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# Storage quality of strawberry fruit treated by pulsed light: Fungal decay, water loss and mechanical properties

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ABSTRACT

The effect of different pulsed light (PL) doses (2.4–47.8 J/cm$^2$) on water loss, fungal spoilage, mechanical properties and structure of strawberries stored for up to 8 days at 6 °C was studied. Incidence of postharvest molds on strawberry fruits was reduced by over 16–42% with PL application. There were no significant differences in maximal rupture force ($F_R$), mechanical work (W) and deformability modulus ($E_d$) values between treated and untreated fruits immediately after treatments. After 8 days storage at 6 °C, untreated strawberries showed a pronounced softening (≈48% reduction in $F_R$), but stored strawberries exposed for 10 s and 40 s to PL presented slight or not significant changes in the mechanical parameters regarding day 0, while $F_R$ and W values of 20 s-PL treated samples were increased by 35% and 88% compared to those at 0 day storage. Micro and ultrastructure changes evaluated by LM and TEM images demonstrated ITW cell wall strengthening and a major integrity of walls of hypodermis cells induced by PL stress, while cell wall disassembly and reduction of cell-to-cell contact were detected in stored untreated fruit. There were no significant differences in weight loss among untreated and PL treated fruits after storage, excepting at the highest PL dose. PL technique would be able to simultaneously provide disinfection and delete softening of the tissues along cold storage. Present results make this non-thermal, residue-free alternative promising for extending shelf-life of traditional and organic strawberry production.

*Industrial relevance:* The present results demonstrated that pulsed light (PL) treatment is a promising alternative for extending the shelf-life of strawberries. A decrease in fungal incidence and a depletion of softening, important factors which limit the strawberry postharvest storage life, were achieved by the application of PL.



## 1. Introduction

Consumption of fresh fruits has dramatically increased during the past few decades and far exceeded the increases observed for processed fruit products (Barth, Hankinson, Zhuang, and Breidt, 2009). This rise in produce consumption was driven, at least in part, by increased awareness in healthy habits. The "soft fruit" group, which includes strawberries, raspberries, blueberries, cranberries and gooseberries, invariably ranks high among fresh fruits due to their powerful antioxidant content and its putative role in the prevention of several chronic and degenerative diseases associated with oxidative damage like cancer and heart disease (Battino et al., 2009). The storage life of soft fruits is greatly shortened by both physiological and pathological deterioration (Barkai-Golan, 2001). Strawberry, the most important world crop in this group, is a popular and attractive fruit due to its high visual appeal and desirable flavor. Strawberry belongs to the family Rosaceae and is considered a false fruit since the edible structure originates from the expansion of the receptacle as a pseudocarp (Aharoni and O'Connell, 2002; Vicente and Sozzi, 2007). Physical, sensory and nutritional qualities of strawberry fruits are associated with traits like size, firmness, color, taste and aroma, vitamin C and phenolic contents (Mazur et al., 2014). Dynamic changes in chemical composition, and tissue structure during ripening, senescence, and processing cause variations in sensory, chemical and physical properties. Although strawberry is characterized by a high metabolic rate, decay development is the primary cause of loss. Postharvest diseases are the result of latent infections that occur in the field during the growing season and infections from wounding during harvest and handling operations and contribute to major economic losses to growers, processors, marketers and consumers (Michailides, Morgan, and Luo, 2010). The major postharvest pathogen of strawberry is *Botrytis cinerea*, the causal agent of gray mold. It survives on organic debris in the field; during the flowering and fruiting season fungal spores are common in the atmosphere and are deposited on flowers. The disease is manifested only during the postharvest phase, when the fruit ripens, during transit and marketing (Ceredi et al., 2009).

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Other fungi responsible for postharvest rot include species of *Mucor*; *Rhizopus*, the causal organisms of "leak" disease; *Colletotrichum*, which cause anthracnose, and *Phytophora*, which initiate leather rot (Barkai-Golan, 2001).

Postharvest fungicidal applications are not practical for ripe strawberries because of their sensitivity to wetting. The minimal growth temperature of *Botrytis* is about −2 °C and cold storage can only retard decay development. Extension of strawberry postharvest life has been an ongoing challenge and some studied alternative antifungal agents to reduce fruit losses, alone or in combination, include heat, UV-C irradiation, pulsed light, ozone, chlorine dioxide, ultrasound, natural antimicrobials and edible film coatings (Barkai-Golan, 2001; Vicente and Sozzi, 2007; Aday and Caner, 2014; Marquenie, Michiels, Van Impe, Schrevens & Nicolaï, 2003; Gómez-López, Devlieghere, Bonduelle, and Debevere, 2005; Lagunas-Solar, Piña, MacDonald, & Bolkan 2009).

