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Postharvest Biology and Technology 8 (1996) 19–27

Postharvest Biology and Technology

# Improvement of harvested strawberry quality by illumination: colour and *Botrytis* infection

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Accepted 14 September 1995

**Abstract**

Strawberry fruit, cvs. Dorit and Ofra were illuminated at 14.5 and 17.5 $Wm^{-2}$, respectively, by white fluorescent light at 2°C. A two-hour treatment was sufficient to overcome the genetic limitation of "white shoulders" (WS) in Dorit and the "poor red colour" (PRC) in cv. Ofra. Illumination enhanced both external and internal fruit colour. The fruit-quality attributes, freshness of calyx, fruit firmness and fruit decay, were not impaired by light treatment after storage simulating air or sea transport followed by shelf-life (18°C). The described treatment reduced fruit rot in both cultivars. In fruit inoculated with *Botrytis cinerea*, the most common storage pathogen of strawberry, the appearance of disease symptoms was delayed.

*Keywords:* Strawberry colour; Decay; Illumination; Postharvest

## 1. Introduction

Strawberry fruit (*Fragaria* × *ananassa* Duch.) grown in northern Europe is usually expected on the market in May and June. Import of fruit from warmer regions hastens earlier availability to April. In recent years early cultivars have been developed in subtropical areas allowing earlier entry of strawberry fruit to the market at the beginning of December. The advantage of the early varieties has been diminished by their poor fruit colour. The fruit of cv. Dorit, although a high-quality fruit in many respects, suffers from "white shoulders" (WS), an area at the calyx end lacking red pigmentation (E. Iszak, pers. commun., 1988). The berries of cv. Ofra suffer from

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Contribution from the Agricultural Research Organization, The Volcani Center, Bet Dagan, Israel. No. 1129-E, 1993 series.


*SSDI* 0925-5214(95)00054-2

"poor red colour" (PRC). Some improvement in red colour development can be obtained after storage at high temperatures (Austin et al., 1960), conditions which advance fruit ripening. At the commonly used low temperatures (2–5°C), colour development is very slow (Kalt et al., 1993). Cool white fluorescent illumination of apples at 2°C enhances red colour without hampering fruit quality and storability potential (Saks et al., 1990). Previous attempts to promote red colour in strawberries by illumination showed no statistically significant results but suggested that the effect, if any, was greater at low than at high temperature (Kalt et al., 1993).

The present study evaluated postharvest strawberry fruit illumination with cool fluorescent light at 2°C as means of reducing the WS in cv. Dorit fruit and enhancing the reddening of the entire cv. Ofra fruit without inducing other deleterious effects.

While UV-254 has been reported to inhibit fungal development in fruit (Creasy and Coffee, 1988; Rodov et al., 1992), the effect of cool fluorescent light, poor in UV-254 part of light spectrum, on fungus development is not known. Therefore the effect of cool white fluorescent illumination on the development of *Botrytis cinerea* Pers., the main postharvest pathogen of strawberry fruit (Barkai-Golan, 1981), was also studied.

## 2. Materials and methods

### *2.1. Experimental material*

Commercially grown, chemically untreated fruit of cv. Dorit with WS, and cv. Ofra, with poorly-developed red colour, were harvested during December–February. The picked fruit was transferred in punnets to the laboratory and within 3–4 h exposed to light and storage treatments.

### *2.2. Illumination and storage*

After assessing the fruit's external red colour or the extent of WS, in cv. Dorit, (see details below) the fruit was either kept in the dark (control) or exposed to continuous cool white fluorescent light. Light intensity and duration were selected, as specified below, on the basis of preliminary experiments. To enhance effectiveness of illumination and to avoid weight loss of fruit fresh, a single layer of fruit was arranged on trays lined with white background (paper) and covered with clear PVC film (17 $\mu$m). Based on preliminary experiments which demonstrated the effectiveness of illumination in conjunction with low temperature, all treatments were performed at 2°C, the commonly-used temperature for strawberry storage.

