UNIVERSITY OF CALIFORNIA, DAVIS
Crocker Nuclear Laboratory
Chemistry & Agriculture Program

FINAL REPORT
FONTEC PROJECT 97-1108

"Development of Pulsed UV Commercial Processes for Fruits and Vegetables"

by

Manuel C. Lagunas-Solar, Ph.D.
Principal Investigator
Crocker Nuclear Laboratory
University of California, Davis

August 11, 1999

ACKNOWLEDGEMENTS

In the execution of this project, the author wishes to acknowledge the support and participation of Mr. Rodrigo López Ulloa, ICC S.A., General Director of the project.

In the preparation of this Final Report, the author acknowledges the input and participation of the following scientific collaborators from the University of California, Davis:

- **Microbiology**

(1) Dr. James D. MacDonald, Department of Plant Pathology

(2) Ms. Linda Bolkan, Department of Plant Pathology

- **Fruit Quality**

(1) Dr. Elizabeth Mitcham, Department of Pomology

(2) Dr. Tayfun Agar, Department of Pomology

(3) Mr. William Biasi, Department of Pomology

- **Entomology**

(1) Dr. Jeffrey Granett, Department of Entomology

(2) Dr. Amir Omer, Department of Entomology

In addition, the assistance of Ms. Krystyna Trzepla-Nabaglo (Crocker Nuclear Laboratory) and of Ms. Cecilia Piña Ulzurrún, a Visiting Scientist from the Catholic University of Valparaíso, Chile, are greatly appreciated.

The author wishes to specially thank the support of the Chilean Exporters Association, and the participation of its Technical Committee, including the scientific consultants Dr. Julio Retamales and Dr. Roberto H. Gonzalez, for the many useful and enlightening discussions on the many different aspects of this project.

Finally, the author acknowledge the support of the Crocker Nuclear Laboratory and its Director, Dr. Robert G. Flocchini.

Table of Contents

EXECUTIVE SUMMARY

Since 1991, pulsed UV (PUV) techniques are being developed at the University of California, Davis for several applications in the areas of biomedicine, environmental sciences, and food & agriculture. This particular report summarizes a research & development effort in the area of fresh produce, in which PUV is being evaluated to allow for a non chemical control of spoilage and pathogenic organisms, particularly fungus, and for controlling insects and/or mites of quarantine importance.

Experimental protocols for this project were established and the general planing and strategy were agreed in consultation and with the collaboration of the Chilean Exporters Association (CEA) Technical Committee. On the other hand, experiments were conducted with expert support from various Departments of the University of California, Davis. Experiments included microbiological, fruit quality, and entomological aspects.

The results and conclusions of this project include:

Microbiological Aspects:

(1) In laboratory scale, PUV photons at 248 nm were demonstrated to be quite effective in controlling a variety of fungal spores with low energy doses ranging from 15 to 3,000 mJ/cm^2 (see Table B (page 28) and Figure 1 (page 29). As shown in these results, (*Alt. alternata* with/without stirring) access of the targeted spores to PUV photons is critical and a determining factor in the overall process efficiency.
(2) On the surface of fruits, however, the low penetrating PUV photons did not reach, in the majority of cases, a large proportion of the naturally present and/or the inoculated fungal spores. During experimentation, effective microbial control could not be excersized due to limitations in PUV light source geometry and the lack of adequate material handling techniques used on the targeted commodities (i.e. static or rotating targets were used). Due to the large number of treated samples for each experiment (several hundred to assure statistical validity of results) no other material handling approach was available.
(3) All microbiology experimentation was conducted using conventional microbial assay methodology, which results in qualitative rather than quantitative microbial information. Therefore, there was no indication of the fraction of spores controlled by PUV versus those not inactivated. Therefore, all the observations conducted to determine controlling effects were masked by the growth of the remaining flora as well as by the invasion of natural flora present on untreated surfaces or from within the fruit surface. This was a consisting observation made by expert collaborators. Although observed and predicted from the initial experiments, this limitation could not be overcome with the available experimental PUV resources.
(4) Other research being conducted at UC Davis and involving many of the same scientific collaborators, have demonstrated PUV efficiency to inactivate pathogens in different solid and liquid media. However, PUV is not able to control any internal contamination.

Fruit Quality Aspects

(1) Chemical and physiological measurements, and sensory observations for 11 different commodities were made. These results are summarized in Appendix 1 (Tables 1A to 22)

(2) For O'Henry peaches, two PUV doses resulted in few measurable but not significant differences with no established trends. PUV samples after 30-day storage showed an increased respiration and ethylene production with time at 20°C. A third higher PUV dose, with Autumn Flame peaches resulted in external injury but no other effect (see Table 1B, Appendix). No weight losses were observed.
(3) August Red nectarines showed not significant effect of PUV on most properties (see Table 3, Appendix). Soluble Solid Concentration (SSC) showed variations with no consistent trend. Control samples and treated showed external browning likely due to handling.
(4) Raspberries showed no significant effects except for Titratable Acidity (TA) and color development although with no clear trend. These changes were considered as not commercially significant.
(5) Red Globe grapes showed no effect on SSC, TA, pH, external color, weight loss, and external or internal condition (see Table 6 & 22, Appendix). Berry firmness and respiration rates varied but with no established trend. Control and PUV treated samples showed rachis browning and berry shatter so no conclusion could be reached.
(6) Thompson Seedless grapes showed no effects on TA, external or internal berry condition, weight loss, or berry shatter (see Table 8 & 22, Appendix). Berry firmness were somewhat different but with no trend with PUV doses. SSC and pH showed some differences with no identifiable trends. Rachis browning increased with time in both control and PUV treated samples. Therefore, no conclusions on this cosmetic aspect can be reached.
(7) Granny Smith apples showed no effect on firmness, SSC, TA, pH, skin color, internal condition or decay (see Table 10, Appendix). The highest PUV dose showed some effect on external injury but other PUV doses were no different from controls. Some variations in weight losses were observed initially (after treatment) in all PUV treatments but the differences were not detected or not significant after prolonged storage. Granny Smith showed the only weight losses among all pome fruits studied (see Table 22, Appendix).
(8) Red Delicious apples showed no effect on firmness, SSC, external or internal condition, decay or weight loss (see tables 12 & 22, Appendix). Some variations of pH, skin color, TA, and respiration were detected but no trend was established.
(9) Fuji apples showed little significant effect in fruit quality (see Table 14, Appendix). Some variations in pH were detected but with no established trend. PUV had no effect on weight loss, respiration rate or ethylene production.
(10) Bosc pears showed no response to PUV treatments in firmness, SSC, TA, pH, external or internal condition, weight loss, decay, respiration rate or ethylene production (see tables 16, 17 & 22, Appendix). Some pH changes were detected but no trend was established.
(11) Hayward Kiwifruit showed no PUV effects on juice pH, external or internal injury, decay, weight loss, respiration rate or ethylene production (see tables 18,19 & 22). Firmness varied during the observations periods as compared to controls. SSC and TA detectable differences in some observation periods showed no established trends.
(12) Eureka lemons showed no effects on SSC, TA, decay, weight loss and ethylene production (see Tables 20, 21 &22, Appendix). Immediately after PUV treatment, fruit respiration was slightly higher but after storage. Severe skin damage was observed in all PUV treated samples.

For the most part, the detected variations in all fruits (except for skin damage to lemons) were considered to be within the ranges of commercial fruit quality and therefore, of no commercial significance.

Entomological Aspects

(1) PUV applied to the surface of insects and/or mites does cause instant and delayed mortality depending on PUV dose and PUV energy fluence. The PUV induced effect is independent on repetition rate. PUV photons at 248 nm are more effective than 308 nm photons
(2) All biological stages are affected. In the mobile phases, adults were found to be more resistant than juveniles. Eggs were determined to be the most sensitive phase (see section 3.2, page 50 and following).
(3) For *Pseudococcus sp.* (Grape Mealy bugs) instant mortality was observed only when PUV doses approached 10 J/cm^2, an energy level that appears excessive for most fruits (see Table E, page 48).
(4) For *Brevipalpus sp.,* instant and delayed mortality were achieved with < 1 J/cm^2 PUV energy levels at 248 nm (see Figures 4, 5, & 6, section III, pages 51 and 52) and slightly higher (< 1.5 J/cm^2) for 308 nm photons (see Figure 7, section III, page 53). These PUV energy levels appeared to be adequate to treat most fresh fruits with only minor effects. These effects, although detectable, were found to be of no commercial significance.
(5) For *Frakliniella occidentalis* (Western Flower Thrips), instant mortality effects were achieved in adults at 2 J/cm^2 levels with 248 nm (see Table D, page 61; and Figure 16, page 62). However, 100% mortality (instant + delayed) was achieved within 24 h after a 3 J/cm^2 PUV exposure.

PUV Technology Aspects

(1) PUV techniques were confirmed to be efficient in controlling spoilage and pathogenic microbial contamination on different solid and liquid media. However, on the surface of most fruits, effective microbial control was not achieved due to several limitations on the PUV light source and the lack of an appropriate mode to present the fruit for proper PUV illumination.
(2) All experimentation in this project was conducted with excimer laser photons at 248 nm (KrF mode) and 308 nm (XeCl form). These photons were monochromatic pulses of 20 ns duration delivered with repetition rates ranging from 1 to 60 Hz (pulses per second). Therefore, the PUV light source delivered photons onto the surface of fruits only in a perpendicular or unidirectional mode. No optical (mirrors, lenses) or mechanical (deflectors) techniques were used to provide multi-directional photon fluxes nor any fruit handling mode was used to assure multidirectional exposure onto the surface.
(3) The results strongly suggest the use of a non coherent pulsed UV light source coupled with an appropriate fruit handling technique to assure photons to interact with the whole (100%) fruit surface from multiple directions. Because light photons move in a straight line from its source, optical mirrors and deflectors must be incorporated into an overall PUV treatment system to assure uniform and multidirectional exposure of fruit surfaces.
(4) For most fruits, an effective PUV treatment requires proper PUV energy (< 2 J/cm^2 for most fruits), controlling PUV fluence (< 10 mJ/cm^2/pulse), and is independent of repetition rate.
(5) A conceptual design for a Modular PUV Illumination System was developed (see Section V, part 5.5.1, page 70; and Figure 18, page 71). This system can be constructed and tested by integrating commercially available components.

August 15, 1999
Davis, California

I. INTRODUCTION

The potential for the commercial scale use of the pulsed UV technology developed and patented by the University of California (US Patents # 5,364,645 and # 5,607,711), is being investigated since 1994, in a research collaboration between the Chilean Exporters Association (CEA) and the University of California, Davis (UCD). Sponsorship of the Chilean government through programs such as FONDEF (FONDEF 2-63 Project completed in December 1996 and later this FONTEC project (FONTEC 97-1095) have been involved in the investigation phase.

This report summarize the data and results, and discuss the conclusions reached during the investigation on the effects of pulsed UV techniques on a variety of fresh fruits, and on the viability of selected insects and mites exposed. This project was recently completed at the University of California, Davis, under research agreement 98K343 and the general administration of ICC, S.A., Santiago, Chile.

A variety of commercial quality fruits originated in California and provided to this project by arrangements made on behalf of CEA were used to perform and document the following studies:

(1) Microbiology, that is to determine the effectiveness of the PUV method to control surface microbes, in particular fungi (see Section II: Microbiology Experimentation).

(2) Food Quality, in which the potential of the PUV method to induce sensory and physiological changes in various conditions were established (see Section III, Fruit Quality Experimentation); and

(3) Entomology, in which several insects and mites were used as models to establish the potential of PUV to provide disinfestation effects (see Section IV: Entomology Experimentation).

Under the general leadership and supervision of Dr. Manuel Lagunas-Solar, Principal Investigator, research was conducted by expert scientists in the field using the resources available at the Davis Campus of the University of California.

The following were the research team which collaborated in this project:

(1) Microbiology: Dr. James D. MacDonald (Department of Plant Pathology), assisted by Ms. Linda Bolkan, Staff Research Associate;

(2) Food Quality: Dr. Elizabeth J. Mitcham (Department of Pomology), assisted by Dr. Tayfun Agar (Post Doctoral Fellow) and Mr. William Biasi (Staff Research Associate); and

(3) Entomology: Dr. Jeffrey Granett (Department of Entomology), assisted by Dr. Amir Omer, Post Doctoral Fellow.

PUV treatment of all samples were conducted under the guidance and leadership of Dr. Manuel Lagunas-Solar (Crocker Nuclear Laboratory), with the assistance of Ms. Krystyna Trzepla-Nabaglo (Staff Research Associate) and Ms. Cecilia Piña Ulzurrún (Visiting Scientist).

In all this experimentation, a one-plane, monochromatic beam of 248 nm (5 eV/photon) from a Lambda Physik 210i excimer laser was used.

Individual reports are summarized here from data provided by each collaborating investigator.

Professional support was also provided to this project through several scientific consultants with expertise in different related disciplines. These consultants provided expert guidance in defining the specific objectives of the project, helped in designing experimental protocols, visited UC Davis to participate in experiments or to relate and discuss aspects of the project with UC Davis scientists and technicians, and participated in the overall evaluation of data and results by providing assistance to the Chilean Exporters Association's Technical Committee.

The scientific consultants were:

(1) Dr. Julio Retamales, National Institute of Agricultural Research (Fruit Quality Experimentation); and

(2) Dr. Roberto H. Gonzalez, University of Chile, (Entomology Experimentation).

The project's general administration was under the direction of Mr. Rodrigo López Ulloa, Ag. Eng., ICC S.A., who also represented the Chilean Exporters Association.

During the preparation of this final report, section II (Microbiology), section III (Fruit Quality), and section IV (Entomology) are presented with only editing interaction from the author and no commentary. Therefore, these sections contain the data, the results, and the conclusions that reflects the expert opinion of the respective collaborators.

Finally, section IV (Discussion and Conclusions) was prepared solely by the author using the data base provided by the respective collaborators, and adding the general information and data of other pulsed UV applications being developed at the University of California, Davis, in areas such as biomedicine, environment, and food technology. In order to protect the confidentiality of other related projects, however, only general information is referenced and no specific details are mentioned.

II. MICROBIOLOGY EXPERIMENTATION

Effect of Pulsed-UV on Surface Microbial Disinfection[1]

James D. MacDonald and Linda Bolkan

Department of Plant Pathology, University of California, Davis, CA 95616

1. INTRODUCTION

A series of experiments were conducted with inoculated fruit samples containing a selected fungi. These experiments were executed as part of the experimental plan formulated for the project.

The objectives were to establish the surface disinfection effects of pulsed UV (248 nm) photons, a fact already established and proven for other applications of pulsed UV being investigated.

Inoculation was done in selected regions of the fruit and pulsed UV (248 nm) photon exposure was done a diverse doses and with samples in a static position or in a rotational mode. In both cases, the beam area covered completely the inoculated area but it did not process the entire surface area of the sample. Assays of the surface microbial disinfection effects were conducted at the Department of Plant Pathology.

These experiments were conducted in parallel with fruit quality experiments (see section III), therefore, the same fruit batches obtained from commercial sources were used. The entire set of experiments is summarized in Table A, next page.

2. MATERIALS AND METHODS

All fruit samples were culled, selected, infested, treated and incubated as per protocols established for this project. Fungi inoculum were prepared and assayed using standard assay methodology.

Evaluation or culling of the fruit was made on a very strict basis in regard to blemishes, cuts, bruises, apparent fungal infection, color, size and other factors. This quality control was initiated and supervised by knowledgeable staff in the UC Davis Department of Pomology. The object was to start with batches of fruit that were as homogeneous as possible in quality and in excellent physical condition.

[1] This section of the report was edited for format by the author, based on Internal Reports.

Table A. Summary of Microbiology Experimentation

EXP. & DATE	FRUIT	PUV DOSE (J/cm²)	FLUENCE (mJ/cm²/p) (REP RATE) (Hz)	CONDITION OF TREATMENT	PUV TIME (s)	PUV DOSE (mJ/cm²) TIME (s)	NOTES
Exp. #1 8/17/98	Heritage Raspberries	0.5 1	1.7 (10) 1.9 (10)	rotation	29 52	190 / 63 365 / 126	optics OK
Exp. #2 8/18/98 (Add. Exp.) 10/7/98	O'Henry Peaches Autumn Flame	0.3 0.6 2	1.1(40) 0.4 (40)	static static	7 14 166	same	optics OK poor optics
Exp. #3 8/25/98	Red Globe Grapes	0.3 0.6	0.15 (30) 0.22 (30)	rotation	67 91	110 / 130 219 / 260	optics OK
Exp. #4 8/26/98 (Add. Exp.) 9/22/98	Thompson Seedless Grapes	0.3 0.6 1 2	0.23 (30) 0.50 (60) 0.51 (60)	rotation rotation	43 86 155 310	108 / 117 216 / 233 same	poor optics
Exp. #5 9/2-3/98	Granny Smith Apples	0.5 1 2	0.97 (20) 0.97 (20) 0.88 (20)	static	25 50 114	same	poor optics
Exp. #6 9/9/98	August Red Nectarines	1 2	0.66(30) 0.66 (30)	static	51 101	same	poor optics
Exp. #7 9/15/98	Bosc Pears	1 2	0.4 (60) 0.4 (80)	static	42 62	same	poor optics
Exp. #8 9/29/98	Red Delicious Apples	1 3	0.31(80)	static	40 120	same	very poor optics
Exp. #9 10/21/98	Fuji Apples	1 2	1 (30)	static	33 67	same	new mirror
Exp. #10 11/17/98	Hayward Kiwis	3	1.8 (40)	shaking bench (up & down)	21 42	same	new mirror
Exp. #11 11/17/98	Eureka & Lisbon Lemons	3	1.8 (40)	shaking bench (up & down)	21 42	same	new mirror

3. DATA AND RESULTS

The following is a summary of all the observations and general results obtained in these experiments.

3.1 Raspberries - Heritage

Raspberries are very fragile and demand a minimum amount of handling to stay in good condition. To facilitate this, we laid out individual fruit onto O-rings in Petri dishes. The idea was to reduce the chance of the berry rolling around during transport and treatment.

The individual fruit was sprayed once with an airbrush spray unit delivering close to 0.02 mL of inoculum per berry. We sprayed one group of berries with *Botrytis cinerea* at a concentration of $2x10^5$ spores/mL and another group with *Penicillium frequentans* at a concentration of $7x10^6$ spores/mL.

The fruit was allowed to dry, moved to crispers for transport to CNL then treated the same day with the laser beam. Laser conditions for this series are listed in Table A (page 10).

The laser exposure was at two rates and a control batch of fruit was included in the experiment which received no laser treatment and a second control batch which received neither laser treatment nor sprayed fungal spores. The fruit was always handled carefully to avoid injury but during laser treatment strict sterile procedures were not adhered to due to practical considerations.

Laser exposure was directed to the sprayed side of the berry. After treatment the berries were placed back onto the O-rings in the crispers, with the treated side facing up, and incubated at room temperature (ranging from 21-25°C) for several of days with readings being taken at regular intervals.

Detailed data summary in graph form of these observations is on record. Photos were taken.

The data show that regardless of whether or not the berries were treated with fungus or exposed to high or low dosages of laser UV, by day 4, all of the berries were totally covered with fungi. The fruit became over run with various fungi, not just the fungus applied. In other words it was apparent that these fruit had so much natural infestation of fungi that experimental results were masked.

