UV-C light inactivation kinetics of *Penicillium expansum* on pear surfaces: Influence on physicochemical and sensory quality during storage

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Abstract

UV-C inactivation kinetic data of *Penicillium expansum* on intact and wounded pear disks were determined. *Penicillium expansum* conidia (0.5 mL, 1.6×10^7 CFU/mL) were spot inoculated onto intact and wounded pear with skin (excised disks), treated with UV-C doses ranging 0.101-3.06 kJ/m^2 at 23^{o}C and surviving conidia were enumerated. Changes in selected physicochemical parameters and sensory quality following UV-C treatment of whole pear were determined immediately after treatment, and 4 and 8 weeks of storage at 4^{o}C. A greater UV-C intensity was required for similar inactivation level of *P. expansum* population on wounded pear disks (3.1 kJ/m^2 for 2.7 log reduction) compared to intact pear disks (1.7 kJ/m^2 for 2.8 log reduction). No significant difference in % weight loss, or soluble solids content and texture was observed between UV-C treated and untreated pears. However, browning was observed on UV-C treated pear surfaces after 4 and 8 weeks along with changes in flavor and texture. An increase in consumer preference was noticed for the untreated control pears after 4 weeks storage.

Key words: color, soluble solids content, flavor, surface disinfection, texture

Introduction

An average of 11 percent of fresh fruit and vegetable commodities at the retail level is lost due to microbial spoilage (Buzby et al. 2011). Chemical sanitizers, i.e., chlorine water or hypochlorite solutions, are commonly used for postharvest disinfection of fruit surfaces (Beuchat et al. 1998; Sapers, 2001). Ultraviolet light (UV-C) is an important alternative physical treatment (Bintsis et al., 2000) that can be coupled with the use of chemical sanitizers for reducing microbial load on fruit surfaces while addressing the desire for reducing in chemical usage (Issa-Zacharia et al. 2010). The research conducted during the last decade show that UV-C could be a potential physical method for sanitization of fresh fruits and vegetable surfaces (Nigro et al. 1998). However, the efficacy of UV-C is dependent on the product surface morphology and the resistance of target microorganisms against UV-C light (Syamaladevi et al. 2012).

The postharvest storage life and quality of pears are limited by spoilage fungi such as *Penicillium expansum* (Rosenberger, 1990; Robiglio et al. 2011). UV-C has been investigated for reducing decay by *Botrytis cinerea* on bell pepper (Mercier et al. 2001), chilling injury and decay in pepper (Vicente et al. 2005), and lesion development on mushroom surfaces (Guan et al. 2012). The decay of bell pepper was reduced by inactivating *Botrytis cinerea* conidia in fruit wounds by UV-C doses of 2.2-4.4 kJ/m^2 (Mercier et al. 2001). UV-C dose of 7 kJ/m^2 on peppers showed lower injury and severity of chilling compared to the untreated peppers during 22 days at 0^{o}C and 4 days at 20^{o}C by analyzing the percentage of injured fruit and the presence of dried discolored spots (Vicente et al. 2005). Significantly lower lesion development in UV treated (doses 0.2-0.9 kJ/m^2) button mushrooms was observed in comparison to the untreated mushrooms after 21 days storage due to the inactivation of *Pseudomonas tolaasii* (Guan et al. 2012). Lagunas-Solar et al. (2006) reported that pulsed UV inactivated several fungi species

69 including *P. expansum* on a variety of fruit surfaces. However, few studies related to efficacy
70 and inactivation kinetics of *P. expansum* by UV-C on fruit surfaces have been conducted. Along
71 with microbial inactivation, research on food quality changes after UV-C treatment and during
72 storage life of fresh produce is important for industrial applications of UV-C technology.
73 Perkins-Veazie et al. (2008) reported that weight loss, firmness and phenolic content of
74 blueberries were not affected by UV-C treatment (1–4 kJ/m^2) while they observed a decrease in
75 decay incidence from ripe rot (*Colletotrichum acutatum*, syn. *C. gloeosporioides*), and an
76 increase in total anthocyanin and antioxidant capacity with increase in UV-C intensity.
77 Teichmann et al. (2007) reported that UV-C treatment increased the vitamin D2 content in
78 mushrooms after harvest. However, few studies report the physicochemical properties and
79 sensory quality changes in fruits after UV-C treatment and during storage. The objectives of the
80 present study were to determine the UV-C inactivation kinetics of *P. expansum* on intact and
81 wounded pear surface, and the influence of UV-C treatment on physicochemical and sensory
82 quality changes of pears during storage.
83
84 **Materials and Methods**
85 A single-conidium culture of *P. expansum* (CLX1499) from decayed pear fruit that exhibited
86 typical blue mold rot was used. The isolate was stored in 15% glycerol (1:1 v/v) at –80°C. Later,
87 conidial suspensions were produced from growth on half strength V8 agar for 7 to 14 days at
88 20°C under combined cool white and near UV for 12 h and darkness for 12 h. Spore suspensions
89 were prepared by flooding sporulating cultures with sterile distilled water and bringing conidia
90 into suspension by stirring with a glass rod. Concentrations of spores were determined with a
91 hemocytometer with suspensions in 2% water agar of ~10^7 conidia/mL prepared.