### *2.3. Experiments*

*Illumination to diminish the extent of WS in cv. Dorit fruit*

Fruit was illuminated at 14.5 $Wm^{-2}$, 2°C for 0 (control), 2, 5, 7, and 15 h. Both illuminated and non-illuminated fruit were then stored at 18°C in the dark, representing shelf-life conditions during which pigment accumulation continued.

The extent of WS was re-evaluated after 24 and 48 h shelf-life periods, the commercially practised storage durations for local marketing.

*Effect of illumination on fruit quality under storage conditions simulating sea transport in Dorit fruit*

Dark control fruit were compared with fruit illuminated at 14.5 $Wm^{-2}$ for 2 h. After 120 h at 2°C, simulating sea transport conditions, external red colour, fruit firmness, and percent decay were determined (details below) prior to shelf-life storage at 18°C in the dark for 72 h. At the end of this period, external and internal colour intensity, firmness, and percent of decay were assessed (details below).

*Illumination to enhance red colour of cv. Ofra fruit*

Fruit was illuminated at 17.5 $Wm^{-2}$ for 2–16 h. The light-treated and non-treated fruit were stored for 24 h of shelf-life at 18°C in the dark after which fruit red colour was re-evaluated.

*Effect of illumination on fruit quality under storage conditions simulating air freight in cv. Ofra fruit*

After illumination at 17.5 $Wm^{-2}$ for 2 h, the illuminated and non-illuminated fruit were stored at 2°C for 48 h simulating air freight storage conditions, followed by shelf-life (18°C, dark) for 48 h. At the end of these periods, fruit colour, firmness, calyx freshness, and percent decay were assessed to determine the suitability of fruit for export (details below).

*Effect of illumination on decay development in Botrytis-inoculated fruit*

Cv. Ofra fruit was contact-inoculated with *B. cinerea* by rolling each fruit in a ten-day-old single spore culture of the fungus. The fungus has been isolated previously from decayed strawberry fruit. Following inoculation, half of the fruit lot was illuminated at 17.5 $Wm^{-2}$ and the remaining lot was kept as control in the dark. Next, the illuminated and non-illuminated fruit were incubated for 72 h at 18°C. Each fruit was evaluated daily to determine the percent of decayed fruit.

### 2.4. Measured parameters

Extent of WS was visually evaluated as a percent of the fruit surface exposed to light.

Fruit colour was measured at the fruit equator on the side facing the illumination using a Minolta Chromometer CR200 (Japan). Colour was estimated as hue angle in radians: hue angle = $\tan^{-1} b/a$ (Little, 1975). A decreasing hue angle indicates an increase in red colour intensity.

Internal colour was measured as described above in fruit dissected longitudinally to three different depths: (1) 2 mm beneath the surface; (2) at the cortex; (3) at the pith.

Fruit firmness was measured at the equator of each fruit by use of a penetrometer (flat head, 10 mm in diameter), and expressed in Newtons (N).

Calyx freshness was assessed visually in terms of its turgidity and green colour using an index of 1–5, where 1 = fresh and green and 5 = wilted and somewhat brown.

Fruit decay was determined by counting the number of infected fruit. The rate of rot development on the fruit was not taken into account.

Fifty replicate fruits were used for evaluation of colour and other fruit quality parameters. Ten berries in five replicas were used to assess the percent of fruit decay in inoculation experiments.

Each of the experiments was repeated at least three times throughout the harvest season using fruit from different field populations. The reported results are from one representative experiment.

## 3. Results

Two hours of cool white fluorescent illumination of harvested strawberries at 2°C improved their quality by increasing the red colour and delaying decay.

