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The Potential Use of a Microsensor to Measure Endogenous Oxygen Content in Fresh Fruit

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A pc-controlled, fiber-optic oxygen meter was tested to determine the potential of measuring endogenous oxygen levels in fresh fruits. Cucumber (*Cucumis sativus* L.) and tomato (*Solanum lycopersicum* L.) fruit were selected for this study. Endogenous oxygen level of cucumber fruit was measured using several methods; however, obtaining results without damaging the sensor was difficult due to the firm structure of the mesocarp tissue. Method 1 involved creating a small hole (perpendicular to the fruit surface), for sensor placement, by inserting a 23-gauge needle (0.6-mm diameter and 25-mm length) to a depth of 25 mm. Method 2 was developed to avoid damaging sensors, which involved creating a larger cavity for sensor placement by removing a 5-mm diameter, 34-mm length directly under the epidermis, starting at the blossom end. Oxygen content of cucumber fruit was approximately 19% when measured at 6-mm or 12-mm depth (using Method 1). Cucumber fruit treated with a commercial vegetable coating had lower oxygen content (11%) compared to untreated (18%) using Method 2. Endogenous oxygen level of tomato was also determined in locule and blossom-end tissues (10-mm depth). Fruit at pink and light red ripeness stages were measured initially and after 3 d at 24 °C. The oxygen level was lower in the locule (5%) than in the blossom end or columella tissue (15%). There was no difference in oxygen level for either ripeness stage. Real-time measurement of endogenous oxygen is feasible using this microsensor, although its fragile construction requires precise positioning and use of soft-textured fruits and vegetables.

Exocarp tissue is the primary barrier of gas exchange between fruit and the environment. Coatings are applied to some commodities to minimize gas exchange and water loss. However, postharvest treatments such as waxing not only reduce permeability, but also alter gas exchange mechanisms (Kaplan, 1986) and consequently affect fruit quality (Bower et al., 2000; Petracek, 1995). Accurate measurement of the internal concentration of gases is often difficult. Internal gases can be sampled by a number of destructive and nondestructive methods for analysis by gas chromatography (Salviet, 1982). A needle attached to a syringe can be used to penetrate fruit and take endogenous samples within the tissue or in fruit with internal cavities, like melon and apples (Lyons, 1962; Sfakiotakis and Dilley, 1973). Vacuum extraction in air or under an aqueous salt solution can provide a composite sample of the gases within the commodity by allowing gases to flow out of the fruit through regions of low resistance (lenticels, stomata, pores) and accumulate at the top of the submerged container (Culpepper, 1947). These methods have limitations because the measurements are time-consuming, not real-time or continuous, and can be affected by the exogenous environment.

In recent years, there has been rapid development of optical sensors to measure specific compounds. Oxygen microsensors are extensively used in the medical and biotechnology fields (Peterson et al., 1984). Recently, Rolletschek et al. (2003) used oxygen microsensors to measure the spatial distribution of O_2 within pea (*Pisum sativum*) seeds and also to determine the extent of oxygen depletion in different regions of developing maize kernels (Rolletschek et al., 2005). Research involving the use of microsensors to determine oxygen levels in whole fruit is currently unavailable.

The objective of this study was to investigate the potential use of a microsensor to measure real-time endogenous oxygen concentration in coated and uncoated cucumber fruit. Cucumber fruit was initially selected for oxygen content evaluation since it is commonly coated with vegetable wax, and the sensor would enable a comparison of coated and uncoated fruit.

Materials and Methods

The endogenous oxygen concentration of cucumber (*Cucumis sativus* L.) fruit was measured using oxygen-sensitive optical microsensors (OxyMicro, Sarasota, FL) in a procedure modified by Rolletschek et al. (2002). The 40-μm sensor tip used was housed in a 27-gauge needle (0.4-mm diameter and 22-mm length). The instrument recorded O_2 concentration as percentage of atmospheric saturation (21 kPA = 100% O_2). The microsensor was calibrated with saturated ambient air (100% O_2) and deaerated water (0% O_2). Saturated air was obtained by placing a cotton ball soaked in deionized (DI) water inside a sealed, 20-mL glass vial with a small opening for insertion of the microsensor. To obtain deaerated water 1 g $NaSO_3$ was dissolved in 100 mL DI water, then placed in a sealed 20-mL vial as previously described.

