XIUHUA CHEN AND LUCIE A. GRANT
EcoScience Produce Systems Corp.
4300-C L. B. McLeod Road
Orlando, FL 32811

Abstract. To extend storage life of lemons (Citrus limon Burm. f.), Nature Seal® 2020 full strength, half strength, a storage wax, and water were applied to lemon fruits. External fruit background color was measured after two and three weeks of storage at 13°C by using a Minolta Chromameter. The results show Nature Seal® 2020 full strength significantly delayed ripening of lemons as indicated by “a,” “b” and “L” value. Storage wax was not effective, as compared to water control. Nature Seal® 2020 half strength was more effective than storage wax and less effective than Nature Seal® 2020 full strength.

Lemons are harvested year-round, but most fruit reach harvestable size and are picked during the winter when consumption is relatively light. Fruits are washed; sanitized in water with either sodium ortho-phenylphenate (SOPP), chlorine or soda ash; and coated with storage waxes. Fruits packed in cartons may be stored for several months before marketing. Decay, over ripening and water loss are major problems which limit the postharvest life of the fruits. Fruits gradually decrease and eventually lose their resistance to pathogens due to ripening and senescence. Methods which delay ripening may also delay decay. Fungicides, thiabendazole (TBZ) or imazalil, are used for decay control. Storage waxes are used mainly as a carrier for the fungicide. They replace natural wax but have little effect on ripening control.

Low oxygen concentration of 5% to 8% can reduce decay and delay color change of lemons (Biale, et al., 1947, Rygg and Wells, 1962). If oxygen falls to below 3% or if CO₂ rises above 10% for a prolonged period, adverse effects may occur. However, Controlled Atmosphere (CA) is not commercially used for lemon storage. Plastic film package was effective on ripening control, but it may promote decay because of high levels of humidity and CO₂ within the sealed package.

A cellulose-based edible coating, Nature Seal®, was developed by USDA in Winter Haven, Florida, improved and produced by EcoScience Produce Systems Corp. It forms a thin film on fruit surfaces which acts as a barrier to gas and water diffusion. Nature Seal® delayed ripening of both climacteric and non-climacteric fruits (Nisperos Carriedo et al., 1991). Nature Seal® 2020 delayed color change and softening of guava (McGuire and Hallman, 1995), papayas (Baldwin et al., 1992), mangoes, bananas and avocados. Storage life of the commodities was extended for about one week. It was more effective on delaying color change of lime fruits than a mineral oil coating. Nature Seal® 4000, used as a pack-out coating, delayed degreening and softening of pears and apples for one week at room temperature. It also delayed scuffing and reduced the decay rate of pears. This experiment was designed to explore the possibility of replacing lemon storage wax with Nature Seal® 2020 to achieve better ripening control during storage.

Materials and Methods

Two cartons of lemon fruits were collected from a standard packing house after washing in California and were shipped to Orlando by overnight express in March. One carton contained light green fruits and the other contained green fruits. Thirty fruits of each maturity were randomly assigned to each coating treatment.

Coating treatments included water control, Nature Seal® 2020 full strength (NSF), Nature Seal® 2020 half strength (1:1 dilution with deionized water, NSH) and storage wax (Commercially used product; label rate for 120 day storage is 2% solution). Each coating also contained 0.2% Imazalil and 250 ppm 2,4-D.

Coatings were applied to fruits by brushing and allowed to dry at room temperature. Each treatment (30 fruits) were packed in a brown paper bag and four bags of same maturity were kept in the same carton. Fruits were stored for three weeks at 13°C and about 90% RH.

Fruit external background color was measured by using a Minolta Chromameter 300. One reading was collected per fruit and all of fruits in a treatment were measured. Data was analyzed as 2 x 4 factorial and means were separated by using Duncan’s Multiple Range Test (DMRT, P < 0.01).

Results

During ripening, lemon fruits lose chlorophyll. Skin color changes from green to yellow. Minolta Chromameter (Ramsay N. J.) “L” measures lightness, “a” represents greenness to red and “b” indicates yellow to blue. “L,” “a” and “b” values increase with ripening of lemon.
In this experiment, the difference between light green fruits and green fruits was always significant. To show the effect of the coatings, the results of the two maturity stages for lemons (light green and green) are presented separately.

**Light Green Fruits**

After one week storage, light green fruits started degreening. The difference among treatments became more significant after two weeks of storage. Fruits coated with Nature Seal® full or half strength were greener than water or wax coated samples, as indicated by the lower “L” and “a” values (Fig. 1, Fig. 2). The difference in “b” values was not significant (Fig. 3). The “L,” “a” and “b” values of storage wax coated fruits were not significantly different from that of water control. On week three, Nature Seal® full strength coated fruits were greener than other treatments. Nature Seal® half strength was not as effective.

**Green Fruits**

Nature Seal® full strength was the most effective on suppressing color change, followed by Nature Seal® half strength. The difference in degreening appeared after three weeks of storage.
storage. Both Nature Seal® treatments resulted in significantly lower "a" values. Compare to the other treatments storage wax only resulted in a lower "a" value than water control (Fig. 4).

The difference in yellowing became significant after two weeks of storage. Nature Seal® full strength resulted in the lowest "b" and "L" values, followed by Nature Seal® half strength. Storage wax and water control resulted in highest "b" and "L" values. No major difference existed between the later two treatments (Figs. 5 and 6).