92 Fresh D'Anjou pears (Pyrus communis L.) were procured from a local retail store and stored
93 immediately at 4°C. After washing with distilled water, fresh whole pears were air dried inside a
94 biological safety cabinet for 30 minutes at room temperature (~23°C) prior to each UV-C
95 disinfection experiment. Then disk-shaped slices of 5.7 cm diameter and about 1 cm thick (~30
96 g, with ~25 cm^2 intact epidermis) were aseptically cut along the longitudinal axis of the pear
97 fruits. For UV-C experiments, pear disks were kept on sterile Petri dishes with epidermal surface
98 facing up. For experiments involving wounding, a sterile needle was used to produce a wound (2
99 mm diameter and 1 mm deep) on the surface equatorial zone of disks. On intact surfaces and
100 wounded surfaces, 0.5 mL of conidial suspension was spot inoculated. For wounded surfaces, at
101 first, the conidial suspension was directly introduced to the wounds and then the remaining
102 suspension was spot inoculated and spread. UV-C treatments were conducted 15 minutes post-
103 inoculation.

104 The inoculated disks were treated inside a UV-C Emitter™ table-top System (Reyco Systems,
105 Meridian ID) comprised of two Steril-Aire™ 16SE food-grade, shatter resistant, sleeved UVC
106 Emitters™ at a wavelength of 254 nm at 23°C. During the UV-C treatments, the UV-C emitters
107 were 0.1 m above the pear disks. A UV radiometer (EIT UVICURE PLUS II, EIT, Inc., Sterling,
108 VA) was used to measure the UV-C intensity and power for each treatment time. The UV-C
109 intensity values were calculated as 0.21, 0.43, 0.64, 1.2, 1.7, 2.1 and 3.1 kJ/m^2 corresponding to
110 treatment times of 10, 20, 30, 60, 90, 120, and 180 sec. The UV-C treatment times can be
111 reduced by adding more number of UV emitters to the system or by reducing the distance
112 between the emitters and the fruits thus increasing the UV intensity/dose. Disks that were
113 inoculated but not treated with UV served as controls for measuring the efficacy of inoculation

and effectiveness of UV treatments. UV-C treatments were performed inside a Class II laminar hood and three UV-C experiments were conducted for each treatment time.

The surfaces of the inoculated and non-inoculated pear disks were rubbed by hand with 100 mL of sterile water (Becton, Dickinson and Co., Cockeysville, MD) inside sterilized stomacher bags (Stomacher® 400 CIRCULATOR, Seward Laboratory Systems Inc. Port Saint Lucie, FL) for 3 minutes to quantify the *P. expansum* conidia on the surface. A 100 µl portion of the supernatant was collected and mixed with 900 µl sterile water and serially diluted. Later, triplicate samples of 100 µl diluted sample were spread on potato dextrose agar (TSA, Hardy Diagnostics, Santa Maria, CA). After UV-C experiments, the agar plates were incubated for 72-96 h at 23°C and colony forming units (CFU) were counted.

UV-C inactivation kinetics

The UV-C inactivation kinetics data were fitted using zero-, first-, second-order reaction kinetic, and Weibull equations. The general equation describing microbial inactivation is

$$-\frac{dN}{dt} = kN^n \tag{1}$$

where N is the number of surviving *P. expansum* conidia after UV-C treatment time t (or dose), k is the inactivation rate constant and n is the order of inactivation (Cunha et al. 1998). The Weibull equation is

$$N = N_o \exp\left[-\left(\frac{t}{\alpha}\right)^{\gamma}\right] \tag{2}$$

Where N is the number of surviving conidia after UV-C treatment time t (or dose) N_o is the initial number of conidia, α is the scale factor and γ is the shape parameter determining the shape of the curve. The values of α and γ are determined by non-linear optimization by Statistica®

