

Bagging 'Fuji' Apples during Fruit Development Affects Color Development and Storage Quality

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Additional index words. gas diffusion, scald, stain, ethylene, respiration, UV-B radiation, *Malus ×domestica*

Abstract. Enclosing 'Fuji' apple (*Malus ×domestica* Borkh.) fruit in paper bags 2 months after full bloom delayed the increase in internal ethylene concentration at the onset of fruit ripening, and increased the respiration rate early in the bagging period. Bagging delayed and reduced red color development, especially on the blush side, but did not affect fruit resistance to gas diffusion. External surface color changed significantly within the first 4 days after bags were removed. Exclusion of UV-B from sunlight by Mylar film after paper bag removal impaired red color development. Bagging during fruit development increased superficial scald but eliminated stain during cold storage. Exposure to sunlight for 19 or 20 days before harvest reduced scald incidence in comparison with leaving bags on until harvest.

Bagging apple fruit during development to enhance late-season red color development has been a common practice for decades in Japan (Mink, 1973; Robinson, 1974). Bagging has also been used extensively in the Pacific Northwest of North America, primarily for 'Fuji' apples. The commercially used paper bags are composed of an outer layer of light-blocking paper and an inner layer of translucent colored paper (usually red or green). Bags are placed on fruit after "June" drop (1–2 months after full bloom). Outer bags are removed 2–3 weeks before anticipated harvest, inner bags 4–7 d later. Previous reports indicate that bagging has inconsistent effects on fruit firmness, but reduces fruit soluble solids and anthocyanin content in several apple cultivars (Kume and Kudo, 1982; Proctor and Lougheed, 1976). Bagging increased mass and acidity loss of 'Delicious' and 'Mutsu' apples during storage (Okamoto et al., 1982), reduced calcium content of 'Jonathan' apples (Perring and Clijsters, 1974) and increased brown core in 'McIntosh' apples after storage (Proctor and Lougheed, 1976). 'Jonathan' apples enclosed in black cloth bags until harvest were smaller and had less starch than

nonbagged fruit, especially in the cortex near the peel (Perring and Clijsters, 1974). Proctor and Lougheed (1976), however, found that bagging had no effect on fruit size or starch content using several apple cultivars. The conflicting results may reflect differences in bags used, exposure time after bag removal, and/or cultivar specific responses.

Resistance to gas diffusion undergoes a climacteric-like change during maturation and ripening of 'McIntosh' apple fruit (Park, 1991; Park et al., 1993), and may be associated with the deposition of cuticular wax and differentiation of lenticel structure (Park, 1991). Light impacts the amount, composition, and structure of leaf waxes (Giese, 1975; Reed and Tukey, 1982; Tevini and Steinmuller, 1987), and shading can reduce the number of lenticels in the apple epidermis (Eccher and Noe, 1993). The impact of bagging, which blocks sunlight, on the resistance to gas diffusion of apple fruit has not been well characterized.

During maturation and ripening of apple fruit, anthocyanin content of the peel increases in red cultivars while chlorophyll content decreases (Lancaster, 1992; Saure, 1990). A number of factors affect the biosynthesis of anthocyanin, but the primary factor is sunlight. Siegelman and Hendricks (1958) found radiation throughout the visible region to be effective, with a maximal promotion of anthocyanin synthesis by red light between ≈640 and 670 nm. Arakawa et al. (1985) showed that white light supplemented with UV light at 312 nm produces three times more anthocyanin in apple discs than did white light alone. Bagging reduces chlorophyll and anthocyanin content and bagged fruits appear less green (Kume and Kudo 1982; Proctor and Lougheed, 1976). Removing bags from apples prior to harvest allows light to reach the fruit surface, resulting in red color development due to anthocyanin accumulation. The impacts of

bagging on the onset and/or progression of apple ripening have not been reported previously.