Also implied was that the Laser UV controlled neither the applied nor the natural fungal units. Since the whole fruit was not treated this could also have been a factor by allowing naturally contaminating spores to escape treatment.

3.2 Peaches – O'Henry

Peaches are fragile and demand a minimum amount of handling to stay in good condition. To facilitate this we placed individual fruit into small plastic weigh boats. The idea was to reduce the chance of the peach rolling around during transport and treatment.

The individual fruit was infested with 3 fungal types sprayed on separately onto marked target areas with an airbrush spray unit delivering close to 0.02 mL of inoculum per target area.

The fungal isolates included *Botrytis cinerea* at a concentration of $2x10^5$ spores/mL, *Monilinia fructicola* at a concentration of $1.2x10^6$ spores/mL, and *Rhizopus stolonifer* at a concentration of $2.5x10^5$ spores/mL.

The fruit was allowed to dry, moved to crispers for overnight storage in a 4°C cold room. The following morning they were transported to CNL then treated with the laser beam.

In this series, the laser exposure was directed in an equatorial band around the fruit which included the target areas of fungal spores. To facilitate this procedure the fruits were place on a rotating apparatus that stayed in motion throughout the experiment.

Laser conditions for this series are listed in Table A (page 10).

The laser treatment was at two rates and a control batch of fruit was included in the experiment which received no laser treatment and a second control batch which received neither laser treatment nor sprayed fungal spores.

The fruit was always handled carefully to avoid injury but during laser treatment strict sterile procedures were not adhered to[2].

After treatment the peaches were placed back into the weigh boats and returned to the crispers. At this stage the fruit was purposely injured with a series of sterile needle punctures in the target area. The wounding was thought to imitate conditions where fungi gain entry in post harvest injury conditions. The negative controls were left uninjured.

The fruit was kept under moist conditions favoring the fungus by using wet paper towels in the bottom of the crisper. The fruit was then incubated at room temperature (ranging from 21-26°C) for several days with readings being taken at regular intervals.

Detailed data summary in graph form of these observations is on record.

---

[2] During PUV exposure, care was excersized to minimize any potential contamination. However, due to practical considerations and operational restrictions, no aseptic procedures could be implemented.

The data show that regardless of whether or not the peaches were treated with fungus or received high or low dosages of laser PUV, within a week most of the peaches were totally covered with fungi.

The fruit became overrun with various fungi, not just the fungus applied.

In other words it was apparent that these fruit had so much natural infestation of fungi that experimental results were masked. In this series most of the natural infection was *Monilinia sp.* originating from within the fruit.

Because of this it is not easily apparent whether the applied spores initiated any infection lesions. Also implied was that the Laser PUV controlled neither the applied nor the natural fungal units. Since the whole fruit was not treated this could also have been a factor by allowing natural contamination to escape treatment.

Also, on the laser treated target areas, fruit discoloration began appearing by day 7.

Photos were taken.

3.3 Grapes – Red Globe

Grapes are fragile and demand a minimum amount of handling to stay in good condition. To facilitate this we placed intact grape bunches into small plastic weigh boats. The idea was to reduce the chance of the bunch rolling around during transport and treatment.

The bunches were set up to an arbitrary standard of size and berry number. The bunches were spread onto butcher paper and sprayed on one side only

Each grape bunch was infested with *Botrytis cinerea* at a concentration of 2.5×10^6 spores/mL using an airbrush spray unit that delivered close to 0.03 mL of inoculum grape bunch. The fruit was allowed to dry then moved to weigh boats with treated side facing up.

The weigh boat units were held in crispers overnight at 4°C. The following morning they were transported to CNL then treated with the laser beam.

In this series, bunches were hung on a special apparatus while being exposed to the PUV expanded beam. Laser conditions for this series are listed in Table A (page 10).

The laser treatment was at two rates and a control batch of fruit was included in the experiment which received no laser treatment and a second control batch which received neither laser treatment nor sprayed fungal spores.

The fruit was always handled carefully to avoid injury but during laser treatment strict sterile procedures were not adhered to.

Following treatment the bunch was then returned to its original weigh boat with the treated side facing up and returned to the crispers. The fruit was kept under moist conditions favoring the fungus by using wet paper towels in the bottom of the crisper. The fruit was incubated at room temperature (ranging from 21-26°C) for several days with readings being taken at regular intervals.

Detailed data summary in graph form of these observations is on record.

The data show that regardless of whether or not the grapes were treated with fungus or received high or low dosages of laser PUV, within a week most of the grapes had some degree of fungal growth.

By 10 days after treatment most units were covered with various fungi, not just the fungus applied. In other words it was apparent that these fruit had so much natural infestation of fungi that experimental results were masked.

In this series most of the natural infection was *Aspergillus sp.* originating from within the fruit bunches and from *Botrytis sp.* that was present in abundance on the stem. *Rhizopus sp.* was also present.

Further implied was that the Laser PUV applied dose controlled neither the applied nor the natural fungal units. Since the whole fruit was not treated this could also have been a factor by allowing natural contamination in crevices and the back part of the bunch to escape treatment.

Photos were taken.

3.4 Apples – Granny Smith

After the selection process individual fruit were placed into small plastic weigh boats to reduce the chance of the apple rolling around during transport and treatment.

The individual fruit was infested with one of three different fungal types sprayed onto marked target area with an airbrush spray unit delivering close to 0.02 mL of inoculum per target area. The fungal isolates included *Botrytis cinerea* at a concentration of 2.5×10^6 spores/mL, *Penicillium frequentans* at a concentration of 15×10^6 spores/mL and *Alternaria alternata* at a concentration of 3.4×10^6 spores/ mL.
The fruit was allowed to dry, moved to crispers for overnight storage in a 4°C cold room. The following morning they were transported to CNL then treated with the laser beam.

In this series, the laser exposure was directed to a target area of fungal spores. The fruit remained stationary. The fruit was always handled carefully to avoid injury but during laser treatment strict sterile procedures were not adhered to.

Laser conditions for this series are listed in Table A (page 10).

The laser treatment was at two doses for the *Botrytis* and *Penicillium* series and at three rates for the *Alternaria* series. A positive control batch of fruit was included in the experiment which was sprayed with fungal spores but received no laser treatment. A second, negative control batch which received neither laser treatment nor sprayed fungal spores was also included.

After treatment the apples were injured at the target site with a series of sterile needle punctures. The wounding was thought to imitate conditions where fungi gain entry in post harvest injury conditions. The apples were placed back into the weigh boats and returned to the crispers. The negative controls were left uninjured.

The fruit was kept under moist conditions favoring the fungus by using wet paper towels in the bottom of the crispers. The fruit was incubated at room temperature (ranging from 21-26°C) for several days with readings being taken at regular intervals.

Detailed data summary in graph form of these observations is on record.

There were no positive readings until week 3. In other words the intended fungus did not rot the fruit or form lesions in the way we have experienced with other commodities. There was eventual proof of some *Alternaria* and *Botrytis* infection through re-isolation from sub-surface lesions but there are no data for graphing.

It should be noted however, that by the beginning of week 2 most of the apples displayed a surface fungal growth mostly on the shoulders of the fruit. It appeared to be a surface contaminant or was imbedded in the wax layer. This fungus was identified as *Aspergillus sp*.

Also in the 2nd week some discoloration at the targeted treatment site was noticeable. By the third week many of the stems became moldy.

It should be noted that no naturally infested fungi appeared to be controlled with this treatment regime. This could be due to the fact that only a target area was exposed to the laser pulses. There were target fungi that survived treatment which eventually produced infection through artificial wounding process.

Photos were taken.

3.5 Grapes – Thompson Seedless 1

Grapes were handled in a similar manner as explained in sub section 2.3. The grape bunches were set up to an arbitrary standard of size and berry number. The bunches were spread onto butcher paper and sprayed on one side only. Each grape bunch was infested with *Botrytis cinerea* at a concentration of $2.5x10^6$ spores/mL using an airbrush spray unit that delivered close to 0.03 mL of inoculum per grape bunch. The fruit was allowed to dry then moved to weigh boats with treated side facing up.

The weigh boat units were held in crispers ~36 h at 4°C. The second morning they were transported to CNL then treated with the laser beam. In this series, the bunches were hung on a special apparatus while being exposed to the PUV expanded beam. Laser conditions for this series are listed in Table A (page 10).

The laser treatment was at two rates and a control batch of fruit was included in the experiment which received no laser treatment and a second control batch which received neither laser treatment nor sprayed fungal spores. The fruit was always handled carefully to avoid injury but during laser treatment strict sterile procedures were not adhered to.

Following treatment the bunch was then returned to its original weigh boat with the treated side facing up and returned to the crispers. The fruit was kept under moist conditions favoring the fungus by using wet paper towels in the bottom of the crisper. The fruit was incubated at room temperature (ranging from 21-26°C) for several days with readings being taken at regular intervals.

Detailed data summary in graph form of these observations is on record.

The data show that regardless of whether or not the grapes were treated with fungus or received high or low dosages of laser PUV, within 4 days most of the grapes had some degree of fungal growth.

By 1 week after treatment most units were covered with various fungi, not just the fungus applied. In other words it was apparent that these fruit had so much natural infestation of fungi that experimental results were masked. In this series most of the natural infection was from *Aspergillus sp.* originating from within the fruit bunches and from *Botrytis sp.* that was present in abundance on the stem. *Rhizopus sp.* and *Penicillium sp.* were also present.

Further implied was that the laser PUV controlled neither the applied nor the natural fungi. Since the whole fruit was not treated, this could also have been a factor by allowing natural contamination in crevices and the back part of the bunch to escape treatment. Photos were taken.

3.6 Pears – Bosc

After the selection process individual fruit were placed into small plastic weigh boats to reduce the chance of the pear rolling around during transport and treatment.

The individual fruits were infected with one of three different fungal types sprayed onto marked target areas with an airbrush spray unit delivering close to 0.02 mL of inoculum per target area. The fungal isolates included *Botrytis cinerea* at a concentration of 2 $x10^6$ spores/mL, *Penicillium frequentans* at a concentration of $13x10^6$ spores/mL and *Alternaria alternata* at a concentration of $3x10^6$ spores/mL. The fruit was allowed to dry, moved to crispers for overnight storage in a 4°C cold room.

The following morning they were transported to CNL then treated with the laser beam. In this series, the laser exposure was directed to a target area of fungal spores. The fruit remained stationary. The fruit was always handled carefully to avoid injury but during laser treatment strict sterile procedures were not adhered to.

Laser conditions for this series are listed in Table A (page 10). The laser treatment was at two rates,1 J/cm^2 and 2 J/cm^2. A positive control batch of fruit was included in the experiment which was sprayed with fungal spores but received no laser treatment. A second, negative control batch which received neither laser treatment nor sprayed fungal spores was also included.

Additionally, the post-treatment batches were divided into two units. One batch unit was injured at the target site with a series of sterile needle punctures. The wounding was thought to imitate conditions where fungi gain entry in post harvest injury conditions. The second batch unit was not artificially injured but the target area, where the spores were sprayed and where the laser exposure occurred, was sliced off under sterile conditions and placed skin-side down onto selective media in a Petri plate. After 24 hours the fruit target discs were removed from the Petri plates and whatever fungal spores remained on the agar were left to incubate.

Fruit target discs were deposited in clean crispers for later observation. The negative controls were left uninjured and uncut. The fruit was kept under moist conditions favoring the fungus by using wet paper towels in the bottom of the crisper. The fruit and the Petri plates were incubated in crispers at room temperature (ranging from 21-26°C) for several days with readings being taken at regular intervals.
Detailed data summary in graph form is on record. Photos were taken.

The Bosc pear is a very tough-skinned fruit. In this series there were few positive fungal lesion readings on intact fruit. In other words the intended fungus did not rot the fruit or form lesions in the way we have experienced with other commodities. However, there was proof of spore survival of *Alternaria* and *Botrytis* and *Penicillium* on the pear target disc agar plates and also on the excised pear target discs.

3.7 Nectarines – FlameKist

After the selection process individual fruit were placed into small plastic weigh boats to reduce the chance of the nectarine rolling around during transport and treatment. The individual fruit was infested with one of three different fungal types sprayed onto marked target area with an airbrush spray unit delivering close to 0.02 mL of inoculum per target area. The fungal isolates included *Botrytis cinerea* at a concentration of $2.5x10^6$ spores/ mL, *Monilinia fructicola* at a concentration of $13x10^6$ spores/mL and *Rhizopus stolonifer* at a concentration of $1x10^6$ spores/mL.

The fruit was allowed to dry, moved to crispers for overnight storage in a 4°C cold room. The following morning they were transported to CNL then treated with the laser beam.

In this series, the laser exposure was directed to an equatorial band around the fruit which included the target areas of fungal spores and which rotated through the pit of the fruit. To facilitate this procedure the fruits were place on a rotating apparatus that stayed in motion throughout the exposure time. Experimental rotation protocol was changed from previous peach experiments where it was apparent that much natural infection seemed to generate from the stem portion of the fruit. The fruit was always handled carefully to avoid injury but during laser treatment strict sterile procedures were not adhered to.

Laser conditions for this series are listed in Table A (page 10).

The laser treatment was at two rates and a positive control batch of fruit was included in the experiment which was sprayed with fungal spores but received no laser treatment and a second negative control batch which received neither laser treatment nor sprayed fungal spores.

After treatment the nectarines were placed back into the weigh boats and returned to the crispers. Additionally, the post- treatment batches were divided into two units. One batch unit was injured at the target site with a series of sterile needle punctures. The wounding was thought to imitate conditions where fungi gain entry in post harvest injury conditions. The second batch unit was not artificially injured but the target area, where the spores were sprayed and where the laser exposure occurred, was sliced off under sterile conditions and placed skin-side down onto selective media in a Petri plate.
After 24 hours the fruit target discs were removed from the Petri plates and whatever fungal spores remained on the agar were left to incubate. The negative controls were left uninjured and uncut. The fruit was kept under moist conditions favoring the fungus by using wet paper towels in the bottom of the crisper. The fruit and the Petri plates were incubated at room temperature (ranging from 21-26°C) for several days with readings being taken at regular intervals. Data summary in graph form is attached.

The data show that regardless of whether or not the nectarines were treated with fungus or received high or low dosages of laser PUV, within a week most of the nectarines were totally covered with fungi. The fruit became overrun with various fungi, not just the fungus applied. In other words it was apparent that these fruit had so much natural infestation of fungi that experimental results were masked.

In this series most of the natural infection was *Monilinia sp.* originating from within the fruit. Also implied was that the Laser PUV controlled neither the applied nor the natural fungal units. Since the whole fruit was not treated this could also have been a factor by allowing natural contamination to escape treatment. Also note that the plates representing viable spores remaining after laser PUV exposure were full of fungus, from both sprayed and natural infestation. This is independent of fruit infection.

Photos were taken.

3.7.1 Additional Experimentation

The lack of efficacy in killing fungal spores both sprayed and natural on the fruit surface was puzzling and prompted a new series of tests to evaluate this situation. We therefore began a parallel "dose response experiment series" in which the target fungal spores were sprayed onto a Petri plate of selective media. The target size and spray rate of spores was equivalent to used on the fruit.

The series included for each target fungus a control plate and triplicate plates for each laser PUV exposure rate. There were three exposure rates employed: 0.5 J/cm^2, 1.0 J/cm^2,and 2.0 J/cm^2.

Results and Observations

In all cases the controls displayed abundant growth of fungus in the target area. On the contrary, the PUV treated plates demonstrated a clearing in the target area demonstrating the efficacy of PUV treatment under these conditions.
In other words under the same PUV exposures, all fungi were controlled on agar in Petri plates but not controlled on fruit surfaces.

3.8 Grapes – Thompson Seedless 2

Grapes are fragile and demand a minimum amount of handling to stay in good condition. To facilitate this we placed intact grape bunches into small plastic weigh boats. The idea was to reduce the chance of the bunch rolling around during transport and treatment. The bunches were set up to an arbitrary standard of size and berry number. The bunches were spread onto butcher paper and sprayed on one side only.

Each grape bunch was infested with *Botrytis cinerea* at a concentration of $1.5x10^6$ spores/ mL using an airbrush spray unit that delivered close to 0.04 mL of inoculum grape bunch. The fruit was allowed to dry then moved to weigh boats with treated side facing up. The weigh boat units were held in crispers overnight hours at 4°C.

The next morning they were transported to CNL then treated with the laser beam. In this series, the bunches were hung on a special apparatus while being exposed to the PUV expanded beam. Laser conditions for this series are listed in Table A (page 10).

The laser treatment was at two rates $1J/cm^2$ and $2J/cm^2$. A control batch of fruit was included in the experiment which received no laser treatment and a second control batch which received neither laser treatment nor sprayed fungal spores. The fruit was always handled carefully to avoid injury but during laser treatment strict sterile procedures were not adhered to for reasons explained above.

Following treatment the bunch was then returned to its original weigh boat with the treated side facing up and returned to the crispers. The fruit was kept under moist conditions favoring the fungus by using wet paper towels in the bottom of the crispers.

The fruit was incubated at room temperature (ranging from 21-26°C) for several days with readings being taken at regular intervals.

Detailed data summary in graph form of these observations is on record.

The data show that regardless of whether or not the grapes were treated with fungus or received high or low dosages of laser PUV, within 3 days most of the grapes had some degree of fungal growth.

By 1 week after treatment most units were covered with various fungi, not just the fungus applied. In other words it was apparent that these fruit had so much natural infestation of fungi that experimental results were masked. In this series most of the natural infection was *Aspergillus sp.* originating from within the fruit bunches and from *Botrytis sp.* that was present in abundance on the stem. *Rhizopus sp.* and *Penicillium sp.* were also present.

Further implied was that PUV controlled neither the applied nor the natural fungal units. Since the whole fruit was not treated this could also have been a factor by allowing natural contamination in crevices and the back part of the bunch to escape treatment.

3.8.1 Additional Experimentation

A parallel dose response evaluation was carried out using similar laser PUV parameters.

Agar plates were sprayed with *Botrytis cinerea* under the same experimental conditions as the fruit then later exposed to laser PUV (1 and 2 J/cm^2) under the same experimental conditions as the fruit.

These dose response plates were cleared at the laser target area indicating PUV efficiency under these conditions. Besides, clearly the PUV dose applied was enough to kill the fungus.

Photos were taken.

3.9 Apples – Red Delicious

After the selection process individual fruit were placed into small plastic weigh boats to reduce the chance of the apple rolling around during transport and treatment. The individual fruit was infested with one fungus, *Alternaria alternata* at a concentration of 1.65×10^6 spores/mL, sprayed onto marked target area with an airbrush spray unit delivering close to 0.02 mL of inoculum per target area. The fruit was allowed to dry, moved to crispers for overnight storage in a 4°C cold room.

The following morning they were transported to CNL then treated with the laser beam. In this series, the laser exposure was directed to a target area of fungal spores. The fruit remained stationary. The fruit was always handled carefully to avoid injury but during laser treatment strict sterile procedures were not adhered to.

Laser conditions for this series are listed in Table A (page 10).

