1/3 to 1/5 the rate of the O_2 modified treatments.

The CO_2 accumulation in the pouches with air averaged $<2\%$ after 12 h, while pouches flushed with 8% or 14% O_2 accumulated $\approx 4\%$ CO_2 . This difference was maintained or increased for 74 h, the point at which the O_2 was depleted to $<1\%$ for the reduced O_2 treatments (Fig. 5). These results suggested a consistent tendency of the watermelon cubes to accelerate CO_2 production at a relatively high O_2 level, e.g., 14%, verifying the hypothesis that ACP is above 14% O_2 suggested by the data from the prediction model. Several alcohols and aldehydes have been found as major volatile flavor and odor components in watermelons recently harvested (Kemp, 1975; Yahima et al., 1985). The concentration of these volatiles may change at a critical O_2 level (Beaudry, 1999), which could partially explain the off-odor at the end of the shelf life of the product in the storage temperature trial.

When using data from the product in barrier pouches, the model approximated the respiration of the air treatment, but underestimated the 8% and 14% initial O_2 level treatments when the O_2 level was still above 1% (data not shown). This was expected as the model was based on data yielded from a closed system that had air at the starting point, and because increased CO_2 may suppress respiration (Watkins, 2000). A study of increased CO_2 with a nonmodified level of O_2 may reveal whether such a treatment further extends shelf life of fresh-cut watermelon. Cartaxo et al. (1997) previously found positive results with high levels of CO_2 , which support this hypothesis.

The most important point with developing closed system models, as presented here, is to

provide a pattern of respiration of a fresh-cut product at different temperatures and changing O_2 or CO_2 (if calculating respiration in terms of O_2 consumption), and estimate the ACP level as described by Boersig et al. (1988). Accuracy should still be a concern, since our empirical model indicates a fixed lower O_2 limit for the 0 to 30 °C range. Beaudry et al. (1992) revealed that the RQB of blueberries increased with increasing temperature. The lower O_2 limit also has been reported to increase with increasing temperature in whole apples (Gran and Beaudry, 1993), and raspberries (Joles et al., 1994). Despite this, Yearsley et al. (1997) reported ACP based on internal lower O_2 limit and concluded that the effect of temperature on the ACP of whole apples stored between 0 and 28 °C was not significant. Little has been reported on the effect of temperature on the lower O_2 limit of fresh-cut products but it appears that the effect is not as marked as with whole products, perhaps due to higher O_2 diffusion in fresh cuts. Lakalul et al. (1999) observed an increase of the FT with increasing temperature in apple slices but the increase was only 0.2 kPa in the range of 0 to 15 °C. Our regression estimated 94% of the respiration data and predicted a single ACP that was verified at 7 to 9 °C. Experiments evaluating ACP at higher temperatures are needed to represent other temperatures also encountered during the retailing and consumer's handling.

Another consideration is that analyses were based on watermelon from a distant production region (Mexico). Transportation stress might have played a role in the observed ACP, as it has been reported that ACP shifts toward higher concentrations with the physiological aging of intact fruits (Boersig et al., 1988).

Since the model depends on changing gases, as in any closed or static system, a subsequent step must involve the use of permanent controlled atmospheres (Yang and Chinnan, 1988).

Fig. 3. Predicted plot surface of CO_2 production of fresh cut watermelon as a function of O_2 (%) and temperature (°C) based on data collected starting 6 h after storage.

Fig. 4. Respiration rate of watermelon cubes stored in barrier pouches at 7 to 9 °C with initial O₂ levels of 20.9%, 14.0%, or 8.0%. Vertical bars indicate $\pm$ SE. When bars are absent the SE is smaller than the symbol.

Fig. 5. Carbon dioxide and O₂ levels in barrier pouches filled with watermelon cubes with different initial O₂ levels. Closed symbols (●, ▲, ■) indicate O₂ content in the headspace, while open symbols (○, △, □) indicate CO₂ content. Initial O₂ levels in the packages were 20.9% (●, ○), 14% (■, □), and 8% (▲, △). Vertical bars indicate $\pm$ SE. When bars are absent the SE is smaller than the symbol.