135 version 5 computer program. The Weibull parameters were used to determine the reliable life
136 time/dose (t_R), which is the time/dose required for 90% reduction in the number of target
137 microorganism (Van Boekel, 2002). The value of t_R can be determined as:

138 $$t_R = \alpha \left(2.303\right)^{\frac{1}{\beta}} \quad (3)$$

139 *Physicochemical parameters of pears*

140 To investigate the influence of UV-C treatment on physicochemical and sensory quality of pears,
141 entire fruits were treated at dose of 2.1 kJ/m^2 corresponding to 3.5 log reduction of *P. expansum*.
142 The pear surface was exposed to UV-C light by rotating the fruit after half the treatment time.
143 Untreated pears served as control. Treated and untreated pears were stored in two separate
144 cartons under identical conditions. The temperature and relative humidity conditions inside the
145 two cartons were not significantly different during the storage. The selected physicochemical
146 parameters of pears were weight loss, total soluble solids, color, texture and sensory quality.
147 These parameters of treated and untreated pears were monitored immediately after UV-C
148 treatment and after 4 and 8 weeks of storage at 4°C.

149 Three pears from each lot of UV-treated and untreated pears were used to determine weight
150 loss at two week intervals during eight weeks of storage. Results were expressed as percentage of
151 weight loss relative to the initial weight. Tristimulus color characteristics of UV treated and
152 untreated pears during storage was evaluated using a Minolta Chroma CR-200 color meter
153 (Konica Minolta Sensing Americas, Inc. Ramsey, NJ) to determine L^* value (lightness of color
154 from zero (black) to 100 (white); *a* value (degree of redness (0 to 60) or greenness (0 to -60); and
155 *b* values (yellowness (0 to 60) or blueness (0 to -60). An overall color measurement was
156 obtained by taking 3-4 measurements on each fruit (N=10) tested.

157 The total soluble solids (TSS) content calculated as g/100 mL in duplicate measurements from
158 two pears for UV treated and untreated pears (N=4) was determined using a pocket PAL-1
159 refractometer (Atago USA. Inc. Bellevue, WA). Compression tests of pear cubes ($1cm^3$) (N = 8)
160 were carried out by using a texture analyzer (TA-XT2 Texture analyzer, Stable Microsystems
161 Ltd, Surrey UK) at 23°C. The texture analyzer was in compression mode, and connected to a 250
162 N load cell. Uniaxial compression was performed against a horizontal plate fixture. The test was
163 then performed with pre- and post-test speeds of 3 mm/s, a test speed of 1 mm/s, and a 5 g auto-
164 trigger force. UV treated and untreated pear cubes were cut after peeling and the cubes placed on
165 the plate. Four replicates of pear cubes perpendicular to the axis core were compressed and the
166 average force and work required to cause 50% deformation were determined on the basis of
167 force-deformation curves (Bondaruk et al. 2007). Hardness (peak force of the second
168 compression cycle in N) and adhesiveness (negative area under the baseline between the
169 compression cycles in Ns). The ratio of the positive force areas during the second and first
170 compression was considered as the cohesiveness. Springiness is defined as the inverse of the
171 ratio of duration between beginning of the first area and first probe reversal and duration
172 between beginning of the second area and second probe reversal (Alvarez et al., 2002).
173 *Sensory Analysis*
174 Sensory analysis of UV-C treated and untreated pears during storage was conducted to identify
175 whether consumers (N = 60) could tell the difference between the UV-C treated and untreated
176 (control) based upon certain sensory attributes, and whether these consumers preferred the UV-C
177 treated or the untreated (control) pear. Pears were stored in boxes at ~4°C in the Washington
178 State University, School of Food Science pilot plant. Sensory evaluation was conducted at the
179 WSU School of Food Science sensory facility in Pullman, WA. Untrained sensory panelists were

180 from a diverse ethnic backgrounds and ages ranged from 18 to 65 year.

181 Sensory testing was conducted in the WSU School of Food Science sensory laboratory on
182 three separate days (0, 4 weeks and 8 weeks of storage). For all sensory testing, consumers were
183 provided with reagent grade deionized water and unsalted-top saltine crackers for rinsing the
184 palate. On the evaluation day, pears were removed from cool storage two hours before testing to
185 equilibrate to room temperature. Pears were cut into ¼ pieces with knife and one piece of pear
186 was place on the 6-inch paper plates prior to serving. Pear samples were assigned a 3-digit
187 random code. Each panelist (N = 60) received 1 flight of samples to make the following blind
188 comparison: UV-C treated vs. untreated (control). The order within each comparison was
189 randomly determined.