The laser treatment was at two rates: 1 J/cm^2 and 2 J/cm^2. A positive control batch of fruit was included in the experiment which received no laser treatment and a second negative control batch which received neither laser treatment nor sprayed fungal spores. Additionally, the post-treatment batches were divided into two units. One batch unit was injured at the target site with a series of sterile needle punctures. The wounding was thought to imitate conditions where fungi gain entry in post harvest injury conditions. The second batch unit was not artificially injured but the target area, where the spores were sprayed and where the laser exposure occurred, was sliced off under sterile conditions and placed skin-side down onto selective media in a Petri plate.

After 24 hours the fruit slice discs were removed from the Petri plates and whatever fungal spores remained on the agar were left to incubate. The negative controls were left uninjured and uncut. The fruit was kept under moist conditions favoring the fungus by using wet paper towels in the bottom of the crisper. The fruit and the Petri plates were incubated at room temperature (ranging from 21-26°C) for several days with readings being taken at regular intervals.

Detailed data summary in graph form of these observations is on record.

After 1 week all post-treatment injured fruit read positive for lesions in the target area. In other words there were target fungi that survived treatment which eventually produced infection through artificial wounding process. Confirmation of *Alternaria sp.* infection was made through re-isolation from the lesion area.

Photos were taken.

3.10 Peaches - Autum Flame

Peaches are fragile and demand a minimum amount of handling to stay in good condition. To facilitate this we placed individual fruit into small plastic weigh boats. The idea was to reduce the chance of the peach rolling around during transport and treatment. The individual fruit was infested with just one fungus, *Rhizopus stolonifer* at a concentration of $2.5x10^5$ spores/mL, sprayed onto marked target areas with an airbrush spray unit delivering close to 0.02 mL of inoculum per target area. The fruit was allowed to dry, moved to crispers for overnight storage in a 4°C cold room.

The following morning they were transported to CNL then treated with the laser beam. In this series, the laser exposure was directed at a target area of fungal spores on stationary fruit. The fruit was always handled carefully to avoid injury but during laser treatment strict sterile procedures were not adhered to.

Laser conditions for this series are listed in Table A (page 10).

The laser treatment was at one rate, 2 J/cm^2. A positive control batch of fruit was included in the experiment which received no laser treatment as was a second negative control batch which received neither laser treatment nor sprayed fungal spores. Additionally, the post- treatment batches were divided into two units. One batch unit was injured at the target site with a series of sterile needle punctures. The wounding was thought to imitate conditions where fungi gain entry in post harvest injury conditions. The second batch unit was not artificially injured but the target area, where the spores were sprayed and where the laser exposure occurred, was sliced off under sterile conditions and placed skin-side down onto selective media in a Petri plate.

After 24 hours the fruit slice discs were removed from the Petri plates and whatever fungal spores remained on the agar were left to incubate. The negative controls were left uninjured and uncut. The fruit was kept under moist conditions favoring the fungus by using wet paper towels in the bottom of the crispers. The fruit and the Petri plates were incubated at room temperature (ranging from 21-26°C) for several days with readings being taken at regular intervals.

Detailed data summary in graph form of these observations is on record.

The data show that regardless of whether or not the peaches were treated with fungus or received a high dose of laser PUV, within a week most of the peaches were totally covered with fungi. The fruit became overrun with various fungi, not just the fungus applied. In other words it was apparent that these fruit had so much natural infestation of fungi that experimental results were masked. In this series most of the natural infection was *Monilinia sp*. originating from within the fruit.

Also implied was that the Laser PUV controlled neither the applied nor the natural fungal units. Since the whole fruit was not treated this could also have been a factor by allowing natural contamination to escape treatment. Also note that the plates representing viable spores remaining after laser PUV exposure were full of fungus, from both sprayed and natural infestation. This is independent of fruit infection.

Photos were taken.

3.11 Apples – Fuji

After the selection process individual fruit were placed into small plastic weigh boats to reduce the chance of the apple rolling around during transport and treatment. The individual fruit was infested with one fungus, *Alternaria alternata* at a concentration of $1.9x10^6$ spores/mL, sprayed onto marked target area with an airbrush spray unit delivering close to 0.02 mL of inoculum per target area. The fruit was allowed to dry, moved to crispers for overnight storage in a 4°C cold room. The following morning they were transported to CNL then treated with the laser beam.

In this series, the laser exposure was directed to a target area of fungal spores. The fruit remained stationary. The fruit was always handled carefully to avoid injury but during laser treatment strict sterile procedures were not adhered to. Laser conditions for this series are listed in Table A (page 10).

The laser treatment was at two rates, 1 J/cm^2 and 2 J/cm^2. A positive control batch of fruit was included in the experiment which received no laser treatment and a second negative control batch which received neither laser treatment nor sprayed fungal spores. Additionally, the post-treatment batches were divided into two units. One batch unit was injured at the target site with a series of sterile needle punctures. The wounding was thought to imitate conditions where fungi gain entry in post harvest injury conditions. The second batch unit was not artificially injured but the target area, where the spores were sprayed and where the laser exposure occurred, was sliced off under sterile conditions and placed skin-side down onto selective media in a Petri plate.

After 24 hours the fruit slice discs were removed from the Petri plates and whatever fungal spores remained on the agar were left to incubate. The negative controls were left uninjured and uncut. The fruit was kept under moist conditions favoring the fungus by using wet paper towels in the bottom of the crispers. The fruit and the Petri plates were incubated at room temperature (ranging from 21-26°C) for several days with readings being taken at regular intervals.

Detailed data summary in graph form of these observations is on record.

After 9 days all post-treatment injured fruit read positive for lesions in the target area. In other words there were target fungi that survived treatment which eventually produced infection through artificial wounding process. At the end of 3 weeks confirmation of *Alternaria sp.* infection was made through re-isolation from the lesion area. Fruit discoloration at the target site was also noted at the high dosage rate, 2 J/cm^2.

Photos were taken.

3.12 Kiwi – Hayward

After the selection process individual fruit were placed into small plastic weigh boats to reduce the chance of the Kiwi rolling around during transport and treatment. The individual fruit was infested with one fungus, *Botrytis cinerea* at a concentration of $0.1x10^6$ spores/ mL, sprayed onto marked target area with an airbrush spray unit delivering close to 0.02 mL of inoculum per target area. The fruit was allowed to dry, moved to crispers for overnight storage in a 4°C cold room. The following morning they were transported to CNL then treated with the laser beam.

In this series, the laser exposure was directed to a target area of fungal spores. The fruit remained stationary. The fruit was always handled carefully to avoid injury but during laser treatment strict sterile procedures were not adhered to. Laser conditions for this series are listed in Table A (page 10).

The laser treatment was at two rates: 1 J/cm^2 and 3 J/cm^2. A positive control batch of fruit was included in the experiment which was sprayed with fungal spores but received no laser treatment. A second negative control batch which received neither laser treatment nor sprayed fungal spores was also included

Additionally, the post-treatment batches were divided into two units. One batch unit was injured at the target site with a series of sterile needle punctures. The wounding was thought to imitate conditions where fungi gain entry in post harvest injury conditions. The second batch unit was not artificially injured but the target area, where the spores were sprayed and where the laser exposure occurred, was sliced off under sterile conditions and placed skin-side down onto selective media in a Petri plate.

After 24 hours the fruit slice discs were removed from the Petri plates and whatever fungal spores remained on the agar were left to incubate. Fruit slice discs were then deposited in clean crispers for later observation. The negative controls were left uninjured and uncut.

The fruit was kept under moist conditions favoring the fungus by using wet paper towels in the bottom of the crispers. The fruit and the Petri plates were incubated in crispers at

room temperature (ranging from 21-26°C) for several days with readings being taken at regular intervals.

Detailed data summary in graph form of these observations is on record.

The Kiwi fruit is a very tough-skinned fruit. In this series there were no outward signs fungal lesions on intact fruit. However, there was proof of spore survival of *Botrytis sp.* and other surface contaminating fungi on the agar plates. At 5 days, although the fruit remained firm and seemingly disease free, there was noticeable mold growing at the stem scar.

Also note that at the end of 2 weeks the injured Kiwis were sliced in half for photos.

At this point it was apparent that there were subsurface fungal encapsulations. In other words there was an absence of apparent surface lesions but in many instances at the site of experimentally induced injury it appeared that fungal spores were introduced, grew a bit then the fruit walled the area off. The entire fruit did not rot or become symptomatic.

Re-isolations from these encapsulations yielded a number of fungi (data not shown). Photos were taken.

3.13 Lemon – Eureka

After the selection process individual fruit were placed into small plastic weigh boats to reduce the chance of the lemon rolling around during transport and treatment. The individual fruit was infested with one fungus, *Phytophthora citrophthora* at a concentration of 2.0×10^6 spores/mL, sprayed onto marked target area with an airbrush spray unit delivering close to 0.01 mL of inoculum per target area. The fruit was allowed to dry, moved to crispers for overnight storage in a 4°C cold room. The following morning they were transported to CNL then treated with the laser beam.

In this series, the laser exposure was directed to a target area of fungal spores. The fruit remained stationary. The fruit was always handled carefully to avoid injury but during laser treatment strict sterile procedures were not adhered to.

Laser conditions for this series are listed in Table A (page 10).

The laser treatment was at two rates: 1 J/cm^2 and 3 J/cm^2. A positive control batch of fruit was included in the experiment which was sprayed with fungal spores but received no laser treatment. A second negative control batch which received neither laser treatment nor sprayed fungal spores was also included.

Additionally, the post-treatment batches were divided into two units. One batch unit was injured at the target site with a series of sterile needle punctures. The wounding was

thought to imitate conditions where fungi gain entry in post harvest injury conditions. The second batch unit was not artificially injured but the target area, where the spores were sprayed and where the laser exposure occurred, was sliced off under sterile conditions and placed skin-side down onto selective media in a Petri plate.

After 24 hours the fruit slice discs were removed from the Petri plates and whatever fungal spores remained on the agar were left to incubate. Fruit slice discs were then deposited in clean crispers for later observation. The negative controls were left uninjured and uncut. The fruit was kept under moist conditions favoring the fungus by using wet paper towels in the bottom of the crispers. The fruit and the Petri plates were incubated in crispers at room temperature (ranging from 21-26°C) for several days with readings being taken at regular intervals.

Detailed data summary in graph form of these observations is on record.

The lemons are a very waxy, tough-skinned fruit. In this series there were no outward signs of *Phytophthora sp.* lesions on intact fruit or excised fruit slices. However, there was proof of spore survival of surface contaminating *Penicillium sp.* on the agar plates. *Penicillium sp.* also survived outside the target area to infect some fruit even after laser PUV exposure. Note also that by 3 days after laser PUV exposure all fruit were discolored at the target site.

Photos were taken.

4. DISCUSSION

Eleven commodities have been tested under the current experimental setup. A few observations should be noted:

(1) Some fruits had so much natural infestation of fungi that experimental results were masked. These fruits would include all berries, grapes, peaches, and nectarines.

(2) Some of the available fruits were difficult to artificially infect with test fungi because of the fungicidal waxes applied at point of origin. These fruits would include all apple varieties.

(3) Even at highest doses, 2 J/cm^2, test fungi are not controlled on the fruit surface. In post treatment assays of larger fruit, the test fungi are easily re-isolated from targeted areas on the surface of the fruit immediately after treatment and later from fruits with infected wounds. These fruits would include peaches, nectarines, pears, and apples.

(4) Fungi outside of the target area are not controlled. This was shown to be true on all fruits and on agar "control indicator" plates.

(5) The test fungi on the agar "control indicator" plates were easily killed in the target area regardless of the energy dose (0.5 J/cm^2, 1 J/cm^2, or 2 J/cm^2). These include *Alternaria alternata*, *Botrytis cinerea*, *Monilinia fructicola*, *Penicllium frequentans*, and *Rhizopus stolonifer*.

Because of our experience with fungi and with a similar PUV treatment using the excimer laser techniques, the lack of efficacy in killing sprayed fungal spores and naturally infested spores on the fruit surface was rather puzzling to understand and explain.

Previous tests on fungi suspended in a flowing water system showed a treatment response at much lower energy exposure levels. Spore death initiated at around 0.15 J/ cm^2 and spores were totally killed with < 0.5 J/cm^2.
Therefore, we began a parallel "dose response series" in which the same batch of fungal spores sprayed on the fruit were also sprayed onto Petri plates of selective agar media. The target size and spray rate of spores was equivalent to those used on fruit surfaces.

These plates were then treated in sequence on the same day and under the same conditions as fruits. The series included for each target fungus a control plate and triplicate plates for each laser PUV exposure rate. There were generally three exposure rates employed: 0.5 J/cm^2 , 1.0 J/cm^2, and 2.0 J/cm^2.

Consistently, the controls displayed abundant growth of fungus in the target area and the PUV treated plates demonstrated a clearing in the target area demonstrating an efficient and complete inactivation of fungal spores. However, these were visual observations as no quantitative determinations were judged as necessary.

Therefore, under the same pulsed UV laser exposure conditions, all tested fungi were controlled or inhibited on agar in Petri plates but apparently not controlled quantitatively or significantly inhibited on fruit surfaces.

This observation is rather important in analyzing these results as the lack of quantitation of the partial PUV effects is not possible with current techniques of microbial observations and assays.

4.1 Confirmation of Dose Response Relationships

Further dose response assays were run testing the efficacy of this particular PUV (248 nm) laser beam configuration in killing fungal spores on plates and suspended in water, since the laser differed from the one used in the baseline responses mentioned earlier.

These assays were run separately from the fruit series. Five target fungi, *Alternaria alternata*, *Aspergillus niger*, *Botrytis cinerea*, *Rhizopus stolonifer*, and *Penicillium frequentans* were assayed using the experimental design which follows.

All target fungi, with the exception of *Botrytis* which requires an extra week of incubation, were 7-10 days old and in excellent condition. Spores were harvested and handled under sterile conditions. Counts were made using a hemacytometer and numbers were adjusted to match protocol.

Each fungal set consisted of a high concentration of spores, ~ 10^6 spores/mL, and a lower concentration, ~2000 spores/mL. Both the higher and the lower concentrations were further divided into sub units. One sub unit was distributed into a series of quartz tubes with stir units and treated as a spore suspension. After exposure the spore suspensions were serially diluted and plated onto selective agar media. Another sub unit was distributed onto agar plates at 0.25 mL/plate in a target area.
The suspension was allowed to absorb into the agar to prevent runoff during transport and handling. Later the target area was exposed to the laser beam. All treatments and plating were run in triplicate sets. Pulsed UV (248 nm) treatments included a control set and 5 energy exposure levels; 0.15 J/cm^2, 0.25 J/cm^2, 0.5 J/cm^2, 1.0 J/cm^2, and 3.0 J/cm^2. *Rhizopus* PUV exposures were 0.15; 0.25; 0.5; 0.75; and 1.0 J/cm^2.
Plates were stored in crispers on the lab bench at temperatures around 25°C. A brief summation of results follows.

Results and Observations

The results of these studies are summarized in Table B (page 29) and shown in Figure 1 (high spores/mL concentration) (page 30) and Figure 2 (low spores/mL concentration)(page 31).

These results clearly show the PUV efficacy in inactivating fungal spores of interest in post harvest techniques to preserve fruits. Therefore, the results on fruit surfaces remain unexplained (for further analysis and discussion see: Section IV: Discussion and Conclusions) (page 64 and following).

Table B: PUV (248 nm) Dose vs. Spore Survival Relationships with High Concentration (HC) ($1x10^6$ spores/mL) and Low Concentration (LC)($2x10^3$ spores/mL) Suspensions.

Spores	PUV (248 nm) Dose (J/cm^2)									
	0.15		0.25		0.50		1.0		3.0	
	Spore Survival (%)									
Spore Concentration	HC	LC	HC	LC	HC	LC	HC	LC	HC	LC
Alternaria alt. (no stirring)(*)	26	11	23	9	16	8	10	3	2	2
Alternaria alt.	n/a	8	19	6	2	2	0	2	0.3	2
Botrytis cinerea	0	0	0	0	0	0	0	0	0	0
Penicillium freq.	2	0	0	0	0	0.3	0	0	0	0
Aspergillus niger	3	0	0.5	0	0	0	0	0	0	0
Rhizopus stol.	0	0	0.3	0	n/a	0	n/a	0	0	0

(*) This spore suspension was not stirred during PUV processing. All other tests were done with stirring during PUV exposure.

Figure 1. Microbiology Experiment: Dose Response Relationships Pulsed UV (248 nm) Effects on Spore Suspensions (~ 1.0 x 10^6 cfu/ml)