Cucumber 'Manar' fruit were obtained from a commercial greenhouse in northern Florida, then transported to the Postharvest Horticulture Laboratory in Gainesville and held at room temperature (24 °C) for immediate testing.

Method 1. A small opening was made in each fruit (perpendicular to the fruit surface) by inserting a 23-gauge needle (0.6-mm diameter and 25-mm length) to a depth of 25 mm (Fig. 1A).

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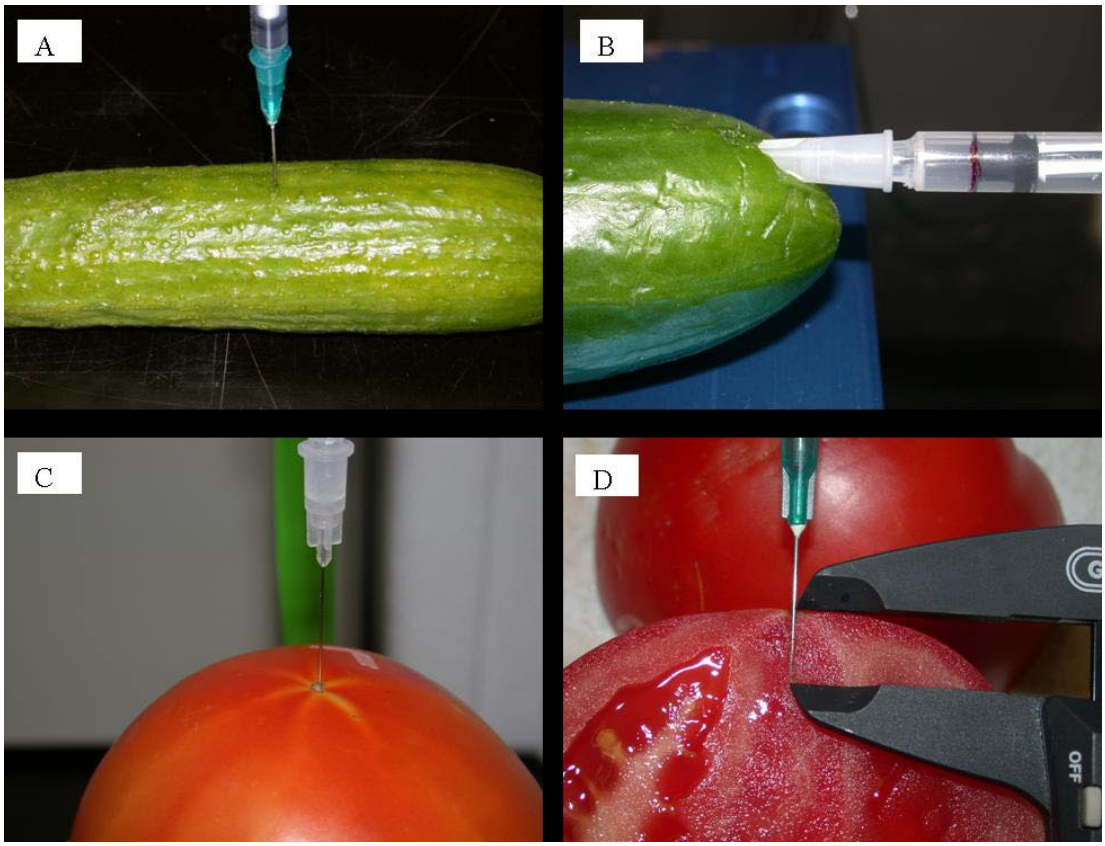

Fig. 1. Method 1 (**A**) and Method 2 (**B**) for cucumber. Method for tomato blossom end (**C**), and tomato dissection (**D**) for verification of sensor path.

The sensor housing was immediately inserted into the prepared opening of each fruit; then the fiber-optic sensor was extended into the surrounding tissue and readings were taken for several minutes at 6- and 12-mm depths (n=3). Since the signal was stable after several seconds and remained so during the testing period we assumed there was no exogenous air infiltration. After each fruit sample the sensor was withdrawn, placed in DI water, and soaked for several minutes to clean any fruit residue. Despite having soaked several times in DI water, the needle housing may have become clogged with fruit residue from the previous sample, causing the sensor to break on the fourth fruit.