*Effect of illumination on the extent of WS in cv. Dorit fruit*

Illumination of 14.5 $Wm^{-2}$ for as little as 2 h was sufficient to decrease significantly the extent of WS on cv. Dorit strawberries in comparison to the dark control treatment (Fig. 1). The illumination effect was not observed during or immediately after the light treatment but was particularly noticeable after 48 h shelf-life at 18°C. A small but significant reduction in WS size was detected during the shelf-life in non-illuminated fruit, but the reduction increased significantly as result of light treatment. After 24 h of shelf-life the WS area decreased by 4, 21, 18, 65, and 60% following 0, 2, 5, 7, and 15 h illumination, respectively. After 48 h of shelf-life, the WS continued to diminish, both in the control and in the illuminated fruit in which

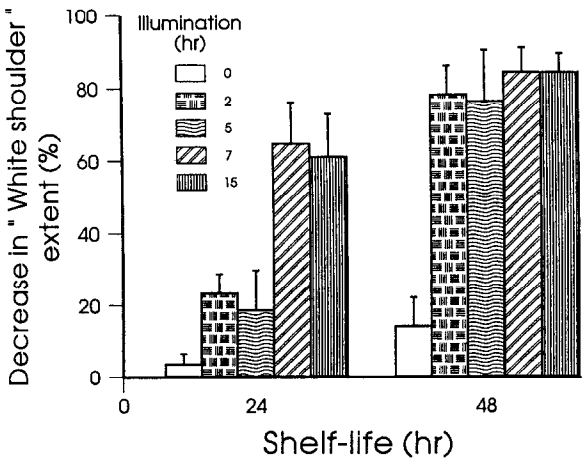


Fig. 1. Effect of various periods of illumination (14.5 $Wm^{-2}$) at 2°C on WS size in cv. Dorit strawberry fruit after storage at 18°C for 24 or 48 h. The vertical bars represent ±S.D., $n = 50$.

Table 1
Effect of cool white fluorescent illumination (14.5 $Wm^{-2}$, 2 h at 2°C) and storage simulating sea transport (120 h at 2°C) followed by shelf-life (72 h at 18°C) on cv. Dorit strawberry fruit quality

| Duration (h) | | Red colour (radians) | | | | Decay (%) | Firmness (N) |
|---|---|---|---|---|---|---|---|
| Light | Shelf-life | External | Internal | | | | |
| | | | 1[a] | 2[b] | 3[c] | | |
| Initial values at harvest | | 53.0 | – | – | – | – | 3.5 |
| 0 | 0 | 55.0 | – | – | – | 0 | – |
| 2 | 0 | 52.0 | – | – | – | 0 | – |
| 0 | 72 | 39.8 | 39.5 | 48.8 | 39.8 | 52 | 2.4 |
| 2 | 72 | 21.5 | 22.0 | 28.3 | 23.7 | 10 | 2.5 |
| LSD (5%) | | 2.3 | 2.2 | 4.7 | 2.3 | 11 | 0.7 |

[a] 2 mm beneath the the surface.
[b] Cortex region.
[c] Pith region.

the effect of illumination duration on the WS size disappeared. As a result, its size decreased by 20 and 80% in the dark- and light-treated fruit after 48 h shelf-life, respectively. The WS size varied greatly, both between fruit and from experiment to experiment, covering 20–50% of the fruit surface. Therefore, the studied effect is expressed as a percentage of decrease in the extent of WS recorded prior to treatment (Fig. 1).

*Effect of illumination on fruit quality under storage conditions simulating sea transport in cv. Dorit strawberry*

Illumination of 14.5 $Wm^{-2}$ at 2°C for 2 h, followed by 120 h storage at 2°C and 72 h shelf-life at 18°C, simulating sea transport, improved cv. Dorit strawberry fruit quality. It enhanced significantly both external and internal fruit red colour in comparison to the dark control fruit without impairing its firmness, and reduced significantly the percent of fruit rot (Table 1). The effect of light on the internal colour was also detected, from 2 mm beneath the surface, through the cortex and into the pith regions. The effect of the illumination on fruit rot was extensive, with disease affecting 52% in the control and 10% in illuminated fruit. The high percentage of fruit rot in the control fruit can be explained by the intentional prolonged storage at 72 h, the purpose being to test the illumination effect under extreme conditions. Considering the experimental conditions of low temperature (2°C), illumination quality (emitting low heat) and its short duration (2 h), the possibility that the difference in the percent of fruit rot in the light-treated and control fruit was caused by reasons other than illumination such as variations in heat or humidity, is unlikely.