The addition of CO₂-salt forming bases such as KOH (Cameron et al., 1989) or the testing of different starting gas levels may also give additional insight. In this study, whether with an initial nonmodified atmosphere or with increased CO₂ concentration in the headspace, the product respired more when exposed to an O₂ level of 14% or lower than for air, suggesting limited applicability of MAP systems for extending the shelf life of this product. Our results should be useful for the design of

postprocessing handling protocols for fresh-cut watermelon, particularly in selecting storage temperatures and packaging materials.

Literature Cited

- Beaudry, R.M. 1999. Effect of O₂ and CO₂ partial pressure on selected phenomena affecting fruit and vegetable quality. *Postharvest Biol. Technol.* 15:293–303.
- Beaudry, R.M., A.C. Cameron, A. Shirazi, and D.L. Dostal-Lange. 1992. Modified atmosphere pack-

- aging of blueberry fruit: Effect of temperature on package O₂ and CO₂. *J. Amer. Soc. Hort. Sci.* 117:436–441.
- Boersig, M.R., A.A. Kader, and R.J. Romani. 1988. Aerobic-anaerobic respiratory transition in pear fruit and cultured pear fruit cells. *J. Amer. Soc. Hort. Sci.* 113:869–873.
- Cameron, A.C., W. Boylan-Pett, and J. Lee. 1989. Design of modified atmosphere packaging system: Modeling oxygen concentrations within sealed packages of tomato fruits. *J. Food Sci.* 54:1413–1421.
- Cameron, A.C., R.M. Beaudry, N.H. Banks, and M. V. Yelanich. 1994. Modified-atmosphere packaging of blueberry fruit: Modeling respiration and package oxygen partial pressures as a function of temperature. *J. Amer. Soc. Hort. Sci.* 119:534–539.
- Cartaxo, C.B., S.A. Sargent and D.J. Huber. 1997. Controlled atmosphere storage suppresses microbial growth on fresh-cut watermelon. *Proc. Fla. State Hort. Soc.* 110:252–257.
- Chang, L.A. and S.J. Kays. 1981. Effect of low oxygen on sweet potato roots during storage. *J. Amer. Soc. Hort. Sci.* 106:481–483.
- Elkashif, M., D.J. Huber, and J.K. Brecht. 1989. Respiration and ethylene production in harvested watermelon fruit: Evidence for nonclimacteric respiratory behaviour. *J. Amer. Soc. Hort. Sci.* 114:81–85.
- Fonseca, J.M. 2000. Influence of processing and handling protocols on the physiology and shelf life of fresh-cut watermelon. MS thesis. Clemson Univ., Clemson, S.C.
- Fonseca, J.M., J.W. Rushing, and R.F. Testin. 1999. Shock and vibration influence the shelf life of fresh-cut watermelon. *Proc. Fla. State Hort. Soc.* 112:147–152.
- Gorny, J.R. 1997. A summary of CA and MA recommendations for selected fresh-cut fruits and vegetables, p. 30–66. In: *Proc. 7th Intl. Controlled Atm. Res. Conf. vol. 5: Fresh-cut fruits and vegetables and MAP*. Davis, Calif. 13–18 July 1997.
- Gran, C.D., and R.M. Beaudry. 1993. Determination of the low oxygen limit for several commercial apple cultivars by respiratory quotient breakpoint. *Postharvest Biol. Technol.* 3:259–267.
- Hayakawa, K.I., Y.S. Henig, and S.G. Gilbert. 1975. Formulae for predicting gas exchange of fresh produce packaged in polymeric films. *J. Food Sci.* 40:1033–1035.
- Joles, D.W., A.C. Cameron, A. Shirazi, P.D. Petracek, and R.M. Beaudry. 1994. Modified-atmosphere packaging of 'Heritage' red raspberry fruit: Respiratory response to reduced oxygen, enhanced carbon dioxide, and temperature. *J. Amer. Soc. Hort. Sci.* 119:540–545.
- Kader, A.A., D. Zagory, and E. Kerbel. 1989. Modified atmosphere packaging of fruits and vegetables. *CRC. Crit. Rev. Food. Sci. Nutr.* 28:1–30.
- Kays, S.J. 1991. *Postharvest physiology of perishable plant products*. 1st ed. Van Nostrand Reinhold. New York.
- Kemp, T.R. 1975. Identification of some volatile compounds from *Citrullus vulgaris*. *Phytochemistry* 14:2637–2638.
- Knee, M. 1980. Physiological responses of apple fruits to oxygen concentrations. *Ann. Appl. Biol.* 96:243–253.
- King, A.D. and H.R. Bolin. 1989. Physiological and microbiological storage stability of minimally processed fruits and vegetable. *Food Technol.* 43(2):132–135, 139.
- Lakulul, R., R.M. Beaudry, and R.J. Hernandez. 1999. Modeling respiration of apple slices in modified-atmosphere packages. *J. Food Sci.* 64:105–110.