190 A paired comparison test was used to evaluate the differences between samples. Specifically,
191 consumers were asked to indicate their overall preference based on appearance. Consumers were
192 then asked to indicate the sample with more intense 1) pear flavor, 2) sweet taste, and 3) sour
193 taste. Texture attributes were also examined and consumers were asked to indicate the sample
194 with 1) more firm and 2) more crisp. Also, the panelists were asked to comment on their
195 preference of one sample over the other. Results were collected by Compusense®*five* software
196 (Compusense Inc., Guelph, ON). Data were analyzed using results published in Roessler et al.
197 (1978) and significance was reported at $P \leq 0.05$.

198 *Statistical analysis*

199 The data for inactivation of *P. expansum* by UV-C and the physicochemical quality changes
200 during storage were analyzed for statistical significance using SAS 9.1 (SAS Institute, Inc., Cary,
201 NC). The experiment involved a completely randomized design with two-way ANOVA by
202 Fisher's Least Square Difference (LSD) method where a value of $P < 0.05$ was selected as

statistically significant. Two-way ANOVA analysis was conducted to find out significant two-way interaction between UV-C treatment time and type of surface (intact pears and wounded pears) on logarithmic reduction in *P. expansum* population. Storage time and treatment (UV-C treated or untreated) were the two factors considered for the two-way ANOVA analysis in the case of physicochemical quality analysis. Statistical differences in logarithmic reduction in *P. expansum* population are not presented in the results where significant interaction between UV-C treatment time and type of surface was observed. Also, statistical significances in physicochemical quality are not shown in results where a significant interaction between storage time and treatment (UV-C treated or untreated) was observed.

Results and Discussion

UV-C inactivation kinetics

The average population of *P. expansum* on intact and wounded pear surfaces before UV-C treatment was ~5.7×10^5 CFU/g. After UV-C treatment, the population of *P. expansum* was significantly reduced on intact and wounded pear surfaces ($P < 0.05$) (Figure 1, Table 1). No significant interaction between treatment surface (intact pear and wounded pear) and treatment time was observed ($P \geq 0.05$). The level of *P. expansum* inactivation was similar during first 60 seconds of UV-C treatment. For example, during the first 30 seconds of UV-C treatment (equivalent to 0.64 kJ/m^2 UV-C dose), the number of *P. expansum* conidia rapidly decreased by 1.7 and 1.6 log on intact and wounded surfaces respectively (Table 1). With increasing treatment times, greater reduction of *P. expansum* was observed at intact pear disk then wounded disk. For example, a significantly ($P<0.05$) greater inactivation of *P. expansum* by UV-C was observed on intact pear surface with a 2.8 log CFU/g reduction after UV-C treatment for 1.7 kJ/m^2 (treatment

226 time corresponding to 90 seconds) while a 2.7 log reduction was observed on wounded pear after
227 3.1 kJ/m^2 (treatment time 180 seconds) treatment (Table 1). Surface characteristics of pear
228 showed an impact on the efficacy of UV-C in inactivating microorganisms. The wound on the
229 pear surface acts as a shield to partially protect the *P. expansum* cells during the UV-C exposure
230 (Syamaladevi et al., 2013).

231 Studies on UV-C inactivation kinetics of molds on fruit and vegetable surfaces are limited,
232 however there a few studies reporting the effectiveness of UV-C in inactivating fungi on various
233 food surfaces such as figs, fresh cut apple slices, and blueberries. UV-C treatment reduced 1.5
234 log of *Rhodotorula mucilaginosa* population on fig fruit (Hamanaka et al. 2011). Mercier et al.
235 (2001) reported that UV-C was effective in inactivating *Botrytis cinerea* on bell peppers at 2.2
236 and 4.4 kJ/m^2 intensities in a post-inoculation (24 h) UV-C treatment. Rodov et al. (2010)
237 observed about 30% of the inoculated peeled onion bulbs treated with the UV dose of 1.2×10^3
238 J/m^2 remained healthy after 5 days storage in comparison to the untreated onion bulbs.