Pulsed light (PL) involves the use of intense and short-duration (1 μs–0.1 s) pulses of broad spectrum light of wavelength ranging from UV to near-infrared (200–1100 nm). Power is magnified by storing electricity in a capacitor over relatively long times (fractions of a second) and releasing it in a short time (millionths of thousandths of a second) (Gómez-López, Ragaert, Debevere, and Devlieghere, 2007). It has, comparatively to continuous UV-C light, higher penetration depth and emission power (Krishnamurthy, Demirci, and Irudayaraj, 2007). Its use has been approved by the FDA (1996) for the decontamination of food and food surfaces. PL is one of the most promising non-thermal surface decontamination technologies for food produce due to the significant microbial reduction in very short intervals (tens of seconds) compatible with the logistics of the fresh fruit industry, the limited energy cost, the low environmental impact, the lack of residual compounds and its great flexibility (Lagunas-Solar, Piña, MacDonald, and Bolkan, 2006; Oms-Oliu, Martín-Belloso, and Soliva-Fortuny, 2010). Its efficacy has been mainly attributed to microbial DNA damages by thymine dimmer formation (photochemical effect) and/or to localized overheating of microbial cells (photothermal effect) and/or to structural damage caused by the pulsing effect (photophysical effect) ((Wekhof, 2000; Krishnamurthy et al., 2007).

The objective of this work was to investigate the effect of different PL doses on water loss, fungal spoilage, mechanical properties and structure of strawberries stored for up to 8 days at 6 °C. How differences in tissue structure were expressed by penetrometric parameters and water loss was also studied.

## 2. Materials and methods

### 2.1. Plant material

Strawberries (*Fragaria* × *ananassa* Duch., cv. Camarosa; pH 3.5 ± 0.3; 7.4 ± 0.5 °Brix) having 100% surface red color were purchased at a local orchard and immediately transferred to the laboratory. Fruits were selected for uniformity of ripeness and size, and absence of physical injuries or microbial infection. Then, they were randomly distributed into polyethylene boxes, stored at 5–7 °C and processed within a day.

### 2.2. Pulsed light equipment and dosimetry

PL treatments were performed with a RS-3000B Steripulse-XL system (Xenon Corporation, Woburn, MA, U.S.A.), which produced polychromatic radiation in the wavelength range of 200 to 1100 nm. The system consisted of a RC-747 power/control module, a treatment chamber that houses a xenon flash lamp and an air cooling system attached to the lamp housing to avoid lamp overheating during operation. The system generated high intensity pulsed light at a pulse rate of 3 pulses per second and a pulse width of 360 μs. According to the specifications supplied by the manufacturer, each pulse delivered 1.27 J/cm$^2$ for an input of 3800 V at 1.9 cm from the quartz window surface of the lamp.

Different fluences were obtained by altering the number of applied pulses at a fixed distance from the lamp. Fluence measurements were taken by a pyroelectric head model ED500 (Gentec Electro-Optics, Québec, Canada) connected to an oscilloscope model TDS 2014 (Tektronix, Beaverton, USA), with an aperture cover of 20.3 cm$^2$. Measurements were performed in triplicate.

### 2.3. Pulsed light treatment

To perform the PL treatments up to four strawberries were treated at the same time. Fruits were put on a sterile glass tray and placed on a stainless steel shelf in the PL unit at 10 cm distance from the quartz window of the lamp. Variations in radiation dose absorption were minimized by placing the samples within a uniform area of the radiation field (beneath the lamp and around the central point). Samples were exposed to irradiation for 2, 10, 20 and 40 s, corresponding to fluences of 2.4, 11.9, 23.9 and 47.8 J/cm$^2$, respectively. Fruits were irradiated on one side and then they were turned upside down on another sterile tray and treated during the same period of time on the opposite side.

Temperature measuring of strawberry during PL treatment was monitored by using T-type thermocouples whose tips were placed immediately beneath the surface and in the center of the fruit. The thermocouples were connected to a data logger Digi-Sense model 69202-30 (Barnant Company Division, Barrington, USA). Temperature measurements were done in triplicate.

PL treated strawberries were compared with untreated fruits (control). Control and irradiated samples were packed in closed plastic boxes permeable to air (26 cm × 19 cm × 6 cm) and stored at (6 ± 1) °C for 8 days. Each box contained about 10–11 fruits. Samples were analyzed immediately after treatment (0 day) and at selected days of storage.

### 2.4. Decay incidence

Postharvest strawberry disease was assessed by incidence, by visually recording the presence or absence of fungal development, regardless of the severity of the infection. Results were expressed as percentage of infected fruit (Aday and Caner, 2014; Michailides et al., 2010). The observations were made in 32 fruits for each condition. The whole experiment was repeated three times.

### 2.5. Mechanical properties

Puncture test was performed with an Instron Testing Machine model 3345 (Canton, Massachusetts, USA) with a flat-end cylindrical probe (4.8 mm in diameter), 50 N-load cell, and a crosshead speed of 30 mm/min. Each specimen was penetrated on the equatorial side. From the force–displacement and stress–deformation curves, three mechanical parameters were computed: the maximal rupture force ($F_R$, expressed in N) that represents the force required to puncture the fruit epidermis, the mechanical work (W, expressed in J) that corresponds to the energy needed to break the epidermis and was estimated by the area under the curve up to the epidermis rupture point, and the deformability modulus ($E_d$, expressed in mPa) calculated from the initial linear portion of the stress–deformation curve. Puncture measurements were done on 22 strawberries for each condition. The whole experiment was repeated twice.

### 2.6. Weight loss

Weight loss along storage of treated and untreated strawberries was recorded in a balance (Precisa 180 A, Switzerland) with a precision of ±0.0001 g. Ten fruits were used for each condition. Results were