'Fuji' apples can develop a peel disorder characterized by a greenish, dark discoloration typically on the portion of the fruit exposed to the sun. This disorder, called stain or sunside scald, usually has a well-defined border and often occurs at the periphery of sunburn. Stain may be observed at harvest but usually develops during cold storage on the portion of the fruit receiving direct sunlight, implicating light as a possible factor in stain development.

Because of the lack of information on the physiological impacts of apple bagging, the effects of bagging on fruit ripening, color development, and resistance to gas diffusion were studied. Fruit peel disorders were also recorded after cold storage.

Materials and Methods

Expt. 1. Effects of bagging on color development, ethylene production, respiration, and resistance to gas diffusion. Commercially grown, fourth-leaf 'Fuji' scion on M. 26 rootstock was the source of fruit for bagging treatments. Apples were covered with double-layer paper bags (Kobayashi Bag Manufacturing Co., Iida, Japan) 2 months after full bloom. The outer bags were gray outside and black inside; the inner bags were red. Six fruits were harvested periodically during development, without prior bag removal, for each sampling date and treatment. External color, internal ethylene concentration (IEC), respiration rate, and resistance to gas diffusion were measured on each date. The IEC of individual apple fruit was measured (Williams and Patterson, 1962) on the day of harvest by removing a 0.5-mL internal gas sample through an 18-gauge stainless steel needle inserted into the fruit core.

Ethylene concentration in the gas sample was determined using a gas chromatograph (HP5880; Hewlett Packard, Avondale, Pa.) equipped with a flame ionization detector (FID) and a 60-cm glass column (3.2 mm i.d.) packed with 80/100 mesh Porapak Q (Millipore Co., Milford, Mass.). Gas flows for N₂, H₂, and air were 30, 30, and 300 mL·min⁻¹, respectively, and oven, injector, and FID temperatures were 30, 60, and 200 °C, respectively. Respiration rate was measured by sealing individual fruit in 4-L glass jars for 1 h, then CO₂ in the headspace was determined using a gas chromatograph (HP5890; Hewlett Packard) equipped with a methanizer (John T. Booker, Austin, Texas) and a 60-cm stainless steel column (2 mm i.d.) packed with 80/100 mesh Porapak Q. Gas flows for N₂, H₂, and air were 65, 30, and 300 mL·min⁻¹, respectively, and oven, injector, and FID temperatures were 30, 50, and 200 °C, respectively. Resistance to gas diffusion was measured according to Cameron and Yang (1982). Fruit color was measured on both blush and shade sides of fruit and recorded as L*, a*, and b* with a chromameter (model CR-200; Minolta Co., Osaka, Japan) using CIE illuminant C and an 8-mm diameter measuring aperture. The blush side of each

Received for publication 22 Dec. 1997. Accepted for publication 17 June 1998. We gratefully acknowledge the technical assistance of David Buchanan and Janie Gausman. Mention of a trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by the U.S. Dept. of Agriculture and does not imply its approval to the exclusion of other products or vendors that also may be suitable. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

fruit was exposed to the sun on the tree, and was redder in nonbagged fruit and more yellow in bagged fruit. Hue values were calculated from a^* and b^* (Hunter and Harold, 1987).

Expt. 2. Effect of UV-B on red color development after bag removal. Fruit were bagged as described earlier. Outer and inner bags were removed 140 and 146 d after full bloom (DAFB), respectively. Mylar film (Dupont Co., Circleville, Ohio) was used to construct bags to cover the fruit in order to eliminate subsequent UV-B radiation at the surface. Apples were covered with Mylar bags on the day of inner bag removal, and one side of the bag was left open to allow for air and thermal exchange. The Mylar used was 23 μm thick and absorbed UV radiation at wavelengths <320 nm. The blush side of each fruit was marked and the color measured daily on the same spot with the chromameter. There were 10 fruits for each treatment (Mylar bag vs. no bag).