- Lee, D.S., P.E. Hagggar, J. Lee, and K.L. Yam. 1991. Model for fresh produce respiration in modified atmospheres based on principles of enzyme kinetics. *J. Food Sci.* 56:1580–1585.
- National Watermelon Promotion Board. 1998. Watermelon's year-round availability boosting sales. *Watermelon Market Rpt.* 7(3):1–2.
- Peppelenbos, H.W. and R. Rabbinge. 1996. Respiratory characteristics and calculated ATP production of apple fruit in relation to tolerance of low O₂ concentrations. *J. Hort. Sci.* 71:985–993.
- Peppelenbos, H.W., L.M. Tijskens, J. Leven, and E.C. Wilkinson. 1996. Modelling oxidative and fermentative carbon dioxide production of fruits and vegetables. *Postharvest Biol. Technol.* 9:283–295.
- Perkins-Veazie, P., J.K. Collins, and E. Baldwin. 1998. Shelf life of minimally processed watermelon. *HortScience* 33:605 (abstr.).
- Platenius, H. 1942. Effect of temperature on the respiration rate and the respiration quotient of some vegetables. *Plant Physiol.* 17:179–197.
- Risse, L.A. and D.N. Maynard. 1990. Evaluation of selected seedless watermelon cultivars during storage. *Proc. Fla. State. Hort. Soc.* 103:288–291.
- Rushing, J.W. 1990. Cytokinins affect respiration, ethylene production, and chlorophyll retention of packaged broccoli florets. *HortScience* 25:88–90.
- Smyth, A.B., J. Song, and A.C. Cameron. 1998. Modified atmosphere packaged cut iceberg lettuce: Effect of temperature and O₂ partial pressure on respiration and quality. *J. Agr. Food. Chem.* 46:4556–4562.
- Talasila P.C., K.V. Chau, and J.K. Brecht. 1992. Effects of gas concentrations and temperature on O₂ consumption of strawberries. *Trans. Amer. Soc. Agr. Eng.* 35:221–224.
- Watada, A.E., N.P. Ko, and D.A. Minott. 1996. Factors affecting quality of fresh-cut horticultural products. *Postharvest Biol. Technol.* 9:115–125.
- Watada, A.E. 1999. Quality of fresh cut produce. *Postharvest Biol. Technol.* 15:201–205.
- Watkins, C.B. 2000. Responses of horticultural commodities to high carbon dioxide as related to modified atmosphere packaging. *HortTechnology* 10:501–506.
- Yahima, I., H. Sakakibara, J. Ide, T. Yanai, and K. Hayashi. 1985. Volatile flavor components of watermelon (*Citrullus vulgaris*). *Agr. Biol. Chem.* 49:3145–3150.
- Yam, K.L. and D.S. Lee. 1995. Design of modified atmosphere packaging for fresh produce, p. 55–73. In: M.L. Rooney (ed.). *Active food packaging*. Blackie Academic and Professional, Imprint of Chapman and Hall, N.Z.
- Yang, C.C. and M.S. Chinnan. 1988. Modeling the effect of O₂ and CO₂ on respiration and quality of stored tomatoes. *Trans Amer. Soc. Agr. Eng.* 31:920–925.
- Yearsley, C. W., N.H. Banks, S. Ganesh, and D.J. Cleland. 1996. Determination of lower oxygen limits for apple fruit. *Postharvest Biol. Technol.* 8:95–109.
- Yearsley, C.W., N.H. Banks, and S. Ganesh. 1997. Temperature effects of the internal lower oxygen limits of apple fruit. *Postharvest Biol. Technol.* 11:73–83.
- Zhu, M., C.L. Chu, S.L. Wang, and R.W. Lencki. 2001. Influence of oxygen, carbon dioxide, and degree of cutting on the respiration rate of rutabaga. *J. Food Chem.* 66:30–37.