Method 2. A cork borer (5-mm diameter) was used to create a 34-mm horizontal opening directly under the epidermis of each fruit, starting at the blossom end. For O_2 measurement the sensor was carefully placed into the opening of each fruit and the sensor housing (syringe) was positioned to seal external air exchange (Fig. 1B). Cucumber 'Manar' fruit (n=2) were either left untreated or treated with Stayfresh 819F vegetable coating (FMC Foodtech, Lakeland, FL). Treated fruit were dipped in the coating for several seconds, then air dried for 2 h. Readings were taken for several minutes per fruit. This test resulted in positive results; however, there were still issues with the sensor breaking during sampling.

Tomato fruit was selected for subsequent testing since the tissue is less dense and does not contain latex as cucumber does. Tomato 'FL 47' fruit were obtained from a commercial field in Palmetto, FL, then transported to the Postharvest Horticulture Laboratory in Gainesville and placed at room temperature (24 °C) for immediate testing. Fruit were selected at pink (n=3) and light red (n=3) stages. Each fruit was carefully fixed into position and the sensor was placed directly into the fruit tissue to a depth of 10 mm at the blossom end and locule positions (Fig. 1C). Oxygen measurements were initially taken from each fruit and position for several minutes and again after 3 d at room temperature (24 °C). After the final measurement, the fruits were dissected at the measured transect to identify the exact position of the sensor path (Fig. 1D).

The data obtained from the sensor were transformed to percent oxygen by the following equation: $\%O_2$ = percentage of atmospheric saturation × 0.21

Results and Discussion

Using Method 1 the sensor constantly logged oxygen concentration in uncoated cucumber during a 40-min period in which the sensor was inserted and removed a number of times (Fig. 2). Among the fruit tested (n=3), two cucumber fruit displayed similar levels of endogenous oxygen (18%). There was no difference in cucumber oxygen content due to depth (6 or 12 mm).

Using Method 2 the unwaxed cucumber fruit also had 18% endogenous oxygen, similar to the fruit tested using Method 1. However, the oxygen content in waxed fruit was significantly lower at 11% (Fig. 3). Despite the fragile nature of the sensor, the results obtained for cucumber were consistent using either method described.

The endogenous oxygen content in tomato fruit ranged from 4% to 7% in the locule cavity and was 15% in the blossom end (columella) tissue (Fig. 4). There was no difference in oxygen

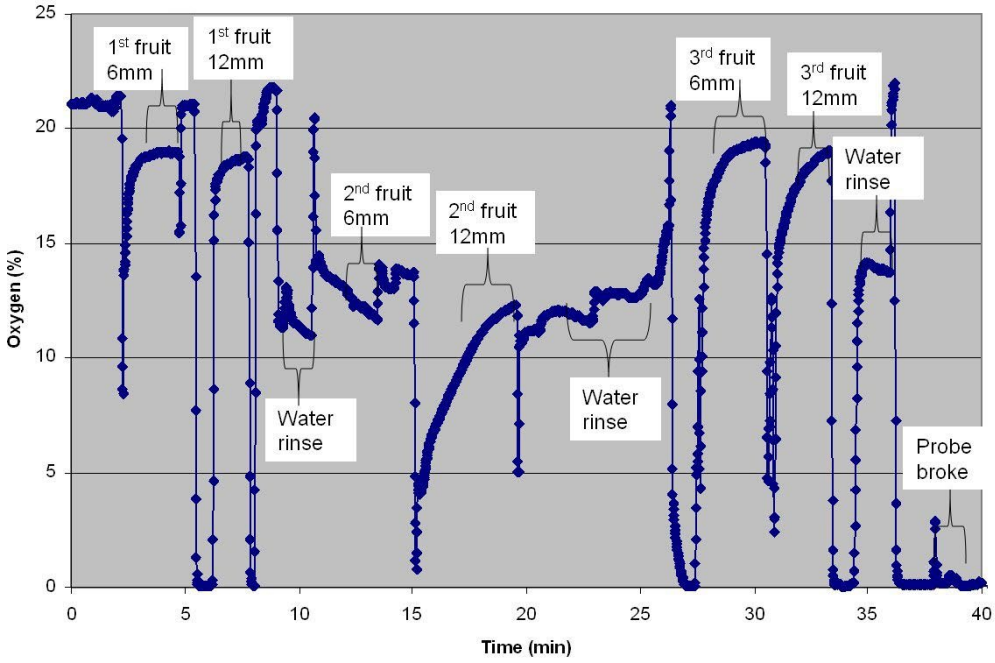

Fig. 2. Oxygen readings during a 40-min period for cucumber fruit (6- and 12-mm depths).