Expt. 3. Effect of bagging on fruit peel disorders during cold storage. Three treatments were used: nonbagged, bagged until harvest, and bagged with bags removed prior to harvest. The study was conducted in two orchards. In orchard 1, fruit were bagged 60 DAFB, outer and inner bags were removed 158 and 163 DAFB, respectively, and fruit were harvested 183 DAFB. In orchard 2, fruit were bagged 65 DAFB, outer and inner bags were removed 162 and 167 DAFB, respectively, and fruit were harvested 187 DAFB. Fruit were examined after 4 months of storage at 0°C . There were eight replicates (18 fruits each replicate) for each treatment per orchard.

Statistical analysis of data. All data were subjected to analysis of variance using the GLM procedure of the SAS statistical package (Statistical Analysis System, SAS Institute, Cary, N.C.). Fisher's protected least significant difference test for mean separation (Expts. 1 and 2) and Duncan's multiple range test (Expt. 3) were performed.

Results and Discussion

Expt. 1. Effects of bagging on color development, ethylene production, respiration, and resistance to gas diffusion. The L^* and hue values decreased during development of nonbagged fruit, especially on the blush side (Figs. 1A and 2C), indicating that the fruit became redder and darker. During development of bagged fruit, L^* values increased on both the blush and shade sides, whereas hue values did not change on the blush side of the fruit but decreased on the shade side. The L^* values were higher on both shade and blush sides of bagged than of nonbagged fruit. Bagged fruit had significantly higher hue values on the blush side 80 d after bagging and later because hue values for nonbagged fruit decreased (Fig. 1C). Shade-side hue values were lower for bagged than nonbagged fruit during the early period after bagging, but no difference was observed 80 d after bagging or later (Fig. 1D). The higher L^* and hue values

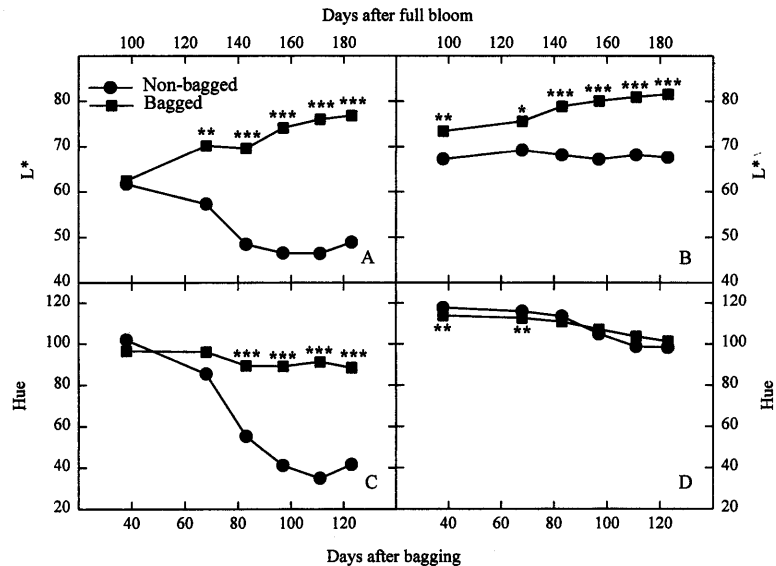


Fig. 1. Effect of bagging from 2 months after full bloom until harvest on (A) L^* and (C) hue values on the blush side and (B) L^* and (D) hue on the shaded side of 'Fuji' apples during development. Values are means for six apples. *, **, ***Significantly different from non-bagged fruit by LSD at $P < 0.05$, 0.01 , and 0.001 , respectively (Expt. 1).