Discussion

During ripening, lemon color changes from green to yellow because of chlorophyll degradation. Ethylene induced a four-fold increase in the specific activity of Citrus chlorophyllase (Amir-Shapira, et al. 1986). Yellowing occurs because pre-existing carotenoids are unmasked by the destruction of chlorophyll. Therefore, external color is an indicator of maturity. However, at harvest, part of the skin on a fruit may be light yellow because of shadings during fruit development on trees. To avoid confusing shading - induced yellowing with ripening-related yellowing, only green area of fruit was measured in this experiment. Therefore color data collected from this experiment represents only ripening-related yellowing.

Though lemons are nonclimacteric fruits, low oxygen delays its ripening. Some plastic film packages and waxes generate modified atmosphere (MA) effects while inducing anaerobic respiration. Nature Seal® coatings are water soluble and form a thin film on fruit's surfaces. The film acts as a barrier to gas and water diffusion, a MA effect similar to that generated by sealed film package (Banks, et al., 1993). The film formed by Nature Seal® is safe for fruits because it selectively resists gas diffusion. The cellulose derivative used in Nature Seal® has higher resistance to oxygen diffusion than to CO₂.

In addition, because of its hygroscopic nature, the coating may hold a thin film of water. Carbon dioxide dissolves and diffuses through water about twenty times faster than oxygen. Because of these two properties of the film, carbon dioxide...
can escape from fruits much easier than oxygen can diffuse into fruits. Therefore, although CO₂ levels may build up, they do not reach harmful levels. Meanwhile, the O₂ concentration within the fruits is sufficient to lower metabolic rate and to delay ripening. In this way Nature Seal® generates a safe MA environment within fruits. In this experiment, Nature Seal® was much more effective in delaying ripening (degreening and yellowing) of lemon fruits than storage wax. Replacement of storage wax with Nature Seal® will extend storage life of lemon fruits.

In summary, Nature Seal® 2020 delayed ripening of lemons as evidenced by the delay in color change. It was more effective on less mature fruits (green fruits) than on more mature fruits (light green fruits). Nature Seal® full strength was more effective than Nature Seal® half strength. Storage wax did not significantly delay ripening of lemons as compared to the water control.

**Literature Cited**


**A TECHNIQUE FOR MEASURING GAS EXCHANGE THROUGH THE PEEL OF INTACT CITRUS FRUIT**

**Peter D. Petracek**  
Florida Department of Citrus  
Citrus Research and Education Center  
Lake Alfred, FL 33850

**Abstract.** A method for measuring gas exchange of localized regions of citrus peel was developed. Glass cells with interfacing silicone o-rings (23 mm inner diam) were strapped to the fruit by a strap and ratchet. Leaks were checked by positive pressure. Strapping produced minimal wound ethylene. Ethylene exchange was measured by attaching single port collection cells to stylar and stem ends and mid-section of the fruit after exposure to ethylene. Water, carbon dioxide (CO₂), and oxygen (O₂) exchange of selected regions of the fruit were measured by a double port flow-through cell. Water exchange was about four to six times greater at the stem end than other regions. Regions damaged by rust mite, wind scar, and pitting due to physical damage had similar gas exchange properties as undamaged regions on the same fruit. Waxing of the fruit increased the proportional contribution of the stem end to gas exchange.

**Introduction and Literature Review**

The peel of citrus is the primary barrier to the exchange of gas between fruit and environment. Packinghouse treatments such as washing and waxing alter the gas exchange characteristics of the peel (Kaplan, 1986) which may consequently affect internal gas levels and fruit quality. Examples of the relationship among packinghouse treatment, gas exchange, and fruit quality include the stimulation of anaerobic respiration (Hagenmaier and Baker, 1994) and the suppression of stem end rind breakdown and chilling injury (Grierson, 1986) by wax application.

Internal gas levels (Hagenmeier and Baker, 1994; Parker et al. 1984; Vines and Oberbacher, 1961) and weight loss (Millier and Brown, 1973; Hagenmeier and Baker, 1994) have been used previously to assess the effects of packinghouse stress on citrus. Static and dynamic measurements of gas exchange (Saltveit and Yang, 1987), which provide a method for determining whole fruit gas exchange rates, also permit the evaluation of stress on fruit physiology. However, these techniques do not determine the distribution of gas exchange over the surface of the fruit. Determining the location of gas exchange may be particularly useful in studying citrus peel disorders that are potentially caused by localized stress. Stem end rind breakdown, for instance, may be stimulated by excessive loss of water from regions around the stem end (Albrigo, 1972). The following technique was developed to determine the location of gas exchange rates of citrus fruit before and after postharvest treatment.

**Materials and Methods**

**Plant material.** 'Hamlin' oranges (Citrus sinensis [L] Osb.) and 'Marsh' white grapefruit (Citrus paradisi Macf.) were harvested from groves at the Citrus Research and Education Center (CREC), Lake Alfred, Florida. For studies on the effects of peel damage on gas exchange, oranges with representative instances of rust mite, wind scar, and pitting due to physical damage were selected. For studies on the effects of packinghouse treatments on gas exchange, grapefruit with no visible peel defects were selected.

**Gas exchange.** A double-ported glass flow-through cell (23 mm inner diam.) was used to capture water, O₂, and CO₂ exchanged through the fruit peel (Fig. 1). During the evaluation of various sized sampling cells, a larger cell (40 mm inner diam.) often sealed improperly and did not fit on small fruit whereas a smaller cell (10 mm inner diam.) had an insufficient area of analysis for measuring gas exchange of waxed fruit. An o-ring, which was cut from a 3 mm thick sheet of silicone (GE Silicone II, General Electric, Waterford, NY), was placed between the cell and the mid-section of the fruit to provide a seal. The cell was held against the fruit surface with