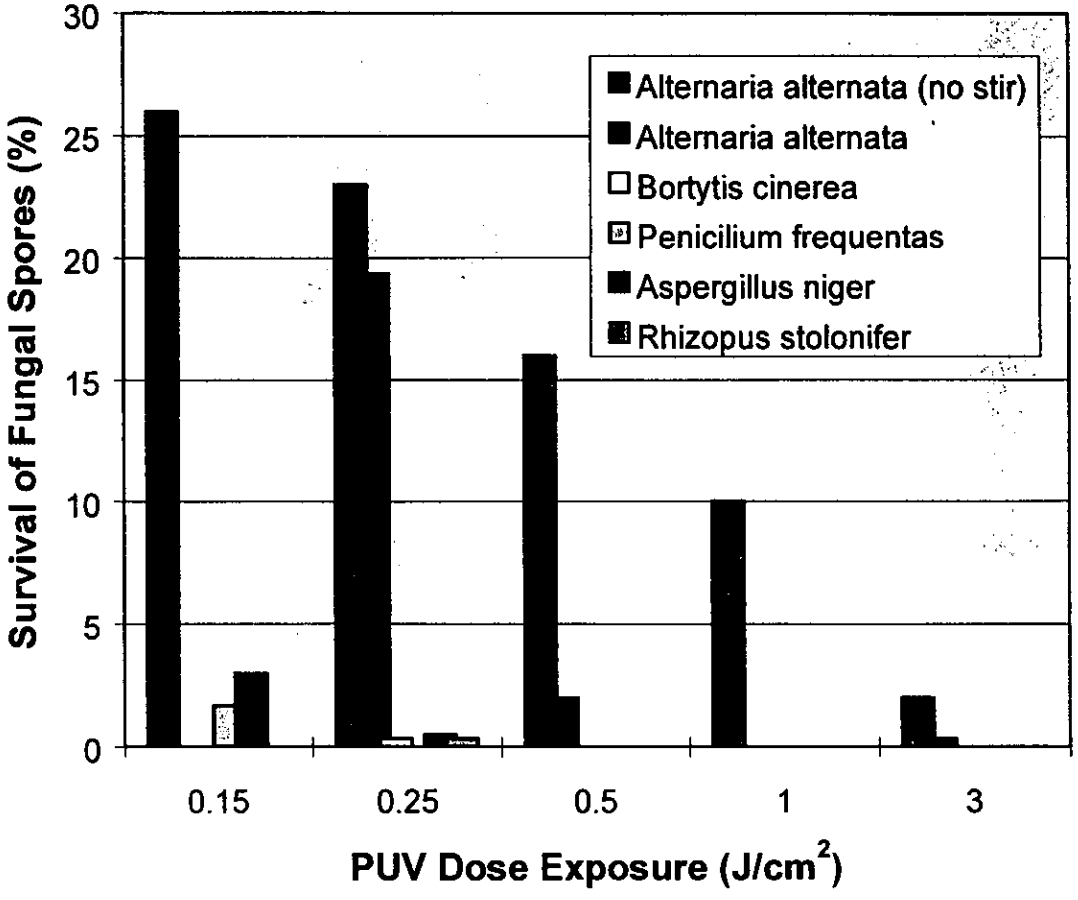
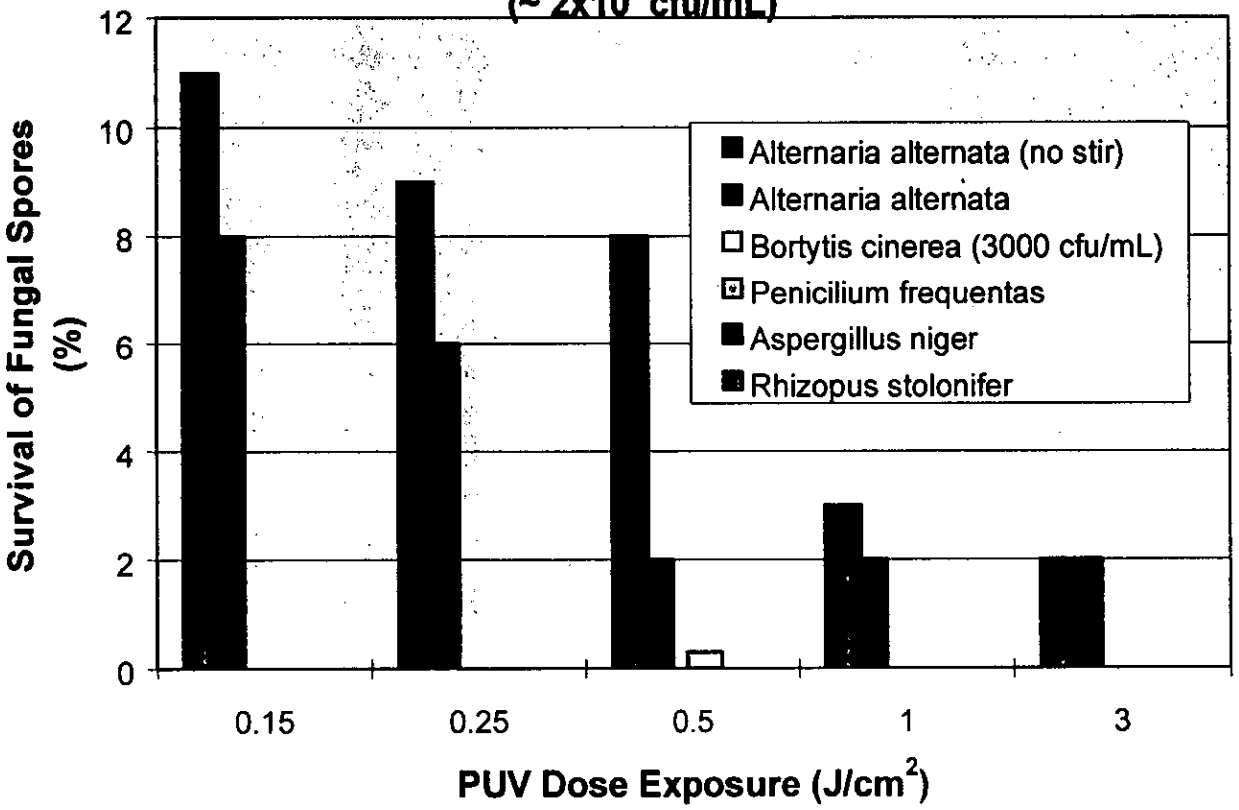


Figure 2. Microbiology Experiment:
Dose Response Relationships
Pulsed UV (248 nm) Effects on Spore Suspensions
(~ $2x10^3$ cfu/mL)



III. FRUIT QUALITY EXPERIMENTATION

Effect of Pulsed-UV Treatment on Fruit Quality[1]

Elizabeth J. Mitcham, I. Tayfun Agar, and William V. Biasi

Department of Pomology, University of California, Davis, CA 95616

1. INTRODUCTION

Pulsed UV (PUV) treatments have been demonstrated in small scale, laboratory studies to kill many important postharvest pathogens and insect pests. As part of an overall effort to evaluate the decay and insect control afforded by PUV treatments in large-scale trials with whole fruit, our specific objective was to evaluate the physiological effects of the various PUV doses on commercially important fruit. We wanted to determine how PUV treatment would influence the quality and storage life of fruit. The efficacy of the PUV treatments for decay and insect control, beyond the scope of the studies described herein, was studied by other UC Davis laboratories; the group evaluating decay control utilized fruit from the same source as we did for the quality evaluations.

2. MATERIALS AND METHODS

2.1 Fruit Material

Fruit were obtained from commercial sources, either through Dole Fruit Company or through General Produce in Sacramento, California. Fruit were to be freshly harvested and packaged according to normal industry practices, including fungicide treatments and wax if normally applied. Upon receipt of fruit, they were sorted to remove damaged or non-uniform samples. A portion of the fruit were used for decay control studies (reported elsewhere) and the remaining fruit were randomly divided into groups for PUV treatment, at two or three doses per fruit type, and an untreated control.

2.2 PUV Exposure Doses

All experiments were conducted with prescribed PUV doses according to the PUV tolerance pre established for most commodities used. To improve exposure uniformity, all samples were rotated during PUV treatment. The PUV dose was calculated from PUV fluence (mJ/cm^2/pulse), rotational velocity (cm/s), repetition rate (pulses/s), and the beam area (cm^2). The PUV doses are summarized in Table C (page 33), below.

[1] **This section of the report is based upon an Internal Report (dated April 22, 1999). Only editing changes for format were introduced by the author.**

Table C: PUV (248 nm) Exposure Doses for All Fresh Fruits

Experiment (Dates)	Fruits	Estimated PUV Dose (J/cm^2)	Fluence ($mJ/cm^2/p$)	Rep. Rate (Hz)	Time Exposure (s)	Observations
Exp. #1 8/18/98	Heritage Raspberries	PUV1=0.5 PUV2=1	1.9 - 2.2	10	24-26 46-52	PUV dose may be lower due to beam geometry variations under rotation
Exp. #2 8/19/98 (Additional) 10/6/98	O'Henry Peaches Autumn Flame Nectarines	PUV1=0.3 PUV2=0.6 PUV3=2	0.5 0.4	10 60	53 107 654	PUV dose may be lower due to beam geometry variations under rotation
Exp. #3 8/25/98	Red Globe Grapes	PUV1=0.3 PUV2=0.6	0.17-0.24	30	48 95	Rotation
Exp. #4 8/26/98 (Additional) 9/22/98	Thompson Seedless Grapes	PUV1= 0.3 PUV2= 0.6 PUV3= 2	0.22 0.25 0.5	30 60	42 84 310	Rotation
Exp. #5 9/1-2/98	Granny Smith Apples	PUV1=0.5 PUV2=1 PUV3=2	1	20	25 50 100	Rotation
Exp. #6 9/9-12/98	August Red Nectarines	PUV1=1 PUV2=2	0.51-0.66	60	126 252	Rotation
Exp. #7 9/15-17/98	Bosc Pears	PUV1=1 PUV2=2	0.4-0.5	80	115 230	Rotation
Exp. #8 9/29/98 10/1/98	Red Delicious Apples	PUV1=1 PUV2=3	0.3-0.7	60/80 60/80	286/213 857/638	Rotation
Exp. #9 10/13-15/98	Fuji Apples	PUV1=1 PUV2=2	2	50	132 264	Rotation
Exp. #10 11/3-4/98	Hayward Kiwis	PUV1=1.5 PUV2=3	2.1-2.5	40	63 126	Rotation
Exp. #11 11/10-11/98	Eureka & Lisbon Lemons	PUV1=1.5 PUV2=3	2.0-2.2	40	83 166	Rotation

2.3 Quality Evaluations

Fruit quality was evaluated prior to treatment, after 15 and 30 days of cold storage at 0°C (10°C for lemons), and after 15 and 30 days of cold storage plus 5 days of shelf life at 20°C. However, raspberries were cold stored for 6 and 9 days at 0°C with 3 days of shelf life at 20°C.

2.3.1 Flesh firmness

Flesh firmness was determined with a University of California Firmness Tester (Western Industrial Supply Co., San Francisco, California) fitted with an 8-mm probe (pears, nectarines, peaches and kiwifruit) or an 11-mm probe (apple). Fruit skin was removed on two sides of the equatorial region of each fruit and firmness was measured on each side. Flesh firmness on grapes and raspberries was measured using a FirmTech1. This device measures fruit resistance to slight compression, and has been shown to be more accurate then the penetrometer in measuring firmness of sweet cherries (Mitcham et al., 1998). It can only be used for small fruit because of its design.

2.3.2 Skin Color

External skin color was measured on opposite sides of each fruit with a Minolta Chroma Meter (Model CR-300, Minolta, Ramsey, N.J.) in CIE L*a*b* mode under CIE Standard Illuminant C. Changes in hue angle (h°), calculated as h°= arctan b*/a* (deg) (McGuire, 1992) were used to indicate fruit color. For blush colored apples (Fuji), nectarines, and peaches, the background color was measured subjectively (visually) to separate the background color from the blush color.

The following scale was used:

1= green, 2= light green, 3= light yellow, 4= yellow.

2.3.3 Soluble Solids Concentration (SSC), pH, and Titratable Acidity (TA)

Composite tissue samples were collected from several fruit and juiced. The sample was analyzed for SSC using a refractometer (Abbe model 10450; American Optical Corp, Buffalo, N.Y.), and pH and TA using an automatic titrator (Radiometer, Copenhagen, Denmark).

Titration was conducted with 0.1 N NaOH to pH 8.2 and percentage acid equivalents were determined. The following acid equivalents were used:

(1) **Malic acid:** **apples, peaches, nectarines**
(2) **Citric acid:** **kiwifruit, lemon, raspberry; and**
(3) **Tartaric acid:** **grapes.**

2.3.4 Fruit Respiration and Ethylene Production Rates

Carbon dioxide and ethylene production rates were measured at 0, 1, 2, 3, and 5 days at 20°C and standard atmospheric pressure, immediately following PUV treatment and after PUV treatment and cold storage. Single fruit or small grape clusters were sealed in jars for 5 to 30 min, depending on the ripeness stage, and the headspace was sampled with a 10-mL syringe.

An infrared CO_2 analyzer (model PIR-2000R, Horiba Instruments, Irvine, Calif.) was used for CO_2 measurements.

A gas chromatograph (Model 211 Carle Instruments, Anaheim, California) with a Flame Ionization detector and alumina column was used to analyze for ethylene production rates.

2.3.5 Decay, External/Internal Injury, and Berry Leakage

Fruit were also evaluated for decay, and for internal and external injury. Specifically, raspberries were evaluated for berry leakage, and 'Thompson Seedless' grapes were evaluated for shatter and rachis browning.

To determine berry shatter, each grape cluster was shaken manually for several seconds. Berries that detached from the rachis were counted. The percentage of berries that detached was calculated. The percentage of fruit showing any signs of decay or injury was recorded.

In addition, the severity of the decay or injury was indicated with the following scale:

0= None, 1=Slight, 2= Moderate, 3= Severe.

An average of the severity score is presented in the results.

2.3.6 Weight Loss

The effect of PUV treatment on fruit weight loss was also evaluated. After weighing, single fruit samples or small grape clusters were placed on a weight loss unit at 20°C. An uniform 15 cubic feet per minute (cfm) flow of non-humidified air was pulled past each sample. After 24 or 48 hours, sample weight was measured again to determine weight-loss differences between samples. For presentation, weight loss was calculated and presented for a 24 hour period.

2.3.7 Sample Size

The sample size for each group of fruits studied is summarized in Table D (page 36) below.

Table D: Sample Sizes per Fruit Commodity

Fruit	Date Fruit Obtained	No. Fruit per Replicate (3 replicates)	No. Fruit per Juice Sample	No. Fruit for Gas Measurements
O'Henry' Peach	8/18/98	8	4	10
'Autumn Flame' Peach	10/10/98	6	3	0
'August Red' Nectarine	9/9/98	6	3	8
'Heritage' Raspberry	8/18/98	24	12	0
'Red Globe' Grape	8/25/98	3 berries from 8 clusters/rep	12	10
'Thompson Seedless' Grape	8/26/98	3 berries from 8 clusters/rep	12	10
'Granny Smith' Apples	9/2/98	8	4	10
'Red Delicious' Apples	9/28/98	6	3	8
'Fuji' Apples	10/13/98	6	3	8
'Bosc' Pears	9/15/98	6	3	8
'Hayward' Kiwifruit	10/4/98	6	3	8
'Eureka' Lemon	11/9/98	6	3	8

2.3.8 Statistical analysis

Analysis of variance (ANOVA), followed by Duncan's Multiple Range Test with a significance level of $P<0.05$ were performed on all data using SAS 6.12 Statistical Software. Results of all determinations reported here contains this statistical analysis method.

3. RESULTS

3.1 'O'Henry' Peaches

There were few statistically significant differences in fruit quality following treatment of 'O'Henry' peaches with PUV 1 and PUV2 (see Appendix: Table 1A, page 73).

There was a detectable higher SSC in PUV-treated fruit at the 15-day evaluation; however, there were no statistically significant differences at any other evaluation times.

There were detectable differences in pH after 5 days of shelf life; however, there was no consistent trend with respect to the treatments.

There were detectable differences in external color at the 15 day evaluation only with treated fruit showing a lower L value (darker) and hue angle (more yellow).

There was no external fruit damage and no significant effect on the natural incidence of fruit decay. There was little decay in fruit samples.

All peaches became mealy after cold storage, regardless of the treatment (data not shown).

There was no statistically significant difference in weight loss during post-treatment storage (see Appendix: Table 22, page 94).

Respiration and ethylene production was not significantly different between treatments, but increased with time at 20°C (see Appendix: Table 2, page 74).

3.2 'Autumn Flame' Peaches

PUV3 treatment had no measurable effect on fruit firmness, SSC, TA, pH or decay at 15+5 days after treatment (see Appendix: Table 1B, page 74).

PUV3 treatment resulted in more than 55% of the fruit exhibiting severe external injury.

3.3 'August Red' Nectarines

Fruit firmness, TA, external color, ground color, and weight loss were not significantly influenced by PUV treatment (see Appendix: Table 3, page 75, and Table 22, page 94).

There was a detectable lower SSC in PUV-treated fruit after 30 and 30+5 days post-treatment.

However, at 15 d there was no statistically significant difference between treatments and at 15+5 days, PUV1-treated fruit had higher SSC.

Fruit pH was higher in PUV2-treated fruit at the 30 day evaluation only.

Decay incidence and severity was the same as untreated fruit or higher.

Nectarine fruit developed a brown external damage. This damage occurred on both untreated and treated fruit, but the incidence and severity was greater with PUV-treatment, regardless of the dose. It is possible that this damage was increased by additional handling of the fruit during PUV treatment.

The exact cause of the damage is unknown, but it may be a disorder which has been referred to as Inking. The incidence of inking has been related to skin abrasion (Cheng and Crisosto, 1994).

All control and PUV treated nectarines developed mealiness after 30 days of cold storage and shelf life, regardless of the treatment (data not shown).

Fruit respiration was elevated by PUV treatment immediately after treatment; however, there was no statistically significant difference in ethylene production (see Appendix: Table 4, page 76).

After 15 or 30 days in storage, no significant differences in respiration or ethylene production were found. Fruit respiration rate and ethylene production increased with time at 20°C.

3.4 Raspberries

There was no effect of PUV treatment on berry firmness (measured at 6 and 6+3 days only due to over-softening and decay at 9 days), SSC, external condition, internal condition, weight loss, or berry leakage (see Appendix: Table 5, page 77 & Table 22, page 94).

Total acidity (TA) was significantly different between treatments at 6 and 9 days; however, at 6 days PUV2-treated fruit had a higher TA than untreated fruit and at 9 days PUV2-treated fruit had a lower TA with corresponding higher pH.

The effect on fruit color was somewhat inconsistent. At 6 and 9+3 days, the higher the PUV dose, the lower the hue angle, indicating darker and more senescent fruit. However, at 6+3 days, PUV2-treated fruit had a slightly higher hue angle than untreated fruit. Decay incidence was very high on the raspberry fruit, especially after 3 days at 20°C.

The incidence of decay was slightly higher in PUV-treated fruit after 6 days of cold storage and the severity was also greater in PUV2-treated fruit. However, after 9+3 days, PUV treatment reduced the severity of decay relative to untreated fruit, although 100% of the fruit had decay.

3.5 'Red Globe' Grapes

PUV treatment had no effect on berry SSC, TA, pH, external color (L value and hue angle), weight loss, and external or internal condition (see Appendix: Table 6, page 78 & Table 22, page 94).

Rachis condition and berry shatter were not evaluated because the rachis were in poor condition at the start of the experiment.

There were statistically significant differences in berry firmness among the treatments; however, there was little consistent trend from one evaluation to the next. At 30 days, the PUV-treated berries were softer than untreated berries. But at 30+5 days, PUV2-treated berries were most firm. At 15 and 15+5 days, PUV1-treated berries were softer than untreated berries, but PUV2-treated berries were not statistically significantly different from untreated berries.

Differences in natural decay incidence between treatments were only detected after 30 days of cold storage. The decay incidence and severity was greater in PUV-treated clusters.

There was a statistically significant higher rate of respiration immediately after treatment (see Appendix: Table 7, page 79). The higher rate of respiration was also noted after 15 days of cold storage. Respiration rate decreased with time at 20°C.

3.6 'Thompson Seedless' Grapes

PUV treatment had no effect on TA, external or internal berry condition, weight loss, or berry shatter (see Appendix: Table 8, page 80 & Table 22, page 94).

As with 'Red Globe', there were detectable differences in berry firmness between treatments, but no consistent trends. After 15 days, PUV-treated berries were softer, but after 15+5 days, PUV-treated berries were firmer. After 30 days, PUV-treated berries were softer than untreated berries. Firmness of 30+5 day fruit was not available due to excessive berry decay.

SSC also showed some detectable differences between treatments but were inconsistent, with PUV-treated fruit having lower SSC at 15 days and higher SSC at 30+5 days.

Berry pH tended to be higher in PUV-treated fruit, indicating lower TA although TA showed no statistically significant differences.

PUV-treated fruit tended towards lower skin color hue angle and L values indicating berries were more yellow as compared with untreated fruit.

Rachis browning increased with time in storage and particularly during the 5 days of shelf life. PUV2-treated clusters had more rachis browning after 15 days and both PUV-treated clusters had more rachis browning after 30 days of cold storage. The severity of rachis browning was greater in PUV-treated clusters as compared with untreated clusters after 30 and 30+5 days.

There was no visible decay after 15 days of cold storage, but decay increased greatly by 30 days of cold storage. After 5 days of shelf-life, regardless of the storage time, decay incidence increased to 100% of the clusters. Decay severity was greater in PUV-treated fruit at the 30 day evaluation.

Cluster respiration was statistically higher immediately after treatment, but differences were not detected after 15 or 30 days of cold storage (see Appendix: Table 7, page 79).