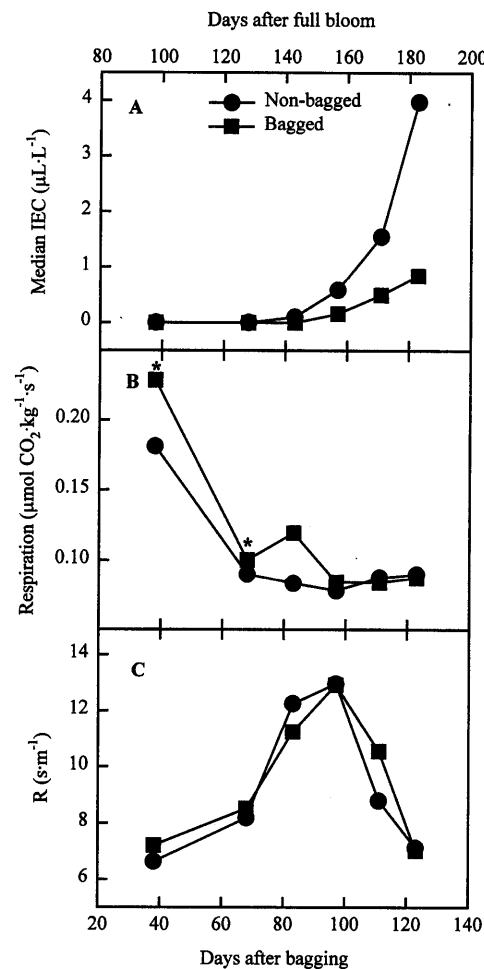


Fig. 2. Effect of bagging from 2 months after full bloom until harvest on (A) internal ethylene concentration (IEC), (B) respiration, and (C) resistance to gas diffusion (R) in 'Fuji' apple fruit during development. Bagged apples were harvested without prior removal of bags. Values are means for six apples. *Significantly different from nonbagged fruit by LSD at $P < 0.05$ (Expt. 1).

indicate that bagged fruits were lighter and less red than nonbagged fruits, confirming earlier reports (Kubo et al., 1988; Proctor and Loughheed, 1976).

Bagging reduced IEC during fruit ripening ($P = 0.06$, 91 and 121 d after bagging) (Fig. 2A) while increasing the respiration rate during the early period after bagging (Fig. 2B). These differences may result from the higher mean temperature of bagged fruit during the middle portion (July–August) of the growing season. Bagging can increase temperature at the apple surface by 3 to 5 °C in the middle of a sunny day (Andrews and Johnson, 1996). Resistance to gas diffusion increased in both bagged and nonbagged fruit during development, then decreased after fruit began to produce detectable quantities of ethylene (Fig. 2C), but bagging did not affect the resistance. Park et al. (1991) reported that resistance to gas diffusion was high in very young ‘McIntosh’ apple fruitlets, reached a minimum 1 month after full bloom, gradually increased to a new high immediately prior to fruit maturity, and then rapidly declined. The profile of resistance to gas diffusion in ‘Fuji’ was similar to that in ‘McIntosh’ apples, but values for ‘Fuji’ were one-half to one-third those for ‘McIntosh’. Because the rapid change in resistance to gas diffusion occurs during the early stage of fruit ripening when ethylene production begins, ethylene may mediate this change. The change may also be associated with differentiation of lenticel structure (Park, 1991).

Expt. 2. Effect of UV-B on red color development after bag removal. During the 17 d following bag removal, both L^* and hue values decreased (Fig. 3). Most of this change occurred during the initial 4 d. Covering fruit with Mylar significantly increased both L^* and hue during most of the 17-d period after bag removal. The higher hue values indicate that Mylar reduced color development, consistent with the enhancing effects of UV-B radiation on anthocyanin formation in apple peel (Arakawa et al., 1985; Kubo et al., 1988).