239 A non-linear Weibull model was used to fit the *P. expansum* inactivation kinetics by UV-C
240 treatment on intact and wounded pears (Figure 1). The Weibull parameter α obtained for UV-C
241 inactivation on intact pear surface and wounded pear were 1.62 sec (0.096 kJ/m^2) and 1 sec
242 (0.085 kJ/m^2), respectively. Syamaladevi et al. (2013) reported the α values for UV-C
243 inactivation kinetics of *Escherichia coli* (ATCC 23716) on intact pear, wounded pear and peach
244 surfaces as 0.06 sec (0.002 kJ/m^2), 0.18 sec (0.007 kJ/m^2) and 0.12 sec (0.005 kJ/m^2)
245 respectively. A greater value for reliable life time (t_R) of 9.77 sec (0.24 kJ/m^2) was observed for
246 UV-C inactivation kinetics of *P. expansum* on the wounded pear, presenting a lower inactivation
247 rate of *P. expansum* in comparison to the intact pear surface (9.56 sec, 0.23 kJ/m^2). A greater
248 survival of *E. coli* was observed on wounded pear surfaces compared to the intact pear surface

249 indicating, the UV inactivation kinetics of *E. coli* and *P. expansum* is dependent on the surface
250 morphological characteristics of the fruits (Syamaladevi et al. 2013). Due to the limited
251 penetration of UV-C into the tissue, a greater survival could be possible for the *P. expansum* at
252 the interstitial spaces and wounds of pear tissue (Syamaladevi et al., 2013).

253 *Physicochemical changes during storage*

254 The % weight loss in untreated pear fruits was 1.3 and 2.8% after 4 and 8 weeks, respectively.
255 For UV-C treated pear fruits, the % weight loss was 1.4 and 3.1% after 4 and 8 weeks,
256 respectively. Manzocco et al. (2011a) reported a significant difference in weight loss between
257 untreated and UV-C treated cut apple slices due to dehydration during intense UV-C treatment
258 with 20W/m^2 UV-C light at 6^{o}C and 90% ERH for 2 h. However, in the present study no
259 statistical difference in % weight loss between untreated and UV-C treated pear was observed
260 during storage ($P \geq 0.05$).

261 Significant interaction between treatments (untreated or UV-C treated) and storage time was
262 observed on soluble solids content values of pear fruits during storage. A slight decrease in
263 soluble solids content value of untreated pear fruits was seen, i.e., the soluble solids content
264 decreased from 14.2 (control) to values of 13.1 and 13.7 after 4 and 8 weeks, respectively (Table
265 2). In the case of UV-C treated pears, a slight increase in soluble solids content to 14.4 after 8
266 weeks storage from initial value of 13.1.

267 A significant two-way interaction ($P < 0.05$) between treatment (untreated or UV-C treated)
268 and storage time on change in L^* value during storage was observed i.e. the change in L^* value
269 during storage was depended on both storage time and effect of treatment (whether UV-C treated
270 or untreated). UV-C treatment reduced the L^* value of pears significantly during storage ($P <$
271 0.05). The degree of lightness (L^* value) of the untreated pears decreased 2.5% after 4 weeks

storage and increased 4.6% after 8 weeks storage in comparison to the untreated fresh pear (control) (Table 3). The increase in degree of lightness after 8 weeks of storage was due to the color change during the ripening of pears. However, we observed browning and a decrease in L^* value after 4 weeks (2.5%) and 8 weeks (5%) storage in UV-C treated pears, in comparison to treated pears (control) (Table 3). Browning during storage after UV-C treatment, also observed in peaches, mushroom and baby spinach, could be due to cell damage and respiratory stress (Gonzalez-Aguilar et al. 2004; Escalona et al. 2010; Guan et al. 2012). Nigro et al. (1998) also observed browning and spot formation on the skin of table grape berries during storage of 7-10 days after UV-C treatment with 1 kJ/m^2 or higher. The *a* value (degree of greenness or redness) increased (10 and 36% after 4 and 8 weeks, respectively for untreated and 19.1 and 49.2 after 4 and 8 weeks, respectively for UV-V treated pear fruits) implying the pear fruits became less green during storage due to ripening. A significant difference in greenness or *a* value of untreated and UV-C treated pears was observed after 8 weeks storage ($P < 0.05$). We observed significant interaction ($P < 0.05$) between treatment and storage time on change in *b* value during storage. The untreated pears became significantly ($P < 0.05$) more yellow (with 4.5% and 10.6% increase in *b* value or degree of yellowness after 4 weeks and 8 weeks, respectively) compared to the untreated fresh pear (control) at 0 days. However, the yellowness of UV-C treated pears increased less (only 2.3 and 2.2%, after 4 weeks and 8 weeks, respectively) compared to the UV-C treated fresh pear (control) at 0 days. Obande et al. (2011) observed a delay in ripening and reduced color change from green to red in tomato treated with UV-C at a dose of 8 kJ/m^2.