*Effect of illumination followed by shelf-life on colour enhancement in cv. Ofra fruit*

Exposure of cv. Ofra strawberries to illumination of 17 $Wm^{-2}$ at 2°C for 2 h followed by 24 h shelf-life was sufficient to intensify significantly the red colour of

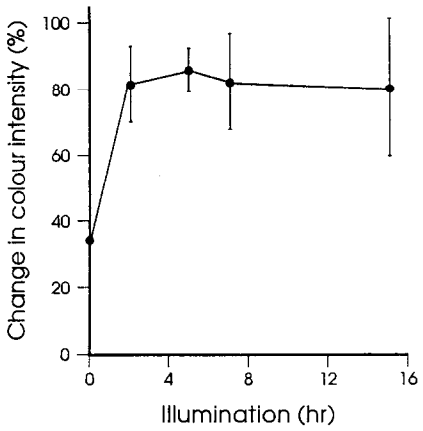


Fig. 2. Effect of the length of illumination (17.5 $Wm^{-2}$) at 2°C on the colour development in cv. Ofra strawberry fruit after 24 h storage at 18°C. The vertical bars represent ±S.D., $n = 50$.

the fruit by up to 80%, as compared to 35% detected in the non-illuminated control (Fig. 2). Treated fruit reached a red colour intensity of about 15 radians (hue angle), the range required for high-quality fruit. Extending the exposure duration beyond 2 h did not enhance improvement in colour intensity. For reasons explained in the WS case, the change in red colour intensity in Fig. 2 is presented as percent of colour value prior to treatments.

*Effect of illumination on fruit quality under storage conditions simulating air freight in cv. Ofra fruit*

Cv. Ofra fruit with a firmness of 4.0 N (S.D. ± 0.4) and calyx freshness of 1.3 (S.D. ± 0.3) after 2 h illumination at 2°C followed by simulated air freight transport (48 h at 2°C) and 48 h shelf-life (18°C) did not soften significantly, compared with non-illuminated fruit. Calyx freshness did deteriorate both in the control and the illuminated fruit, but there was no significant difference between the two. There was no rot either in the treated or non-treated fruit after 24 h of shelf-life, but after 48 h, more fruit had rots in the control (44.3%) than in the illuminated fruit (22.7%) (Table 2).

*Effect of illumination on decay development in Botrytis- inoculated cv. Ofra fruit*

No fungal development was detected in the illuminated or non-illuminated fruit after 24 h incubation at 18°C. After 48 h a small but significant difference in fungal development was observed between the illuminated and non-illuminated treatments, 0 and 10%, respectively. Longer incubation of 72 h indicated that light treatment did not eliminate fungal development but caused a delay in its emergence. A decay level of 14% was also detected in the illuminated fruit at that stage. Once the symptoms of the disease appeared the rate of disease development in the control and illuminated fruit was similar (Fig. 3).

Table 2
Effect on strawberry fruit (cv. Ofra) of illumination for 2 h at 2°C and subsequent storage for 48 h at 2°C (simulating air transport) and a further 48 h at 18°C (simulating shelf-life). Fruit quality in terms of firmness, calyx appearence and disease prevalence were assessed

| Treatment | Fruit quality [a] | | |
|---|---|---|---|
| | Firmness (N) | Calyx appearence index (1–5) [b] | Diseased (%) |
| Non-illuminated | 3.8 | 2.5 | 44.3 |
| Illuminated | 3.7 | 2.2 | 22.7 |
| LSD (5%) | N.S | N.S. | 10.1 |

[a] Fruit quality at harvest: decay = 0, firmness 4.0 ± 0.4 (S.D.), calyx freshness 1.3 ± 0.3 (S.D.).
[b] Freshness of calyx index: 1 = fresh; 5 = wilted.
N.S. = not significant.