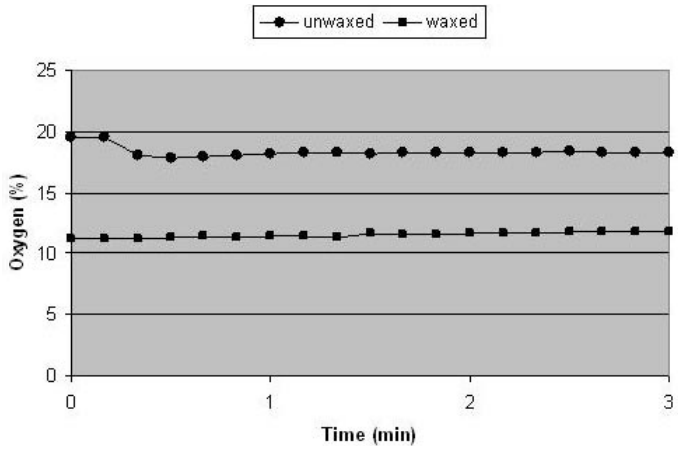

Fig. 3. Oxygen content of cucumber fruit with and without wax coating. Data represent the mean (n=2).

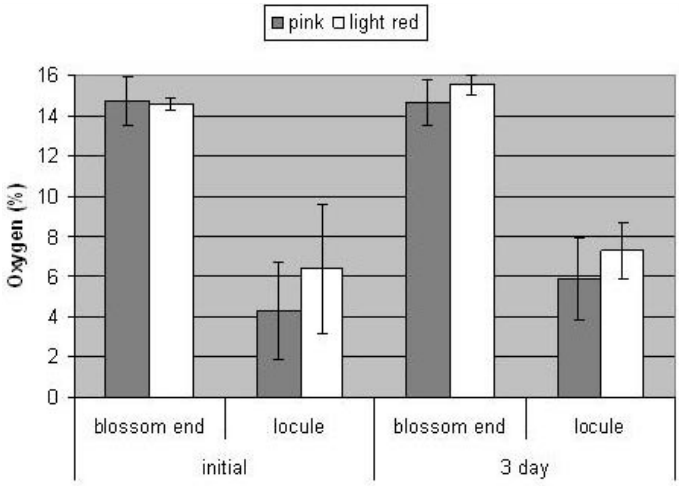

Fig. 4. Oxygen content of tomato fruit initially at pink or light red maturity stage. Data represent the mean (n=3).

concentration between the two tomato maturity stages evaluated. Burton (1982) reported tomato internal oxygen content as 18.8%; however, this value was calculated from experimentally determined CO_2 (Burg and Burg, 1965) based on diffusion coefficients for O_2 (0.178 $cm^3 \cdot cm^{-2} \cdot s^{-1}$) and CO_2 (0.138 $cm^3 \cdot cm^{-2} \cdot s^{-1}$). Yang and Shewfelt (1999) measured O_2 level of tomato fruit via vacuum extraction, which averaged 19% to 20% throughout ripening.

The results of this investigation suggest there is potential use for oxygen microsensors in postharvest research of horticultural crops, particularly those that have soft tissue. Nevertheless, additional research is needed to establish the feasibility of using these sensors to evaluate endogenous oxygen content of diverse commodities in response to various treatment conditions. Several problems need to be addressed, such as sensor cleaning between readings, replacement sensor cost, restricted sampling size, and limitations of commodity or tissue type evaluated. Although extreme care was taken to avoid damaging the fragile (and expensive) sensor, under some circumstances breakage was ultimately unavoidable. There were fewer problems with damaging the sensor during tomato evaluation as compared to cucumber. According to Bower et al. (2000), determining the internal O_2 level by attaching a KE25 sensor (Japan Storage Battery Co. Ltd., Osaka, Japan) to the outside of a capsicum fruit was not effective, and concluded that destructive techniques are still necessary to sample internal atmosphere in capsicum. Therefore, there is a real need for technologies that can accurately and efficiently detect endogenous oxygen in whole fruit.

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