Texture Analysis

Statistical analysis showed a significant two-way interaction ($P < 0.05$) between treatment and storage time on change in hardness of untreated and UV-C treated pears during storage was

observed. In the case of solid foods such as pear fruit, hardness may be considered as the necessary force to compress when placed between molar teeth which may be related to firmness in sensory evaluation (Bourne, 2002). The hardness values of UV-C treated and untreated pears were not significantly different during storage ($P \geq 0.05$). The % decrease in hardness of the untreated pears from control (at 0 days) were 56.7 and 90.2% while for the UV-C treated pears, the % decrease were 67.2 and 81.8% after 4 and 8 weeks, respectively (Table 4). The decrease in hardness of both untreated and UV-C treated pears during storage may be attributed to cell wall degradation, loss of turgidity and water loss during ripening. The adhesiveness (which is the necessary force to remove pear fruit material which adheres to the mouth) between untreated and UV-C treated pear fruits did not change significantly during the storage ($P \geq 0.05$) (Table 4). No significant difference in texture parameters such as springiness (ability to recover), cohesiveness (degree of cohesion between the particles), and chewiness (necessary energy for mastication of food) was observed between untreated and UV-C treated pears after 8 weeks storage ($P \geq 0.05$) (Table 4). However, springiness, cohesiveness, and chewiness changed significantly after 8 weeks storage for both untreated and UV-C treated due to ripening in comparison to the untreated and UV-C treated fresh pears at 0 days storage (control) ($P < 0.05$) attributed to the metabolic activities during ripening and structural changes in fruits during storage. Manzocco et al. (2011a) observed no significant difference in firmness between untreated and UV-C treated cut apple with 20W/m^2 UV-C light at 6^{o}C and 90% ERH for 2 h.

Sensory analysis

Application of the UV treatment did not substantively change the sensory properties of the pears as no significant differences were found between the UV-C treated and untreated pears at zero days of storage, (Table 5). After 4 weeks of storage, the untreated control pears were more

318 preferred overall and also based on their appearance ($P < 0.05$). The browning observed on the
319 UV-C treated pear fruits likely influenced the panelist's preference. The untreated control pears
320 were also found to be superior in flavor and were sweeter compared to the UV-treated pears.
321 This is in contrast to results reported by Manzocco et al. (2011b) in which higher flavor score for
322 UV-C treated cut melon was observed in comparison to the control. The sweetness of the
323 untreated pear was greater than UV-C treated pear after 4 weeks storage but lower after 8 weeks,
324 as observed by panelists (Table 5). The sweetness of the pear fruits may be related to amount of
325 soluble sugars, expressed as soluble solids content. For UV-C treated pear, the soluble solids
326 content value was greater than untreated pear after 8 weeks storage (Table 5). A texture
327 difference was observed after 4 weeks in that the UV-treated pears were more crisp compared to
328 the untreated control pears (Table 5). No significant difference in firmness between untreated
329 and UV-C treated pears was observed during storage (Table 5). Firmness of peaches was also
330 retained during storage after UV-C treatment due to polyamine formation (Gonzalez-Aguilar et
331 al. 2004). Further, UV-C treatment retained the firmness, and delayed the firmness loss and
332 senescence in mushrooms, and fresh-cut cantaloupe melon during storage at 20^{o}C (Lamikanra et
333 al. 2005; Jiang et al. 2010). However, we did not observe a correlation between instrumental
334 hardness and sensory firmness of pear slices during storage. After 8 weeks of storage, fewer
335 differences in sensory properties of treated and untreated pears were noted compared to the 4
336 weeks of storage. The untreated pears were still more preferred based on appearance ($P < 0.05$)
337 but the other differences between pears were no longer significant. The only other difference
338 noted was the untreated pears were now found to be crisper than the UV treated pears ($P < 0.05$).
339 The impact of UV treatments varies with the storage time. Sensory differences were observed
340 between the UV treatment and the control after 4 weeks were more pronounced than after 8

weeks of storage, including a difference in overall preference. The untreated pears were preferred for appearance at both storage times (4 weeks- 42 panelists and 8 weeks-37 panelists) but there was a decrease in the number of panelists who had differences in preference. The problem of surface browning may be a limiting factor for application of UV-C for disinfection of D'Anjou pears.