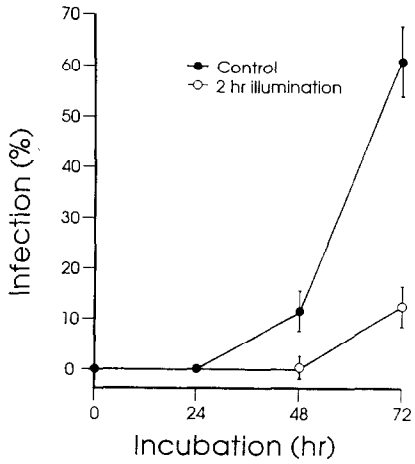


Fig. 3. Percent of infection with *B. cinerea* of illuminated (17.5 $Wm^{-2}$) and non-illuminated cv. Ofra strawberry fruit at 2°C followed by incubation for up to 72 h. The vertical bars represent ±S.D., $n = 5$.

## 4. Discussion

Thus far, attempts to improve red colour by postharvest illumination of strawberries have not produced conclusive results (Austin et al., 1960; Kalt et al., 1993). The present study shows for the first time that red pigmentation can be promoted significantly in harvested strawberries when illuminated by cool fluorescent light. This process can take place at low temperature and is independent of changes related to fruit softening. These data agree with the finding reported for apple fruit (Saks et al., 1990). However, unlike apples, which require 20 h of illumination to induce pigment synthesis (Saure, 1990), a short (2 h) illumination in strawberries was sufficient to induce pigment synthesis in strawberries. These results have important commercial implications. Illumination could reduce the WS, typically covering about 30% of

surface in cv. Dorit fruit at harvest, by 65 and 80%, depending on storage duration. Consequently, in treated fruit WS would be found only over 3–10% of its surface. The fact that the treatment is performed at a temperature commonly used to store fruit, 2°C, has important cost-saving advantages. The most appropriate conditions for any particular commercial application will depend on the destination of the fruit, with the optimum treatment set against the cost-effectiveness and practicality of particular time/temperature combinations. That the illumination treatment does not promote postharvest fruit ripening, even after simulating sea or air freight storage conditions, can delay the appearance of fungal disease symptoms by 24 h. This suggests that such treatments could be an attractive alternative to fungicide application for postharvest disease control (Aharoni and Barkai-Golan, 1987). Based on the present findings it should be possible to develop an efficient technology to upgrade strawberry quality.

The present data is also of scientific interest. Since red colour in strawberry is the result of anthocyanin accumulation, the observation that a short (2 h) illumination is sufficient for improvement of PRC in fruit provides a simple method to further investigate the complex photocontrolled mechanism of anthocyanin synthesis (Saure, 1990).

Of particular interest is the observation that illumination of harvested fruit (cv. Dorit) allowed the expression of a genetic potential to synthesize pigments that failed to emerge in the WS area of attached sun-illuminated berries prior to harvest.

The response of internal tissue of strawberry fruit to illumination confirms previous findings on the penetration of light in apple fruit (Blanke and Notton, 1992). Since the mechanism of a light effect on anthocyanin synthesis is claimed to be localised, not involving transferrable metabolic factors (Saure, 1990), light has to reach the inner parts of an illuminated strawberry fruit in order to affect pigment synthesis. Unlike Blanke and Notton (1992), who measured the intensity and quality of penetrating light, this study reports its effectiveness.

Additional novel data is the inhibiting effect of cool fluorescent light on fungal development. Though cool fluorescent light includes almost the entire light spectrum, it does not include the UV-254 range that has been shown to affect fungal development (Creasy and Coffee, 1988; Rodov et al., 1992), suggesting the possibility of control of fungal development by a part of light spectrum different from UV-254. Thus, a possibility exists that fruit antifungal resistance might be affected by other parts of the light spectrum. It is likely that UV-B, UV-C or red light, each involved in the photocontrol of the process of anthocyanin synthesis (Arakawa, 1988; Saure, 1990), could play a part. The association between anthocyanin synthesis and fungal resistance has not been studied. It has been suggested, however, that development of red colour by the young leaves of tropical species may serve as an antifungal defense (Coley and Aide, 1989). The link between anthocyanin synthesis and antifungal resistance has also been suggested by Jersch et al. (1989), since the prolonged resistance of cultivars with WS to gray mold was related to the level of proanthocyanidenes, one of the metabolites which are involved in the anthocyanin synthesis pathway.

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