Expt. 3. Effect of bagging on fruit peel disorders during cold storage. Only fruit that remained bagged until harvest developed scald during cold storage (Table 1). In both orchards, bagged fruit had a high incidence of scald and calyx-end browning, while nonbagged fruit had neither. The browning became more severe as storage duration increased (data not shown). When bags were removed 20 d prior to harvest, scald did not develop and calyx-end browning was less severe. However, anthocyanin forming during the last 20 d may have masked the calyx-end browning and scald that developed during storage. Bagging ‘Cortland’ apples until harvest decreased α -tocopherol, carotenoid, and ascorbic acid concentrations, and increased scald development (Barden and Bramlage, 1994b). Bagged ‘Mutsu’ fruit exposed to natural light for 20 d before harvest developed less scald than did nonbagged fruit (Noro et al., 1996). A relatively short exposure to natural sunlight between bag removal and harvest has

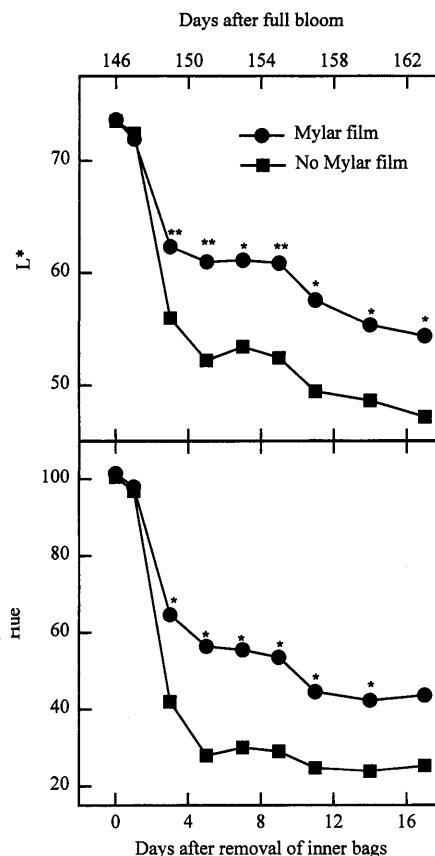


Fig. 3. Effect of UV-B radiation on color change (L^* and hue values) of bagged ‘Fuji’ apple fruit attached to the tree. Day 0 represents the date when inner bags were removed (86 d after initial bagging) and fruits were covered with Mylar bags. Values are means for 10 apples. *,**Significantly different from nonbagged fruit by LSD at $P < 0.05$ and 0.01 , respectively (Expt. 2).

a profound effect on reducing scald susceptibility, and light is a factor in the loss of susceptibility to scald (Barden and Bramlage, 1994a). Nonbagged fruit and a small percentage of the fruit from which bags were removed prior to harvest developed stain while fruit bagged until harvest did not (Table 1). Thus exposure to sunlight appears to favor development of stain.

In summary, bagging results in higher hue and L^* values, especially on the blush side of the fruit. In this experiment, bagging reduced IEC, although resistance to gas diffusion was not affected. Red color development after bag

removal was retarded when UV-B radiation was excluded from natural light. Bagging virtually prevented stain but increased incidence of scald. A short exposure to natural light prior to harvest eliminated scald in the bagged fruit.

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Table 1. Effect of bagging and exposure of bagged fruit to natural light during fruit development on incidence (percentage of fruit affected) of stain, scald, and calyx-end browning of ‘Fuji’ apple during storage at 0 °C for 4 months (Expt. 3). In orchard 1, fruit were bagged 60 d after full bloom (DAFB), bags were removed 163 DAFB, and fruit were harvested 183 DAFB. In orchard 2, fruit were bagged 65 DAFB, bags were removed 167 DAFB, and fruit were harvested 187 DAFB.

| | Nonbagged | Bagged | Bagged and then exposed |
|--------------------|---------------------|------------------|-------------------------|
| | | <i>Orchard 1</i> | |
| Stain | 12.8 a ² | 0.0 b | 0.0 b |
| Scald | 0.0 b | 36.7 a | 0.0 b |
| Calyx-end browning | 0.0 b | 51.0 a | 11.6 a |
| | | <i>Orchard 2</i> | |
| Stain | 20.0 a | 0.0 b | 0.9 b |
| Scald | 0.0 b | 38.9 a | 0.0 b |
| Calyx-end browning | 0.0 b | 59.1 a | 10.2 b |

²Means within a row followed by different letters indicate significant differences between treatments at $P < 0.05$, Duncan’s multiple range test.

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