Conclusions

UV-C reduced the *P. expansum* population significantly on intact and wounded pear surfaces. The physicochemical and sensory quality parameters in untreated and treated pears were not significantly different immediately after the UV-C treatment. No significant difference in % weight loss, soluble solids content and texture parameters was observed between untreated and UV-C treated pear fruits. However, the color parameters were significantly different on pear fruits due to browning caused by UV-C treatment. Significant differences in sensory parameters were observed between untreated and UV-C treated pear fruits at 4 weeks storage. However, many of those differences were not noticeable after 8 weeks storage. These results indicated that UV-C technology can be a useful in reducing *P. expansum* on fruit surfaces; however, color and sensory qualities of some fruits may be affected by the UV-C treatment during storage.

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447
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LIST OF FIGURES

TABLES

Table 1. Average logarithmic reduction levels of *P. expansum* on pear surface (N = 9)

Time (sec)	UV dose (kJ/m^2)	Log reduction	
		Intact surface	Wounded surface
0	0	0^{a}	0^{a}
5	0.10	0.36 ± 0.3^{ab}	-
10	0.21	0.71 ± 0.4^{abcd}	-
15	0.31	-	1.2 ± 0.5^{bcde}
20	0.43	1.4 ± 0.4^{cdef}	-
30	0.64	1.7 ± 0.5^{hi}	1.6 ± 0.3^{defg}
60	1.2	2.2 ± 0.4^{hi}	2.3 ± 0.2^{fgh}
90	1.7	2.8 ± 0.3^{hi}	-
120	2.1	-	2.5 ± 0.1^{gh}
180	3.1	-	2.7 ± 0.3^{hi}

Different superscripts in rows and columns represent statistical significant differences between log reduction values in number of *P. expansum* conidia obtained at selected UV doses ($p < 0.05$).

Table 2. Soluble solids content of untreated and UV-C treated pears during storage (N = 4)

Sample		Soluble solids content (g/100 mL)
0 days	Untreated	14.2±1.1
	UV-C treated	13.1±0.3
4 weeks	Untreated	13.1±0.3
	UV-C treated	13.1±0.9
8 weeks	Untreated	13.7±0.2
	UV-C treated	14.4±0.9

Table 3. Color change in untreated and UV-C treated pears during storage (N = 10)

Sample		L^*	a	b
0 days	Untreated	66.1±3.0	-16.2±1.1	38.7±0.8
	UV-C treated	64.1±2.0	-16.5±1.0	38.8±1.5
4 weeks	Untreated	64.4±4.2	-14.5±1.6	40.5±2.2
	UV-C treated	62.5±3.5	-13.4±2.5	39.7±1.6
8 weeks	Untreated	69.1±3.3	-10.3±0.9	42.9±0.9
	UV-C treated	60.9±4.6	-8.4±2.8	39.7±2.4

Table 4. Texture changes in untreated and UV-C treated pears during storage (N = 8)

Sample		Hardness (N)	Adhesiveness (N.s)	Springiness	Cohesiveness	Chewiness
0 days	Untreated	69.0±19.5	-0.10±0.06^{ab}	0.63±0.07^{a}	0.22±0.09^{a}	9.3±2.4^{a}
	UV-C treated	58.2±18.5	-0.07±0.03^{a}	0.60±0.07^{a}	0.19±0.04^{a}	7.0±3.5^{b}
4 weeks	Untreated	29.9±11.1	-0.12±0.05^{b}	0.51±0.05^{b}	0.15±0.03^{bc}	2.3±1.2^{c}
	UV-C treated	19.1±5.3	-0.12±0.05^{b}	0.47±0.05^{bc}	0.15±0.02^{b}	1.4±0.7^{cd}
8 weeks	Untreated	6.8±1.5	-0.09±0.04^{ab}	0.37±0.05^{d}	0.10±0.02^{d}	0.25±0.09^{d}
	UV-C treated	10.6±3.8	-0.08±0.03^{ab}	0.42±0.08^{cd}	0.11±0.02^{cd}	0.49±0.20^{d}