A limited evaluation of a third PUV dose, PUV3, was conducted with a separate group of control fruit. After treatment, fruit quality was evaluated after 15 days of cold storage.

There were no detectable differences in fruit quality (see Appendix: Table 9, page 81). However, rachis browning and decay were 100% in both treated and control clusters.

Berry firmness was not measured.

3.7 'Granny Smith' Apples

There was no effect of PUV treatment on firmness, SSC, TA, pH, skin color (L value and hue angle), internal condition, or decay (see Appendix: Table 10, page 82).

External injury was observed at the 30+5 day evaluation in PUV3-treated fruit. Slight external injury was noted in the PUV2-treated fruit, but it was not statistically different from the untreated fruit.

Weight loss was higher in fruit PUV3-treated, as measured immediately after treatment, and higher in fruit from PUV1, PUV2 and PUV3 treatments, as measured after 30 days

of cold storage; however, overall weight loss was lower in 'Granny Smith' than in 'Red Delicious' or 'Fuji' apples (see Appendix: Table 22, page 94).

Fruit from PUV2 and PUV3 treatments had higher respiration rate immediately after treatment, while there was no effect on ethylene production (see Appendix: Table 11, page 83). Respiration continued to be higher in treated fruit after cold storage, and after 30 days of cold storage, all PUV-treated fruit had higher respiration rates.

Given these results, it is interesting that there were no detectable effects on fruit quality as a result of these treatments.

3.8 'Red Delicious' Apples

There was no effect of PUV treatment on 'Red Delicious' apple firmness, SSC, external or internal condition, decay or weight loss (see Appendix: Tables 12, page 84 & table 22, page 94).

Juice pH was higher and skin color was darker (lower L value) in PUV2-treated fruit after 30 days of cold storage, but there were no detectable differences at other evaluation times.

There were statistically significant differences in TA between treatments at 15 and 15+5 days, but no pattern relative to treatment emerged.

The rate of respiration was higher in PUV2-treated fruit immediately after treatment (see Appendix: Table 13, page 85). This difference was not detected after cold storage.

3.9 'Fuji' Apples

There was little significant effect of PUV treatment on 'Fuji' apple quality (see Appendix: Table 14, page 86).

At 15+5 days, PUV2-treated fruit were more firm than untreated fruit and had higher SSC.

Juice pH was higher in PUV2-treated fruit after 15 days of cold storage, but no differences between treatments were detected at other evaluation times.

PUV treatment had no effect on weight loss, respiration rate or ethylene production (see Appendix: Table 15, page 87 & Table 22, page 94).

3.10 'Bosc' Pears

There was no effect of PUV treatment on pear firmness, SSC, TA, pH, external or internal condition, weight loss, decay, respiration rate or ethylene production with one exception (see Appendix: Table 16, page 88; Table 17, page 89; & Table 22, page 94).

Juice pH of PUV2-treated fruit was lower than untreated and PUV1-treated fruit after 30+5 days.

3.11 'Hayward' Kiwifruit

There was no effect of PUV treatment on kiwifruit juice pH, external or injury injury, decay, weight loss, respiration rate or ethylene production (see Appendix: Table 18, page 90; Table 19, page 91; & Table 22, page 94).

At 15+5 days, fruit were softer after PUV1 and PUV2 treatment as compared with untreated fruit.

SSC was higher in PUV2-treated fruit after 15+5 days and 30 days of cold storage. TA was lower in PUV-treated fruit at 15+5 days, but no detectable differences were found at other evaluation times.

3.12 'Eureka' Lemons

There was no effect of PUV treatment on lemon SSC, TA, decay, weight loss, or ethylene production (see Appendix: Table 20, page 92; Table 21, page 93; & Table 22, page 94).

Fruit treated with PUV2 had consistently a lower pH, and fruit treated with PUV1 had a lower pH after 15+5 days of storage.

Both PUV doses caused considerable skin damage resulting in changes in the skin color. Both the L value and the hue angle were lower in PUV-treated fruit indicating skin browning. PUV2 had a greater effect on fruit color than PUV1 as shown by L color at all evaluations (except after 15+5 days) and in hue angle at the 30 and 30+5 day evaluations.

External injury was severe in both PUV1 and PUV2-treated fruit and severity was only greater in PUV2-treated fruit at the 30-day evaluation.

The fruit respiration rate was higher in PUV-treated fruit immediately after treatment, but not after cold storage (see Appendix: Table 21, page 93).

4. DISCUSSION

4.1 Fruit Response to PUV Treatment

PUV treatment had an obvious deleterious effect on 'Eureka' lemons, 'Thompson Seedless' grapes, and 'Autumn Flame' peaches (PUV3 only), causing skin damage on the lemon and peach, and rachis browning on the grape.

The PUV3 dose caused skin damage to 'Granny Smith' apples, while there was no significant damage from PUV1 and PUV2 treatments.

It is unknown whether rachis browning would have also been observed on 'Red Globe' grapes as the rachis were already browned at the start of the test. From the 'Thompson Seedless' trials, it seems obvious that a 5 d shelf-life at 20°C was too long. Evaluation after 3 d at 20°C would have been better.

The damage on the 'August Red' nectarines was not caused by the PUV treatment, as control fruit were also affected, although to a lesser degree. It appears that PUV damage exacerbates this skin damage, perhaps due to the increased physical handling during treatment.

In future studies, control fruit should be handled similarly to treat fruit in all aspects of the trial, including handling during PUV exposure.

Further work is necessary to determine if PUV has a physiological effect in increasing the browning damage on the nectarine skin.

Many fruit showed differences in SSC, TA, pH, firmness and skin color between the control and PUV-treated fruit at various evaluation times. The differences were often seen only at one or two evaluation times, and in many cases there were no consistent trends or differences between the treatments.

The only trends that showed some consistency were berry softening in grape and lower pH in 'Thompson Seedless' grape and 'Eureka' lemon juice. However, further work would be needed to determine if these effects would be consistent and of commercial importance.

PUV treatment had no effect on fruit weight loss, except for 'Granny Smith' apples where the weight loss was greater after PUV treatment in some evaluations. The differences in weight loss would become greater after several months of cold storage. However, the weight loss in 'Granny Smith' apples was lower than in 'Red Delicious' and 'Fuji' apples, and weight loss is generally not an issue for 'Granny Smith' apples.

The PUV treatment increased the rate of fruit respiration immediately after treatment of 'August Red' nectarines, 'Thompson Seedless' and 'Red Globe' grapes, 'Granny Smith'

and Red Delicious' apples, and 'Eureka' lemons. The higher respiration rate continued after cold storage in 'Red Globe' grapes and 'Granny Smith' apples.

Higher respiration rates of 'Eureka' lemons, 'Thompson Seedless' grapes, and 'August Red' nectarines might be expected given the damage (or increased damage) from the PUV treatment. The higher respiration rate in 'Red Globe' grapes probably indicates that they too would likely suffer damage to the rachis as with 'Thompson Seedless' grapes.

For 'Granny Smith' apples, respiration rate was higher for fruit from all PUV treatments.

External damage was severe in PUV3-treated fruit, and was slight in PUV2-treated fruit (not statistically significant). While there was no visible external injury in PUV1-treated fruit, the higher respiration rate may indicate that some injury had occurred. This is also supported by the increase in the rate of water loss in PUV-treated fruit at the 30 day evaluation.

The reason for higher respiration in 'Red Delicious' apples is unknown.

For the PUV doses tested, 'Thompson Seedless' grapes, 'Autumn Flame' peach (PUV3 only), and 'Eureka' lemons did not tolerate the treatments.

Additional work is needed on 'August Red' nectarines to look more closely at the skin browning and 'Red Globe' grapes to look at rachis browning.

'Granny Smith' apples should be evaluated after long-term cold storage to determine if increased weight loss and respiration rates effect quality over time.

'Red Delicious' and 'Fuji' apples, 'Bosc' pears, 'O'Henry' peaches, 'Hayward' kiwifruit and 'Heritage' raspberries did not appear to be affected by PUV treatment in the doses used in this study.

4.2 Decay Control

The objective of this portion of the study was to observe the effects of PUV treatment on fruit quality. In a separate experiment, fruit from the same source were evaluated to determine the decay-control afforded by the PUV treatments. However, as a part of our evaluations, we rated fruit for their natural incidence of decay. In many cases, these were latent infections within the fruit.

When decay was found, PUV treatments did not result in lower incidence of decay and in most cases resulted in increases in the incidence and severity of fruit decay.

The effect of additional handling steps for PUV-treated fruit on decay incidence is unknown, but could be significant for fragile fruit such as raspberries.

Acknowledgement

We gratefully acknowledge the excellent technical assistance of David Bouck, Michelle Lauer, George Sakaldasis and Quinn Avery. We are particularly appreciative of statistical assistance from Murray Clayton.

REFERENCES

1. Cheng, G.W. and C.H. Crisosto. 1994. Development of dark skin discoloration on peach and nectarine fruit in response to exogenous contamination. J. Amer. Soc. Hort. Sci. 119:529-533.

2. McGuire, R.G. 1992. Reporting of objective color measurements. HortScience 27:1254-1255.

3. Mitcham, E.J., M. Clayton, and W.V. Biasi. 1998. Comparison of devices for measuring cherry fruit firmness. HortScience 33:723-727.

IV. ENTOMOLOGY EXPERIMENTATION[1]

Jeffrey Granett and Amir Omer
Department of Entomology

(Edited by Manuel Lagunas-Solar)

1. INTRODUCTION

Several adult insect/mite models were used to study the photothermal effect (immediate and delayed) of pulsed UV. Batches of selected insects and mites of quarantine importance in commercial quality fruits were exposed under simulated conditions to pulsed UV light. The most important life cycle stages present in fruits were tested.

Because the objectives of the project is to establish a process for quarantine control of relevant insect and mites, the selection of the models was focused on the following criteria:

(a) A range of PUV tolerance to establish a model relationship between the PUV process total energy and the biological effect on the treated insects/mites, thus permitting the extrapolation to other species that might be involved in the quarantine process.

(b) Exclude the host-insect/mite relationship established in the previous protocol to generalize the applicability of the model data.

(c) To further select the target insect/mites excluding non relevant pest problems of quarantine concern.

(d) Due to quarantine restrictions and/or non availability of comparable target species, other related insects locally available were also studied.

The three chosen insect/mite models are characterized by:

(1) *Pseudococcus sp.* (grape mealy bugs). This model represents the most PUV tolerant species known as of today. This model was studied in the 0.1 to 10 J/cm^2 PUV energy range.

(2) *Brevipalpus* mite (*Brevipalpus sp.*), representing a medium tolerant species. This model was studied in the 0.05 to 2 J/cm^2 PUV energy range.

[1] **This section of the report was edited by the author from data and results obtained from the listed collaborators.**

(3) *Frakliniella occidentalis* (Western flower thrips), as the apparently least tolerant species. This model was studied in the 0.02 to 3 J/cm^2 PUV energy range.

The selected PUV energy ranges were determined based upon existing data on fruit tolerance to PUV being generated in this project (i.e. Food Quality Experiments). However, other PUV energy dose experiments for these models were also conducted when the insect the PUV tolerance range needed to be measured.

The selected models represented a range of PUV tolerances from which it was expected other information could be extrapolated to new insects and/or mites.

PUV dose - biological effects relationships were measured with the three insect/mite selected models.

Threshold PUV dose required for lethal and sub-lethal effects leading to insect/mite controls were also derived from the data.

2. MATERIALS AND METHODS

Insect/mite were collected from several California regions and colonies were maintained at the Department of Entomology laboratory facilities.

Insect/mite batches of > 20 individual specimens were used in each PUV dose measurement.

All insect/mite batches were held onto plant tissue such as leaves and in appropriate containers permitting the handling and the maintenance of each batch.

2.1 PUV Illumination

All the PUV illumination experiments were performed with a pulsed UV laser source with insect/mite samples in a static position. The mobility of insect/mites samples was restricted by either temperature controls or by physical methods (enclosed containers). All non PUV treated samples used as controls were treated in an identical fashion.

Parameters documented included wavelength (248 nm), energy fluence (0.10 - 60 mJ/cm^2/pulse), and total energy (0 - 10 J/cm^2) on the surface of the treated samples.

All energy related measurements were measured using "joulemeter" and standardized and calibrated photon detectors.

The frequency of operation (repetition rate) or the number of pulses per second (PPS) was limited to 80 Hz, and was also recorded.

The range of energy fluence utilized was required to provide information on the desired biological effect (instant or delayed mortality) and was limited to a range of 0.10 -60 $mJ/cm^2/p$.

Insect/mites samples treated with pulsed UV laser sources were exposed in an special holding device in a fix position (without rotation) to allow for precise PUV exposure determination on the samples.

All different biological stages (eggs, juvenile or adults) present in the sample were assayed. However, the most resistant stage, adult insect/mites, were studied under the established statistical criteria.

Depending on the model being studied, immediate observation and up to 8 days after PUV illumination were done for *Brevipalpus sp.* and *Frakliniella occidentalis* to determine instant and/or delayed lethal effects.

However, for *Pseudococcus sp.*, and for non-mobile insects such as San Jose scale, assessment of the potential biological effects were conducted for much longer periods of observation.

For all the insect/mite experiments, survival or mortality was reported.

3. DATA AND RESULTS

3.1 Pseudococcus sp. (grape mealy bugs)

Mealy bugs were chosen and predicted to be the most resistant species against any conventional chemical treatment.

The results of PUV treatment are summarized in Table E (page 49) and shown in Figure 3 (page 50).

The observations after PUV treatment was performed under the following criteria:

1. Biological assays were performed with all samples inside plastic cups. However, insects were provided with fresh grape foliage as food immediately after treatment.

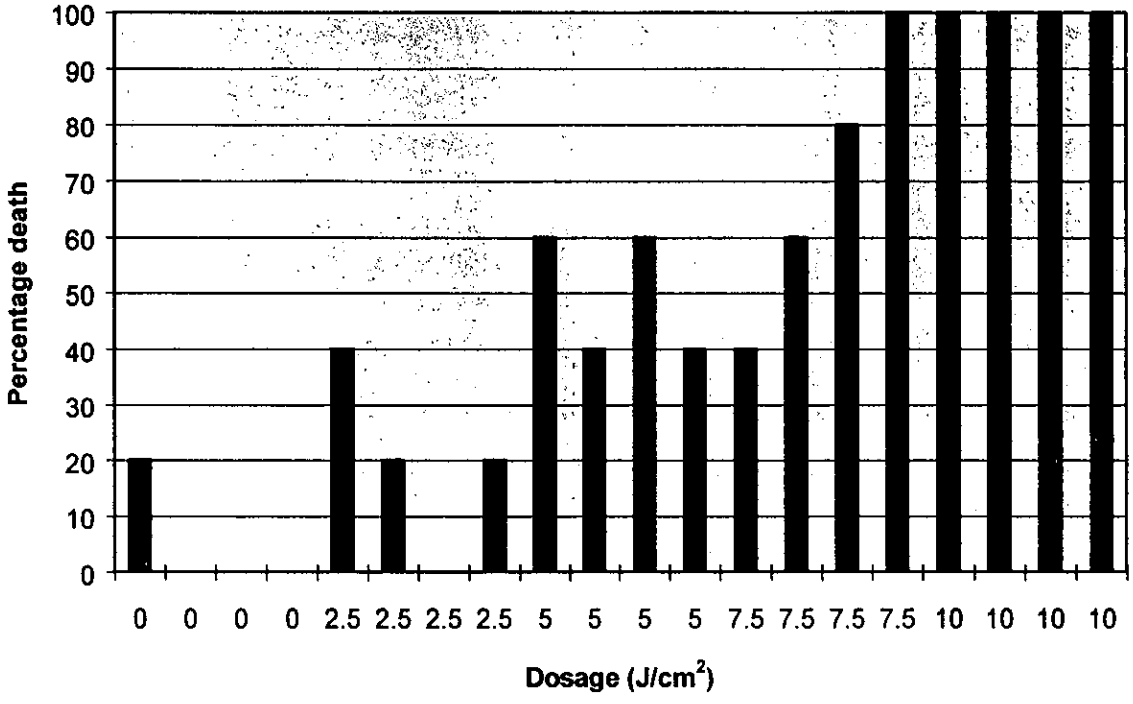
2. Monitoring for immediate or delayed mortality was done for 8 days after treatment with single or double observations daily.

3. Any insect was considered alive if it moved at least one body length when gently prodded with a fine paint brush.

Table E: Mortality Rate of Pseudococcus sp. (Grape Mealy Bugs) Exposed to Pulsed UV (248 nm). PUV Treatment Date: April 6, 1999.

			Daily & Total Mortality Scores									
Dose J/cm^2	Insect Size	Number of insects	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Total Insects	Percent Total (%)
0	Large	5	0	0	0	0	0	0	1	0	1	20
0	Large	5	0	0	0	0	0	0	0	0	0	0
0	Large	5	0	0	0	0	0	0	0	0	0	0
0	Large	5	0	0	0	0	0	0	0	0	0	0
2.5	Large	5	0	0	0	0	0	1	1	0	2	40
2.5	Large	5	0	0	0	0	0	0	1	0	1	20
2.5	Large	5	0	0	0	0	0	0	0	0	0	0
2.5	Large	5	0	0	0	0	0	0	0	1	1	20
5	Large	5	0	0	0	0	1	1	1	0	3	60
5	Large	5	0	0	0	0	1	1	0	0	2	40
5	Large	5	0	0	0	1	1	0	1	0	3	60
5	Large	5	0	0	1	0	0	0	0	1	2	40
7.5	Large	5	0	0	0	0	0	0	2	0	2	40
7.5	Large	5	0	0	0	0	1	1	0	1	3	60
7.5	Large	5	0	1	0	0	1	2	0	0	4	80
7.5	Large	5	0	0	0	1	1	3			5	100
10	Large	5	2	3							5	100
10	Large	5	3	2							5	100
10	Large	5	3	2							5	100
10	Large	5	3	2							5	100

Figure 3: Pulsed UV (248 nm) Induced Mortality on Pseudococcus sp. (Mealy Bugs)



3.2 Brevipalpus mite (*Brevipalpus sp.*)

Brevipalpus sp. were assumed and predicted to be of medium tolerance against the effects of pulsed UV.

Extensive research was done on the different biological cycles of the Brevipalpus sp. as preliminary research was also conducted under the FONDEF 2-63 project completed in December of 1996.

The data summarized here correspond to additional tests conducted using the methodology described here.

3.2.1 High Fluence Studies: General Results with Adults and Juveniles

When high fluence levels were used, instant mortality of adult Brevipalpus sp. was demonstrated as follows:

1. At a 64 mJ/cm^2/p fluence level, a single pulse (1 Hz), that is a 64 mJ/cm^2 energy dose was sufficient to cause instant mortality in both Adult and Juvenile mites (n= 8 adults; n=14 juveniles);

2. At a 200 mJ/cm^2/p fluence level, 4 pulses (at 1 Hz), that is a 800 mJ/cm^2 energy dose was sufficient to cause instant mortality (n= 12 mites).

However, under these high fluence levels, there is no data on the potential effects on the sensory or physiological behavior of fruits. Therefore, despite the low energy dose, and the effective PUV treatment causing instant mortality, this operational mode for PUV has not been considered or studied further.