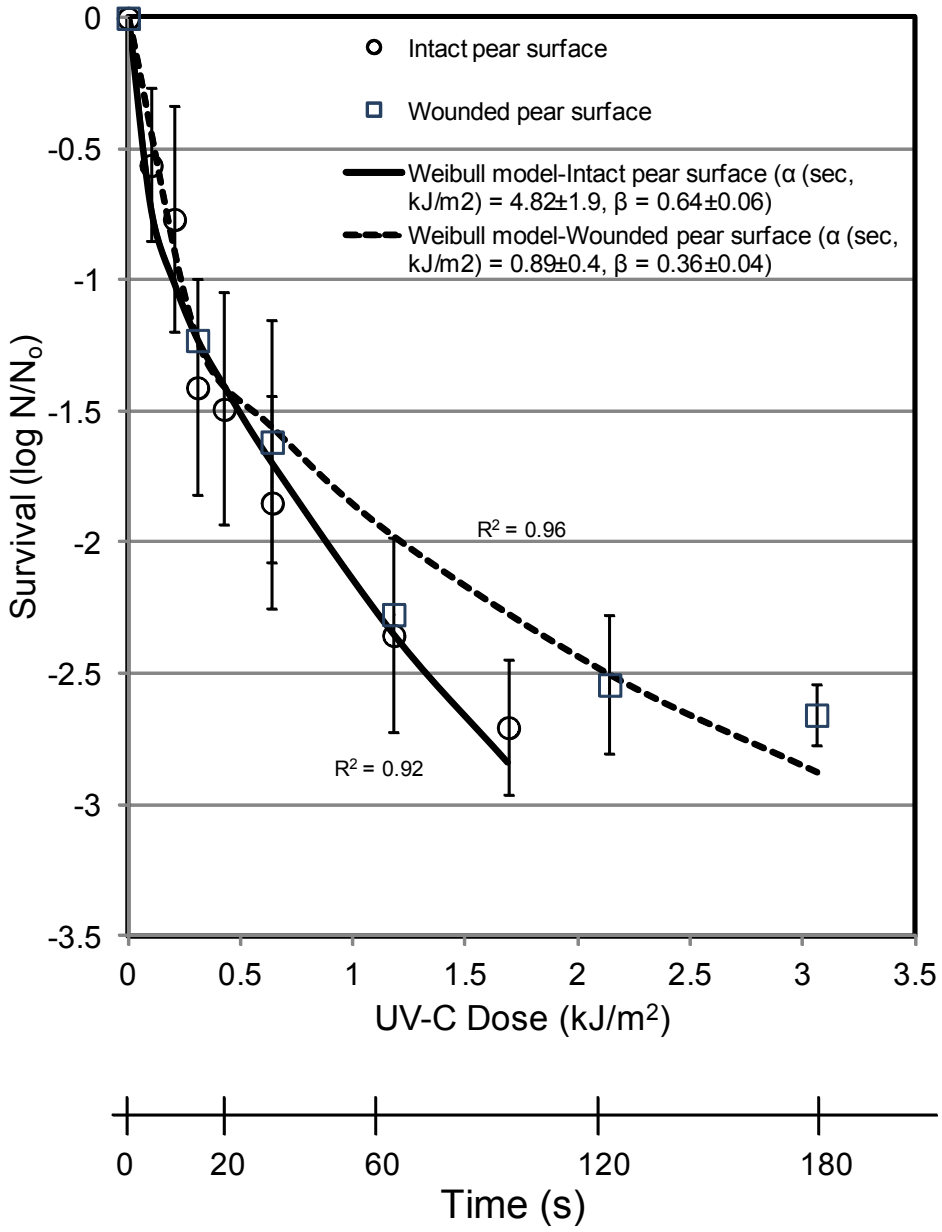
Different superscripts represent statistically significant different values column-wise ($p < 0.05$) between texture parameters in UV-C treated and untreated pears during storage.

Table 5. Untrained panelists (N = 60) score indicating the more preferred sample for appearance and more intense attributes in a pair comparing UV-treated and untreated pears at 0 days of storage.

	0 days		4 weeks		8 weeks	
Attribute	UV-C treated	Untreated	UV-C treated	Untreated	UV-C treated	Untreated
Appearance preference	28	32	18	42*	23	37*
More intense pear flavor	35	25	23	37*	29	31
More intense sweet taste	30	30	21	39*	36	24
More intense sour taste	25	35	34	26	26	34
More crisp	26	34	37*	23	23	37*
More firm	25	35	35	25	27	33
Overall preference	29	31	21	39*	28	32

A * indicates significance at $p<0.05$ between sensory attributes of UV-C treated and untreated pears at each sensory evaluation time.

Figure 1


Intact pear surface
Wounded pear surface
Weibull model-Intact pear surface (α (sec, kJ/m2) = 4.82±1.9, β = 0.64±0.06)
Weibull model-Wounded pear surface (α (sec, kJ/m2) = 0.89±0.4, β = 0.36±0.04)
R² = 0.96
R² = 0.92
Survival (log N/N₀)
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
0
0.5
1
1.5
2
2.5
3
3.5
UV-C Dose (kJ/m²)
0
20
60
120
180
Time (s)