3.2.2 PUV Fluence Effects on Delayed vs. Instant Mortality (Adult Mites)

A series of experiments were conducted with Adult mites to study dose-effect relationships using 248-nm PUV photons.

The results are shown in Figure 4 (page 52); and Figure 5 and Figure 6 (page 53).

Several results are useful and need further comments:

(1) At 248 nm and at 1 Hz repetition rate, instant mortality can be induced with several operational conditions. First. with ~ 14 mJ/cm^2/p fluence levels, approximately 1,200 mJ (1.2 J) of PUV energy is required to achieve instant mortality (Figure 4, page 52). However, no instant mortality was achieved below ~ 900 mJ.

(2) At 248 nm and at 1 Hz repetition rate, instant mortality was induced at a threshold of ~ 1,000 mJ (~1 J) with an energy fluence of 30 mJ/cm^2/p. Higher PUV energies (~ 1,600 mJ and 2,000 mJ) confirmed this result (see Figure 5, page 53).

(3) At 248 nm and 1Hz repetition rate, using a similar fluence level of 30 mJ/cm^2/p as before, instant mortality was observed at a >90% level even with 100 mJ/cm^2 (see Figures 5 and 6, page 53).

(4) Under these same conditions, 100% delayed mortality (1 - 4 h past PUV treatment) was observed with 100 mJ levels and confirmed with 200, 400, and 800 mJ energy levels (see Figures 5 and 6, page 53).

It is concluded that it appears possible to operate at total energies (mJ/cm^2) which may not damage fruits, but further studies are needed to ascertain and document the potential effect of various fluence levels on different commercial varieties.

Figure 4. Pulsed UV (248 nm) Mortality effects on Brevipalpus sp. (Adults: n = 24)

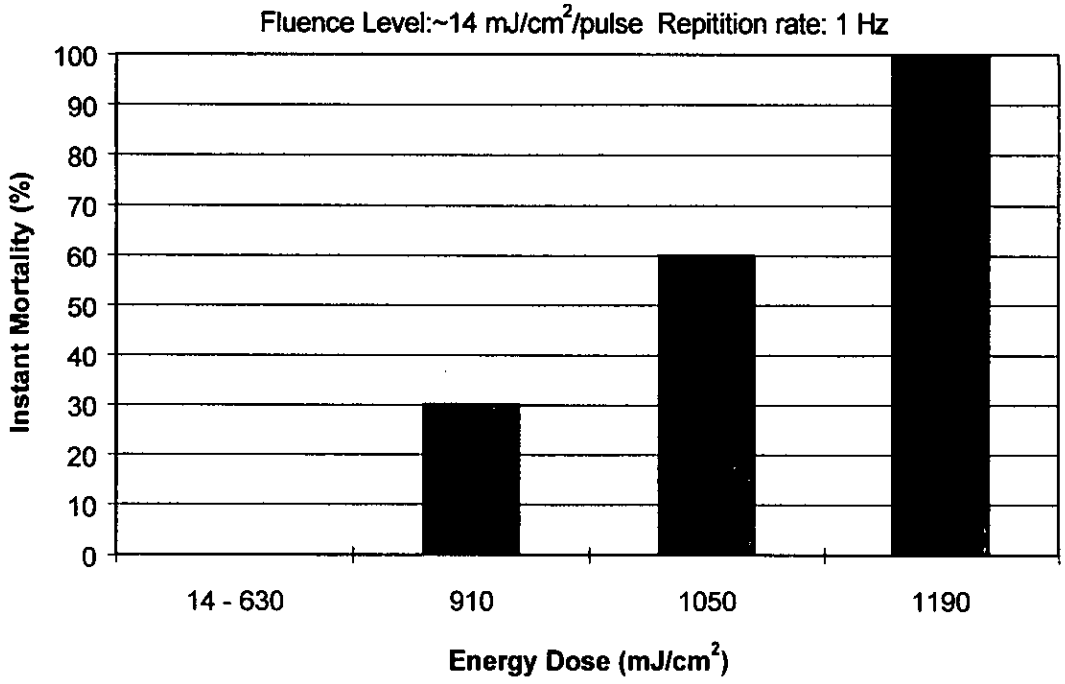


Figure 5. Pulsed UV (248 nm) Mortality Effects on Brevipalpus sp. (Adults; n = 85)

Fluence Level:~30 mJ/cm^2/pulse Repetition rate: 1 Hz for Energy Doses between 0 and 240 mJ, 5 Hz for 300 mJ and greater

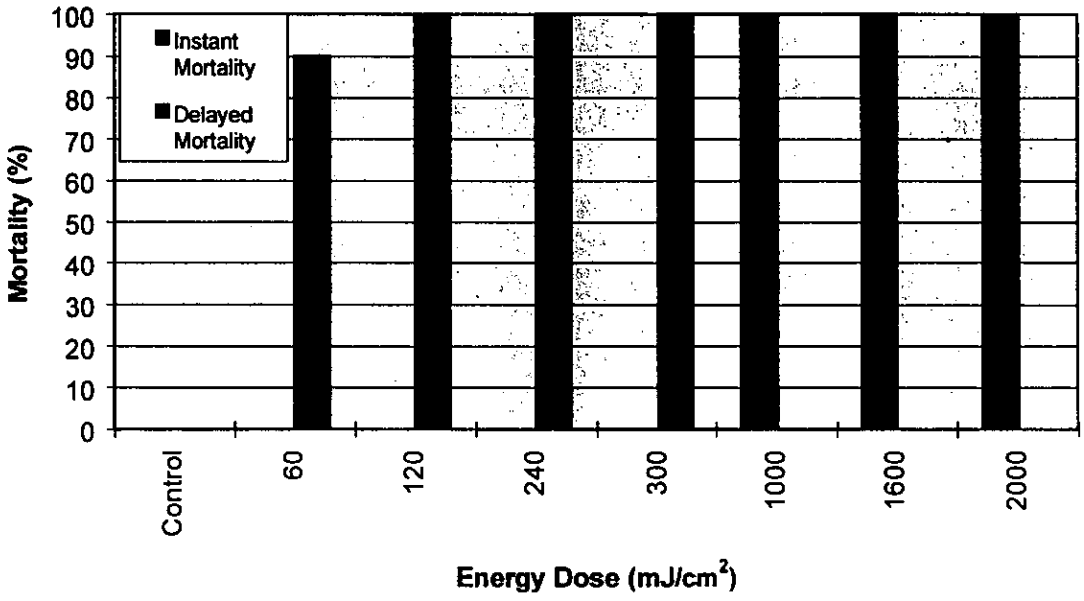
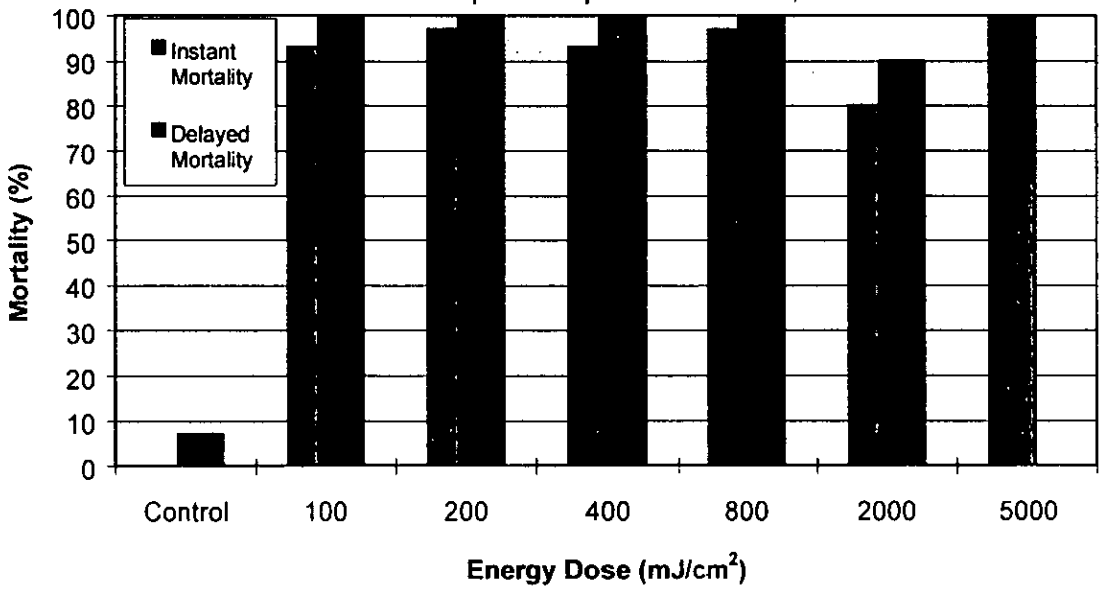


Figure 6. Pulsed UV (248 nm) Mortality Effects on Brevipalpus sp. (Adults; n=35)

Fluence Level:~27 mJ/cm^2/pulse Repetition rate: 1 Hz; 5Hz at 2 & 5J



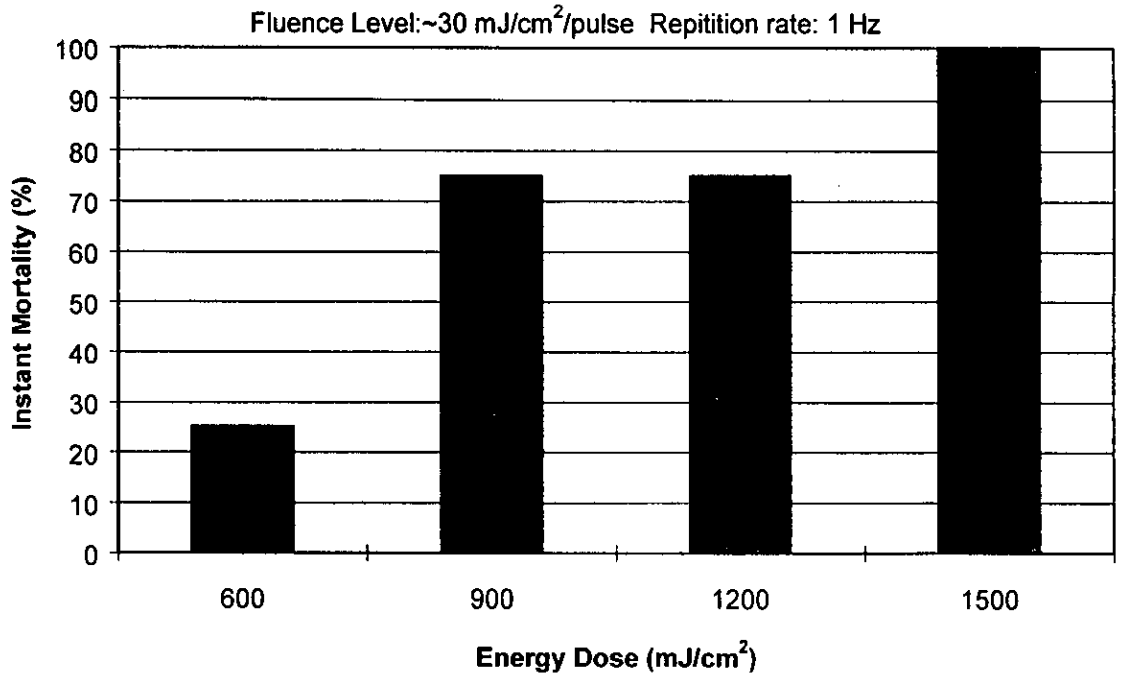
3.2.3 PUV Wavelength Effects. Mortality Effects with 308-nm PUV Photons

Because different PUV light sources are being considered and studied for potential commercialization, studies using 308 nm photons (~ 4 eV/photon) were also conducted. These experiments were conducted using the same methodology as indicated before.

The results of these measurements are shown in Figure 7 (page 54), below, and indicated that effective instant mortality can be achieved at similar fluence levels (~ 30 $mJ/cm^2/p$) as used in similar experiments conducted at 248 nmm (5 eV/photon)(see section 3.3, above).

However, with 308 nm PUV photons instant mortality required approximately 50% (or 1,500 mJ; 1.5 J) more PUV energy dose as compared with the results obtained with 248-nm PUV photons (see Figure 7, below).

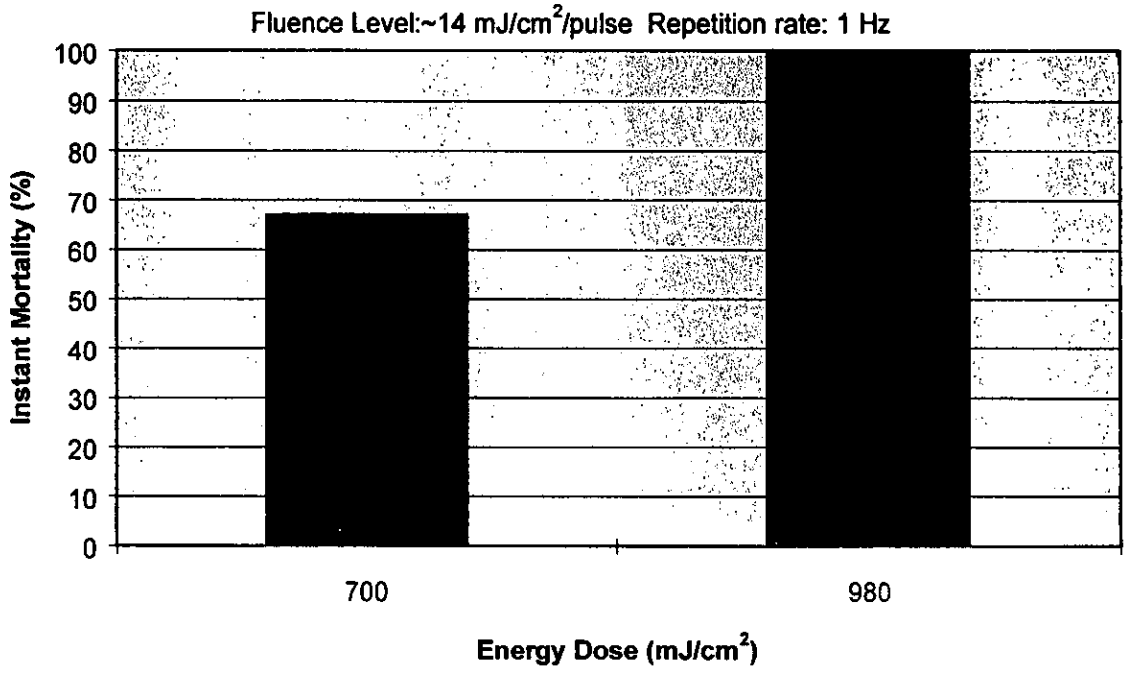
Figure 7. Pulsed UV (308 nm) Instant Mortality Effects on Brevipalpus sp. (Adults; n= 65)



3.2.4 PUV Effects on Juvenile Brevipalpus sp. Mites

Similar studies were conducted with samples of Brevipalpus sp. in the juvenile stage. These mites are, of course, smaller in size and in exposed area as compared to the adults mites and, therefore, under similar PUV exposure conditions juvenile samples will receive proportionally smaller energy doses.
The results of these measurements are shown in Figure 8 (page 55).

Figure 8. Pulsed UV (248 nm) Mortality Effects on Brevipalpus sp. (Juveniles; n= 68)



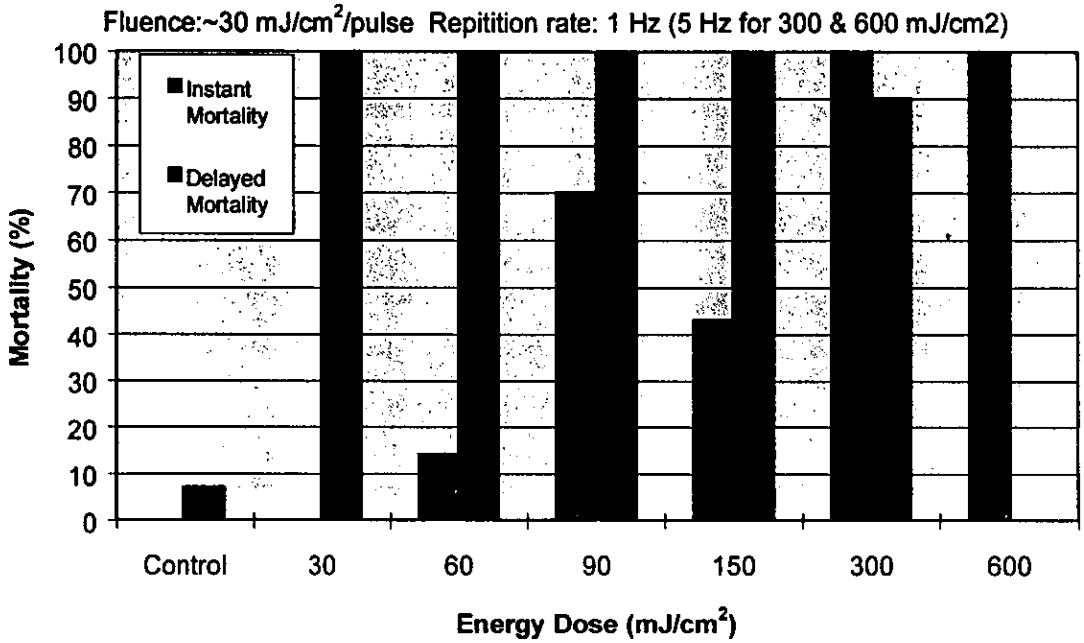
Under similar energy fluence and PUV exposure conditions (~ 14 mJ/cm^2/p), a 100% instant mortality was measured at ~1,000 mJ/cm^2 (1 J/cm^2), a result that is somewhat similar to the adult mites (see section 3.4, above). It was then concluded that there is no significant difference in the PUV (248 nm) mortality effects measured for either adult and juvenile stages of *Brevipalpus sp.*, when operating the PUV source under the conditions detailed above, but only when exposure energy doses are considered.

If exposure levels are converted into absorbed energy, taking into account the surface ratio between adults and juveniles, then juveniles are to be designated as more sensitive to PUV treatment than adult mites.

The effects of PUV on the eclosion of *Brevipalpus sp.* eggs, was further studied with a fluence of ~ 30 mJ/cm^2/p. These results are shown in Figure 9 (page 56), and indicated again similar results to those obtained for adult mites. In this case, however, delayed mortality (1-6 h) at a level of 100% was achieved even at > 30 mJ/cm^2 and above (see Figure 9, page 56), while instant mortality was achieved at > 300 mJ/cm^2.

It appears then that with higher fluence levels, juveniles are more sensitive to PUV by a factor of approximately 3 times with respect to the adult mites.

Figure 9. Pulsed UV (248 nm) Mortality Effects on Brevipalpus sp. (Juveniles, n= 95)



3.2.5 PUV Mortality Effects on Eggs of Brevipalpus sp.

Similar experiments were conducted with egg samples of *Brevipalpus sp.* Again, while exposure energy levels (mJ/cm^2) were monitored, eggs are considerable smaller targets, estimated to be 1/20 of the surface area of an adult mite. Therefore, in delivering the PUV dose, these geometry factors must be considered.

The results of preventing the eclosion of *Brevipalpus sp.* eggs are shown in Figures 10 to 15 (pages 58 to 60) and summarize the following studies:

1. Figures 10-13 (pages 58-59): PUV Fluence & Exposure Energy Effects at 248 nm.
2. Figures 14-15 (page 60): PUV Repetition Rate Effects at Constant Fluence (30 $mJ/cm^2/p$).

The results of these studies are as follows:

(1) Because of geometry factors (i.e. small surface area), high fluence are required for an effective control of eclosion. This can be seen by inspecting the results summarized in Figures 14 & 15 (page 60).

(2) At PUV fluence levels ranging from 4 (Figure 10, page 58) to 60 (Figure 13, page 59) $mJ/cm^2/p$, > 95% control of eclosion can be achieved with PUV exposure levels of ~ 300 mJ/cm^2. Targeting the PUV beam may have been unreliable in these

experiments as ~95% control of eclosion was also achieved with only 30 mJ/cm^2 (see Figure 11, page 58).

(3) There is no measurable effect on eclosion effects due to repetition rate (see Figures 14 & 15, page 60).

The data obtained from all experiments show clearly that for all biological phases of *Brevipalpus sp.* (Acari :Tenuipalpidae) the following can be concluded:

1. Pulsed UV treatments, at 248 nm, as well as at 308 nm, are effective in controlling both, the eclosions (at 248 nm) and survival of *Brevipalpus sp.* mobile phase (248 nm and 308 nm). Pulsed UV treatment at 248 nm seems to be app. 1.5 - 30 times, depending on fluence level, more effective than the same treatment at 308 nm.

2. In case of *Brevipalpus sp.* mobile phase (adults and juveniles) the energy dose required to obtain 100% control of this mite immediately after exposure and 24 h later, varies depending on fluence level.

3. Data obtained at 248 nm with high fluence PUV exposures at 64 mJ/cm^2/p showed that a 100% instant control of adults with app. 60 mJ/cm^2 energy dose is possible.

4. The above fluence and energy levels appeared to be adequate for some fruits although some restrictions are also possible.

5. The mite mobile phase - adult, seems to be the most resistant phase in the live cycles of *Brevipalpus sp.*

6. Minimum energy required for instant dead of juveniles is lower and varies with energy fluence.

7. Eggs of *Brevipalpus sp.* are more sensitive to the UV light at 248 nm than mobile phase of this mite.

8. Changes in physical appearance and discoloration were observed in all samples (eggs, adults and juveniles) treated with doses higher than ~300 mJ/cm^2. This effect is due to a high UV absorption of some surface pigments on mites.

Figure 10. Pulsed UV (248 nm) Eclosion Effects on Brevipalpus sp. (Eggs, n=80)

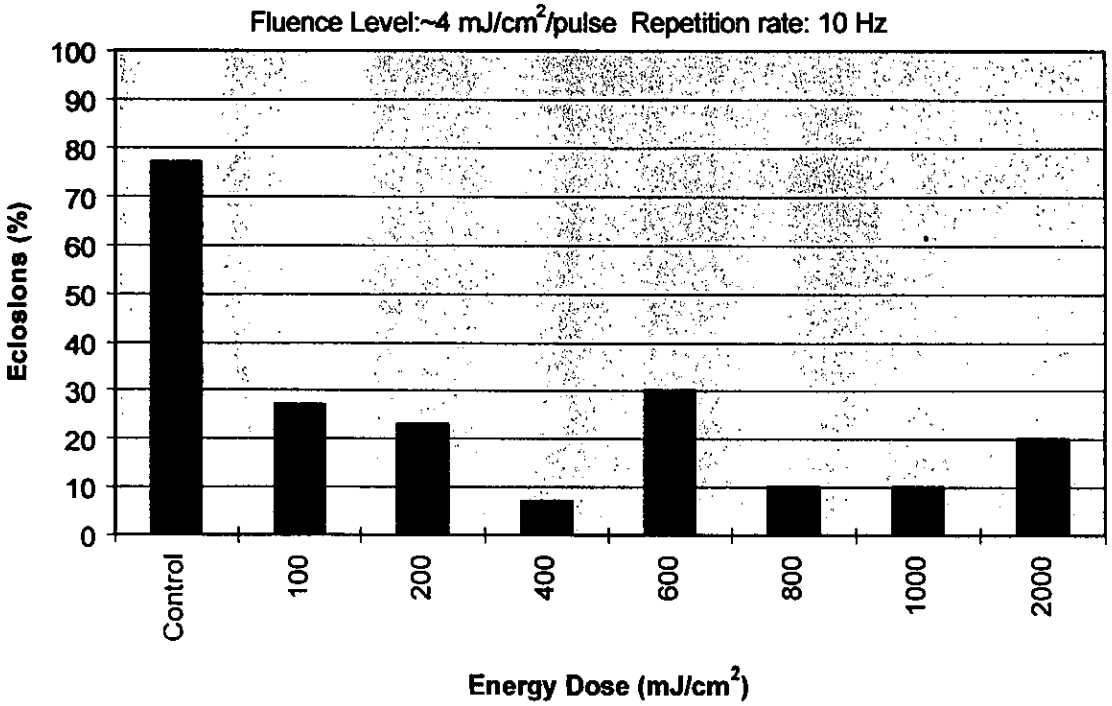
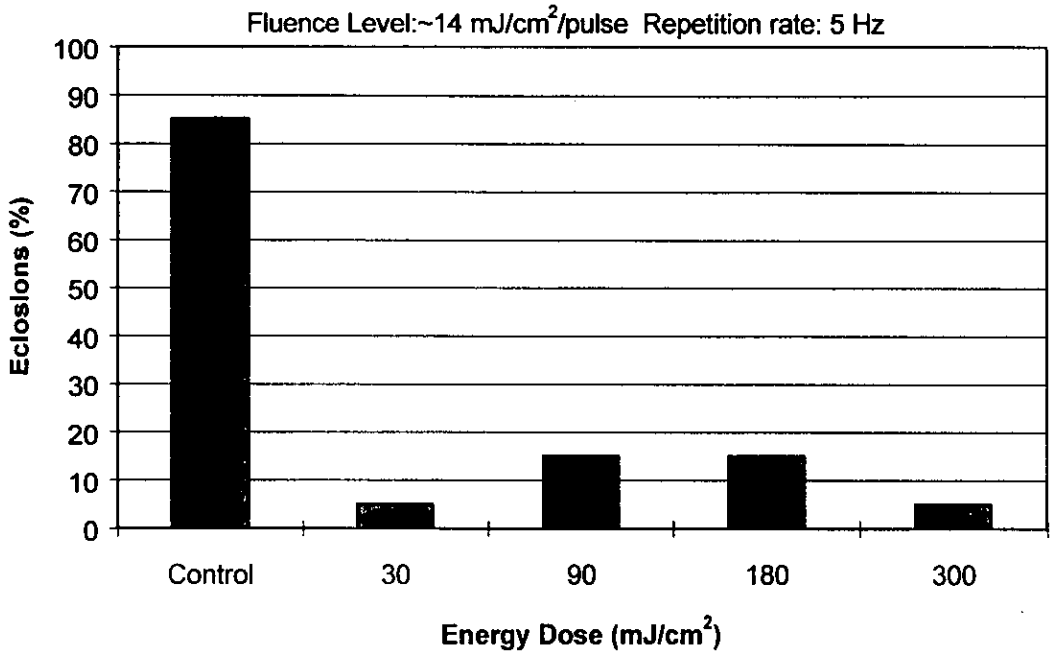


Figure 11. Pulsed UV (248 nm) Eclosion Effects on Brevipalpus sp. (Eggs, n= 96)



JB

Figure 12. Pulsed UV (248 nm) Eclosion Effects on Brevipalpus sp. (Eggs, n=77)

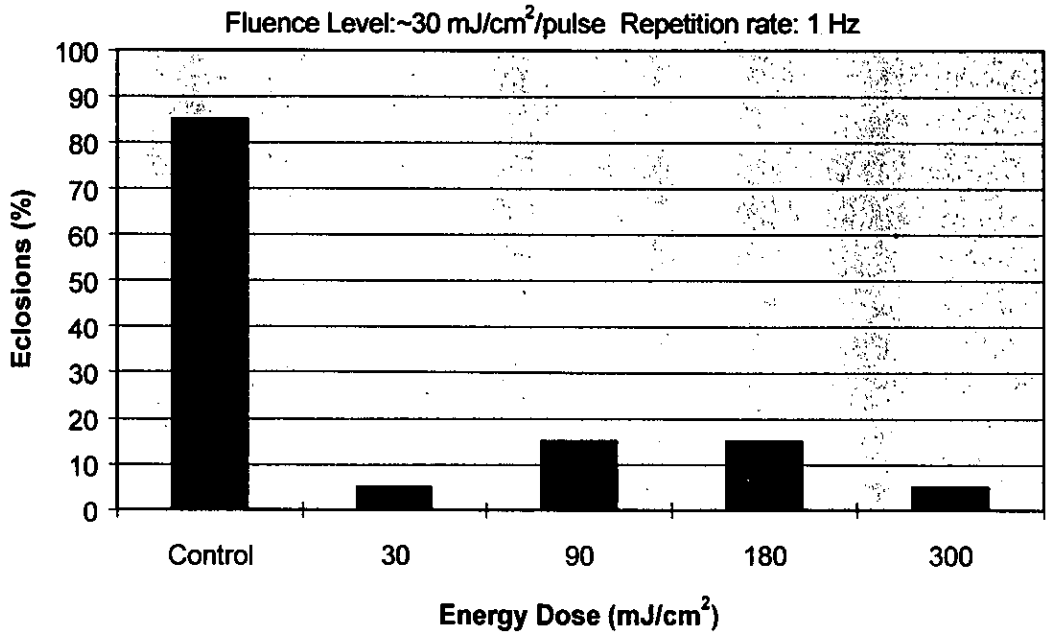


Figure 13. Pulsed UV (248 nm) Eclosion Effects on Brevipalpus sp. (Eggs, n= 85)

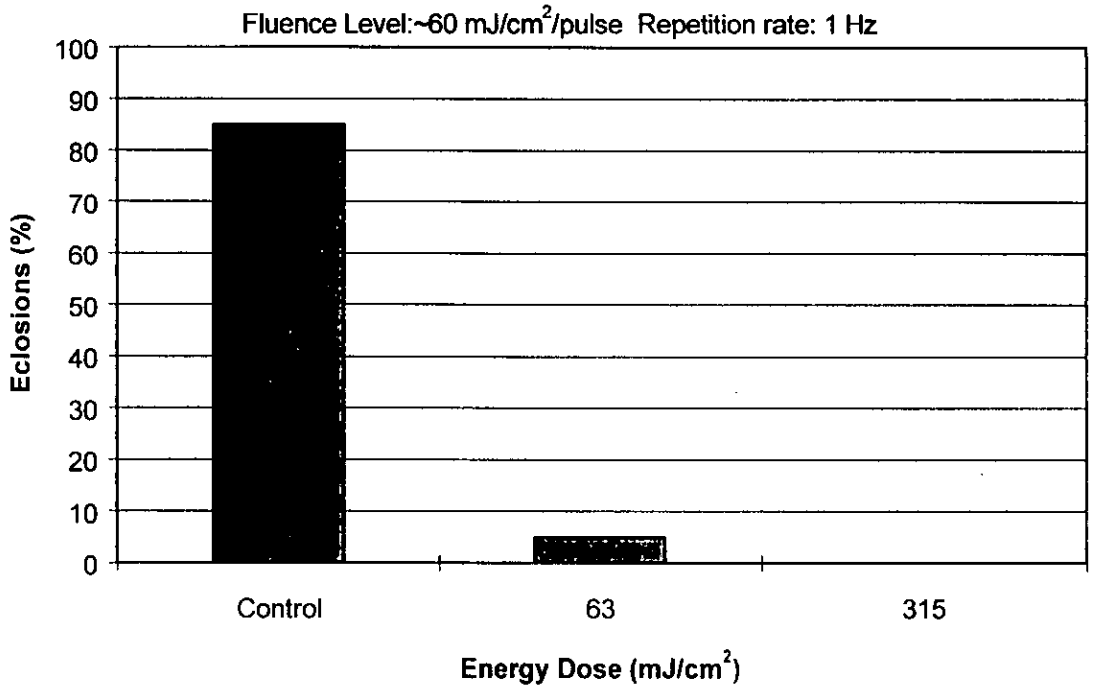


Figure 14. Pulsed UV (248 nm) Eclosion Effects on Brevipalpus sp. (Eggs, n=45)

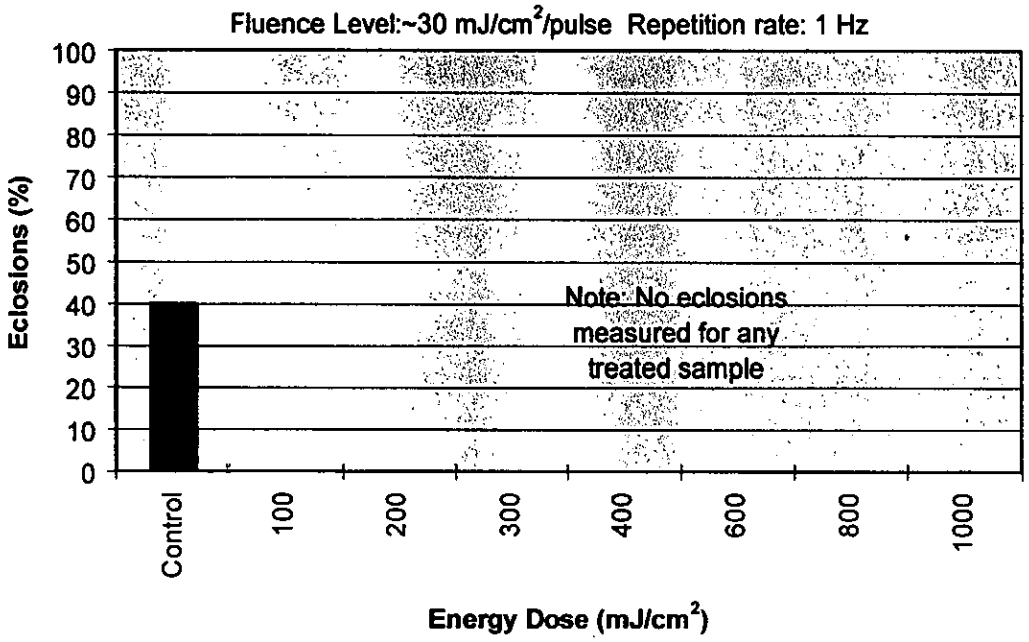
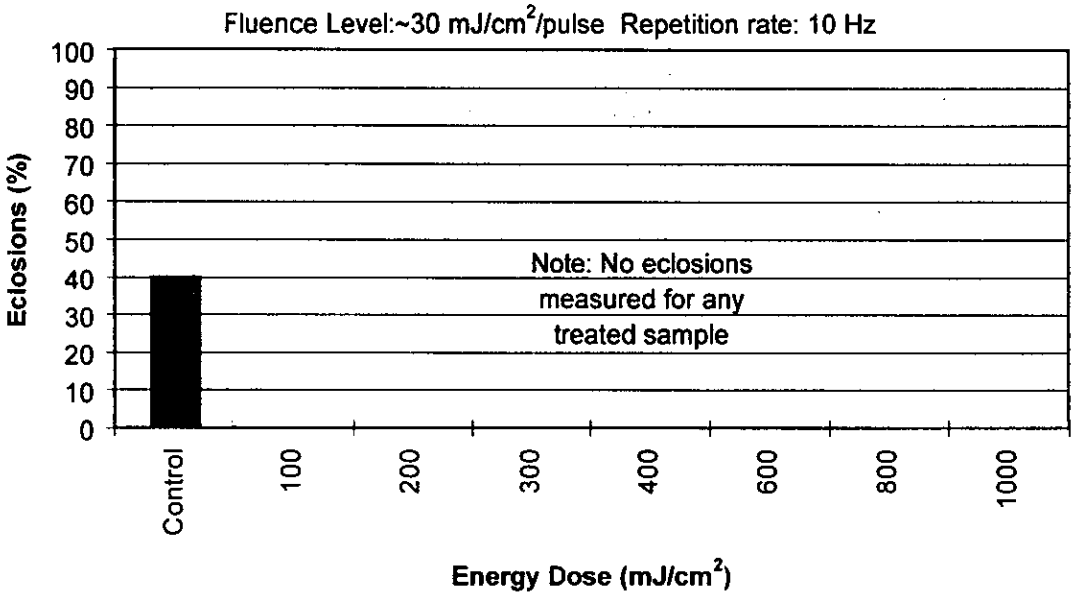


Figure 15. Pulsed UV (248 nm) Eclosion Effects on Brevipalpus sp. (Eggs, n= 66)



3.3 Frakliniella occidentalis (Western Flower Thrips)

These highly mobile insects were presumed and predicted to be highly sensitive to PUV processing.

Experiments were conducted in manner similar to that indicated before with the exception that a thin-film of polystyrene was used to cover a cup or a Petri dish bottom cup in which the Thrips sample was positioned.

The results of these experiments are summarized in Table E (page 62) and shown in Figure 16 (page 63).

During PUV processing these insects demonstrated a typical behavior as other mobile insects did in which it was clear that these (and other insects) demonstrated high sensitivity to PUV by altering their behavior during PUV exposure.

While the objective of these experiments was to determine instant mortality effects - as required by the practical aspects of applicable quarantine regulations, it was alos evident that in all cases a behavioral change was observed in all insects and mites studied in this project. However, these studies did not cover documenting an eventual delayed effect leading to biological sterilization or simply leading to other physiological disorders causing death.

3.4 Other General Studies (Data not shown).

Several other studies were included to document the effects of Pulsed UV on insects and/or mites. Similar results as the ones described in this section III, were obtained for:

1. **Silver White fly**: In adult insects, delayed and instant mortality varied with total energy and fluence and fluctuated from 600 to 1,200 mJ/cm^2 with energy fluence < 10 mJ/cm2/p. Also, pupae (n= 38) were controlled with 2 J/cm^2 energy of 248 nm PUV photons In this experiment, the total assay was practiced by determining the number of empty pupa cases.

2. **San Jose Scales:** Delayed mortality (100%) was demonstrated with adult colonies (n=110) established on the surface of lemons, with PUV energy of 1 J/cm^2 delivered with energy fluence of < 10 mJ/cm^2/p. Instant mortality was suspected in most insects as physical changes in the color and appearance of the targeted insects were immediately obvious by simple observations.

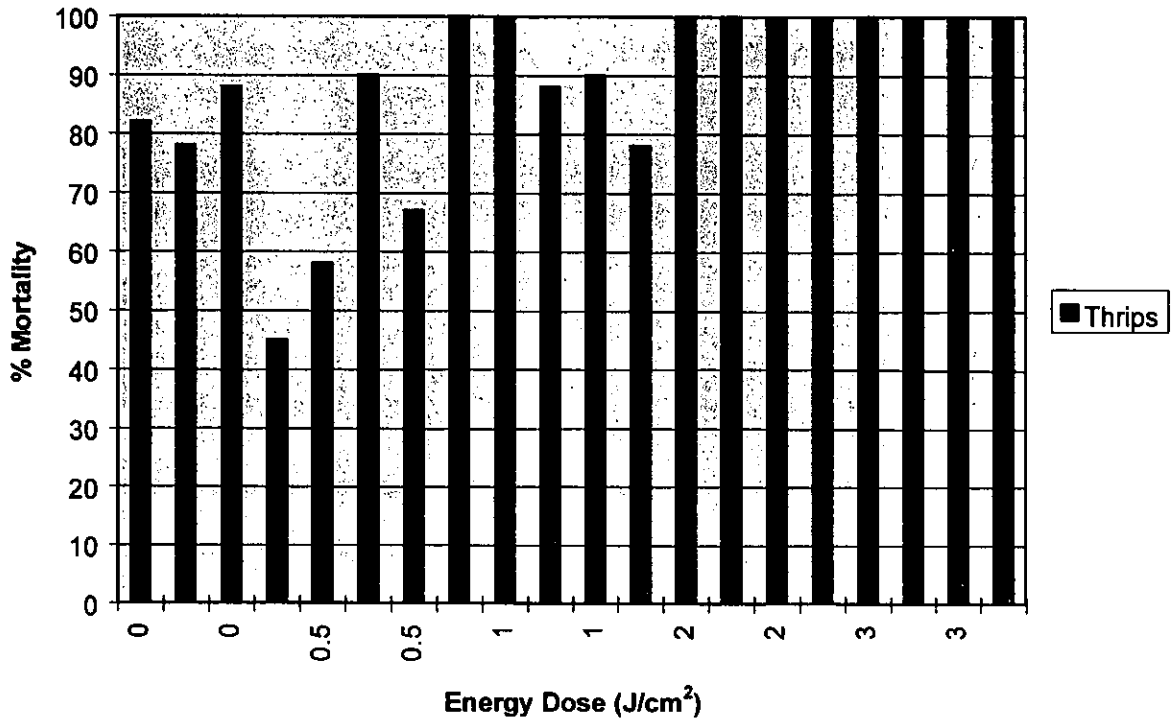
3. **Beet Army Worm:** Using the criterion of development of 2nd instar, 80% mortality was determined with 3 J/cm^2 of 248 nm PUV photons (n= 73).

Table E: Mortality Rate of Frakliniella occidentalis

(Western Flower Thrips) Exposed to Pulsed UV (248 nm).
PUV Treatment Date: April 6, 1999.

			Daily & Total Mortality Scores									
Dose J/cm^2	Insect Size	Number of insects	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Total Insects	Percent Total (%)
0	Adult	11	0	1	0	0	0	4	4	0	9	82
0	Adult	9	0	0	0	2	2	3	0	0	7	78
0	Adult	8	0	0	1	2	0	0	2	2	7	88
0	Adult	11	0	0	0	0	2	1	3	0	5	45
0.5	Adult	12	0	0	0	0	2	4	1	0	7	58
0.5	Adult	10	1	0	1	0	0	2	5	0	9	90
0.5	Adult	9	1	1	0	0	0	2	2	0	6	67
0.5	Adult	11	0	0	0	0	0	4	6	1	11	100
1	Adult	14	2	6	0	0	1	4	1	0	14	100
1	Adult	8	2	2	0	0	1	2	0	0	7	88
1	Adult	10	0	4	0	1	1	2	1	0	9	90
1	Adult	9	1	2	1	0	1	1	0	1	7	78
2	Adult	8	2	4	0	0	0	2	0	0	8	100
2	Adult	13	1	7	1	2	1	1	0	0	13	100
2	Adult	9	3	2	0	1	2	1	0	0	9	100
2	Adult	11	1	3	2	1	1	3	0	0	11	100
3	Adult	12	10	2	0	0	0	0	0	0	12	100
3	Adult	11	10	1	0	0	0	0	0	0	11	100
3	Adult	8	5	3	0	0	0	0	0	0	8	100
3	Adult	13	11	2	0	0	0	0	0	0	13	100

Figure 16. Pulsed UV (248 nm) Mortality Effects on Frakiniella occidentalis (Western Flower Thrips)



V. DISCUSSION AND CONCLUSIONS

All of the objectives established for this project were met based upon experimentation in microbiological, fruit quality, and entomological aspects reported here. The data and results obtained from those experiments have been presented and discussed accordingly in Section II (Microbiology), Section III (Fruit Quality) and Section IV (Entomology). Text and data (sections II and III) and data (section IV) were provided by the individual collaborators and used by the author to edit this report.

The majority of the conclusions reached in this project are also summarized in the Executive Summary (pp. 4-5) and were further detailed in the respective sections by our expert collaborators. Therefore, general comments or observations indicating the observed trends and relationships are also indicated in this section.

5.1 Microbiology Experimentation

Some of the microbiological results obtained were surprising as in many cases PUV treatment resulted in partial rather than complete control of surface microorganisms in the areas treated. This was further compounded by the fact that fruits were partially treated and viable inoculum from not treated areas rapidly invaded the remaining fruit surface obscuring the controlling effects of the PUV treatment. This phenomenon was further enhanced by the high storage temperature (22-26°C) that the fruit was held to maximize the growing conditions of the test inoculum.

In addition, as established later, during the Summer 1998 season, when all fruit used in this experiments was obtained from commercial sources, the fruit was of a lesser quality as compared with other seasons and, therefore, contained a higher than usual natural flora. This was caused by unseasonable rains causing high humidity environs.

At UC Davis, several other projects are underway to effectively decontaminate different media using the ability of pulsed UV to inactivate various pathogens. A current summary of these results is summarized in Table F (page 65)[1].

Therefore , due to the above situation and results, several additional experiments were conducted to establish, once again, the dose-effect relationship for many of the commercially important fungi present in fresh produce. These results, summarized in Table B (page 29) and shown in Figures 1 and 2 (pages 30 and 31) further revealed an anomaly between results obtained in this project (see Section II, page 9 and following) and the results of other UC Davis investigations used as references.

[1] M.C. Lagunas-Solar, Bennie E. Osburn, and James S. Cullor (Unpublished Data).

Table F-1: Summary of University of California, Davis Studies on the Effects of Pulsed UV (248 & 308 nm) on Microorganisms in Different Host Media (*)

Microorganisms	Host Media	PUV (248 nm) & Threshold Lethal Energy (mJ/cm²)		PUV (308 nm) & Threshold Lethal Energy (mJ/cm²)	
FUNGI					
Aspergillus niger	Fruits	Laser/Lamp	1900/900	n/a	n/a
Alternaria alternata	Culture Media	Laser/Lamp	n/a /900	n/a	n/a
Botrytis cinerea	Fruits/Media	Laser/Lamp	50/180	n/a	n/a
Fusarium oxysporum	Fruits/Media	Lamp	n/a /180	n/a	n/a
Fusarium roseum	Fruits/Media	Laser	35	n/a	n/a
Geotrichum candidum	Culture Media	Laser	10	n/a	n/a
Monilinia fructicola	Fruits/Media	Laser/Lamp	100/180	n/a	n/a
Mucor periformes	Culture Media	Laser	20	n/a	n/a
Penicillium expansum	Fruits/Media	Laser/Lamp	50/180	n/a	n/a
Phytophtora citrophthora	Water	Laser	10	n/a	n/a
Rhizopus stolonifer	Fruits/Water	Laser	130	n/a	n/a
Thrichothecium roseum	Culture Media	Laser	275	n/a	n/a
BACTERIA					
Clostridium botulinum	Culture Media	Laser	80	n/a	n/a
Enterococcus faecalis	Culture Media	Laser	10	n/a	n/a
Erwinia carotovora	Culture Media	Laser	30	n/a	n/a
Escherichia coli O157 H7	Almonds, Milk Culture Media	Laser Lamp	10 10	n/a n/a	n/a n/a
Pseudomonas aeruginosa	Culture & Optical Media	Laser Lamp	5 160	Laser	>24,300
Pseudomonas fluorescens	Culture Media	Laser	15	n/a	n/a
Salmonella thyphimurium	Milk, Almonds Culture Media	Laser Lamp	5 5	n/a n/a	n/a n/a
Shigella flexneri	Culture Media	Laser	3	n/a	n/a
Staphylococcus aureus	Culture & Optical Media	Laser/Lamp Laser	3 160	Laser	24,300
Staphylococcus epidermidis	Culture & Optical Media	Laser/Lamp Laser	n/a /5 160	Laser	20,000
Streptococcus pneumoniae	Optical Media	Laser	n/a	Laser	20,000
Serratia marcescens	Liquid Milk	Laser	3000	n/a	n/a
VIRUS					
Bluetongue Virus	PBS and FBS	Laser	200-2500	n/a	n/a
Bovine Diarrhea Virus	PBS and FBS	Laser	3000	n/a	n/a
Porcine Parvo Virus	PBS, FBS, Human Plasma	Laser	<300 <3,000	n/a	n/a
Infectious Bovine Rhinotracheitis Virus	PBS and FBS	Laser	3000	n/a	n/a

(*) Data from various UC Davis research & development projects

To further investigate this matter, several experiments were conducted using hand held fruits that was randomly rotated or moved under PUV illumination to cause a diversity of incident angles to the incoming photons and thus create a multidirectional PUV illumination condition to treat the surface. Under this condition, bunches of grapes inoculated or simply with the natural flora were processed and tested for microbial levels.

The results (on record but not shown) indicated that > 99.9% reduction was obtained in grape bunches. Furthermore, also under these manual conditions, nectarines were inoculated, treated, and then injured to allow for the establishment of infecting flora. Results (on record, not shown) indicated that PUV was again effective in controlling spores even when the fruit was injured immediately after PUV exposure.

5.2 Pulsed UV Geometry Effects

The only likely explanation to the anomaly of the microbiology results is based upon the geometry factors mentioned earlier and that can be illustrated with Figure 17 (page 67).

As indicated earlier, when PUV photons strike a fruit surface it will always reach it from the same direction. This is particularly the case when coherent sources are used such as lasers. Therefore, only readily accessible surface spores could be controlled if a proper PUV dose is delivered and reached them.

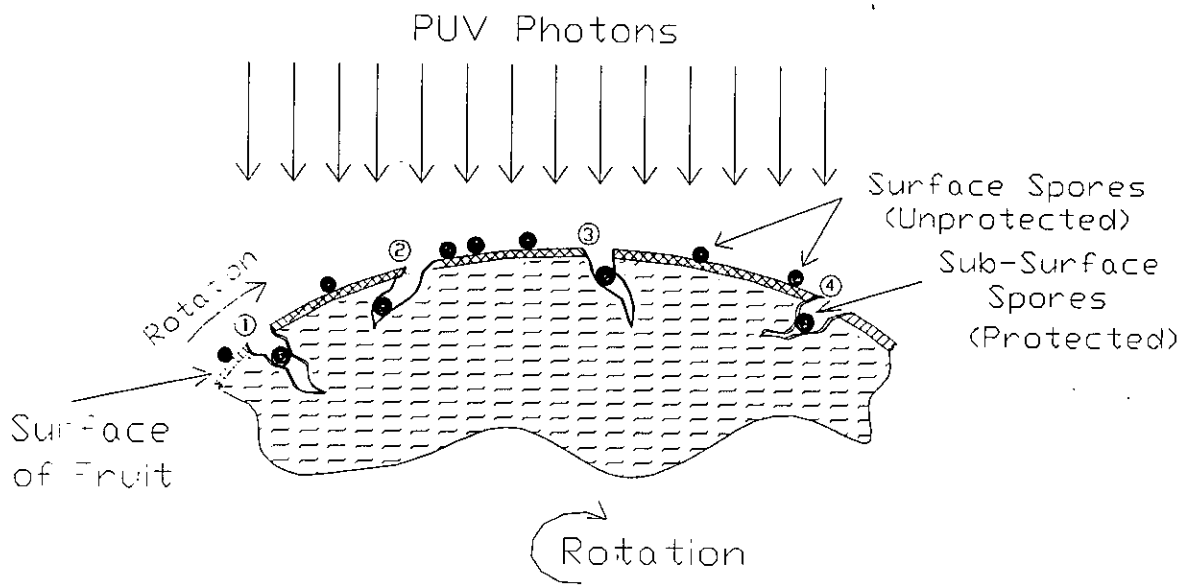
On the other hand, it appears that there are many spores that are actually protected or hidden in cavities or pores present on the fruit surface. In this case, a unidirectional PUV photon beam as the one used in this project and as illustrated in Figure 17 (page 67) may only be able to deliver a controlling dose to "unprotected" spores. However, if the fruit is being rotated (as it was the case in our experimentation, only during a small fraction of the time of exposure, the beam is aligned with the "protected" spore thus reducing the time of actual exposure and reducing the PUV dose delivered to hidden or "protected" spores.

Therefore, it is our conclusion that in many cases with protected spores, the PUV beam did not reach the target spores during a sufficiently long time.

Under this scenario, we also concluded that rotating the fruit was not an appropriate step although one that allowed a larger surface area to be exposed uniformly but from a single direction and the same angle of incidence. The large number of fruits included in each daily experiment prevented us from consider other alternatives.

Several experimental results obtained in this project as well as in other UC Davis projects provide assurances that this surface conditions can be overcome with a combination of a proper PUV illumination system (see section 5.3, below) and with adequate material handling techniques.

Figure 17. Pulsed UV Geometry Effects on Fruit Surfaces



In prior projects and in individual tests conducted in this project, single or few fruits samples manually operated during PUV exposure showed effective PUV induced microbial controls in fruits such as grape bunches, peaches, nectarines, and apples.

At UC Davis, rough surfaces of foods - including the surface of almonds, have been successfully and efficiently (> 5 logs) decontaminated from surface bacteria (natural and inoculated *E. Coli* H7O157) when proper handling techniques are used to provide multi-directional PUV treatment (data not shown)[5].

Cold pasteurization of liquid milk and of fruit juices is also achieved by a combination of PUV beam geometry and material handling techniques (data not shown)[5].

[5] The data indicated as "data not shown" is Confidential information protected by other sponsored research & development projects.

At UC Davis, human cornea tissue is being treated (< 1 J/cm^2) with similar PUV techniques for bacterial decontamination purposes prior to transplantation. Successful bacteria inactivation is achieved even with the natural unevenness of human cornea tissue (data not shown). The human cornea tissue remains viable despite its greater sensitivity than vegetal tissues.

At UC Davis, human plasma containing sensitive plasma proteins and coagulation factors have been successfully treated with similar PUV techniques achieving > 7 log reduction of viral contamination with a small; fraction of damage to essential plasma proteins and factors (data not shown).

Therefore, with data from this project and other related projects using PUV techniques, we concluded that it is critical to match the surface characteristics with a proper PUV illumination system, while the fruit is being handled to expose its surface uniformly to a multi-directional PUV light exposure source.

5.3 Fruit Quality Experiments

Under the PUV processing conditions detailed in this report, there were no major detrimental effects observed (see section III), but there are a few but important aspects that need further investigation to complete an evaluation of PUV techniques intended for the surface decontamination of spoilage and pathogenic organisms. These are as follows:

(1) No major chemical and physiological changes detected in this project had an established trend (see Section III, page 32 and following, and Appendix I, page 72 and following).

(2) Some surface color effects in nectarines and peaches should be studied further. Other pigmented fruits shall be considered for further studies of this potential effect which is assumed to be a relationship between UV sensitive pigments on the fruit surface, and/or the presence of pesticide residues inducing this effect, with the energy density (fluence) of the PUV beam.

(3) Some potentially significant browning effects on the rachis of table grapes were noted and need to be further investigated, as both control and treated samples showed this effect.

Nevertheless, in the opinion of expert collaborators, most detected changes or effects were only statistically significant but of no commercial significance.

Details of these observations and conclusions are summarized in section III, with detailed observations, and in Tables 1A to 24 (Appendix) where the detailed data and results are summarized.

5.4 Entomology Experiments

PUV effects were studied with three model insects/mites, that is:

(1) *Pseudococcus sp.* (mealy bugs);
(2) *Brevipalpus sp.*, (mites) and
(3) *Frakliniella occidentalis* (thrips).

PUV exposure resulted in lethal effects (instant or delayed mortality) in all insects and mites studied in this project. However, sub-lethal effects leading to biological sterility were not studied.

However, PUV exposure levels required for inducing mortality and/or the timing of this effect are significant factors to be considered if practical applications of PUV are developed.

For *Brevipalpus sp.*, the original objective of this project, the results indicate that control of this mite can be performed at PUV energy levels acceptable or tolerable for most fruits (< 1 J/cm^2) (see Section IV). Adult mites were more resistant than juveniles, with eggs being the most sensitive to PUV exposure.

For *Frakliniella occidentalis,* a higher PUV dose (2-3 J/cm^2) was found necessary.

This PUV dose range is still adequate for most fruits studied but other PUV sensitive fruits including green table grapes (color changes), and highly pigmented fruits such as peaches and nectarines need to be treated with adequate PUV energy fluence to minimize effects on pigment (color) development.

Finally, *Pseudococcus sp.* (mealy bugs) were found to be the most resistant insects requiring PUV doses of ~ 10 J/cm^2 , a energy level believed to affect most fruits.

However, physical changes on *Pseudococcus sp.* such as loss of a white fuzz deposit covering the insect, were noted at much lower PUV energy levels. It is not known whether this loss causes increased susceptibility to insecticides or generates irreversible physiological or behavioral changes leading to death or to biological sterility.

5.5 Future Plans

In order to realize further progress in the evaluation of agricultural applications of PUV techniques, the following general strategy is suggested:

(1) Complete the design & engineering of a PUV illumination chamber following the general details given in section 5.5.1 (below) and shown in Figure 18 (page 71)[6] .

(2) Construct and test the PUV illumination chamber under laboratory conditions to determine the best operational - including geometry characteristics, to assure proper surface illumination of fruits.

(3) Elaborate a test protocol and conduct specific tests in commercially important fruits using the PUV illumination chamber and conducting quality tests as per conventional commercial assays used for fruit quality. These tests shall include microbial assays including both fungal and bacterial contamination.

These tests shall provide a complete and final evaluation of both PUV processing efficiency, fruit tolerance, and practical information regarding the adaptability of PUV techniques to the standard commercial practices used in production agriculture.

However, it is also suggested that any further development of this technique shall also include a more detailed study of other factors related to the physiological (i.e. ripeness) and chemical (SSC, TA, pH, etc.) conditions of the targeted fruits.

5.5.1 PUV Illumination Chamber. A Conceptual Design

The concept of a multi-directional PUV illumination chamber was suggested in discussions regarding prototype development activities as early as December of 1996, when the commercial development effort was being studied with Titan Beta Inc., a California technology development group that participated in early negotiations.

Furthermore, in mid 1998, in an Internal Report as a result of a scientific visit to UC Davis by representatives of CEA, the need for a technical solution to this problem was again discussed and suggested.

The solution consisted of designing and building a PUV illumination chamber according to the general design & engineering features illustrated in Figure 18 (page 71).

This PUV illumination chamber has as principal features the following:

(1) A multiple PUV lamp system delivering non coherent (all direction) PUV light;

(2) A deflector system allowing PUV light to be focused onto an specific target area with multi-directional PUV light. In this manner, exposed fruit surfaces under a rotational mode provided by a modified conveyor system can be exposed uniformly and from multiple directions while moving through the PUV treatment area.

[6] Pulsed UV non coherent lamp (arc or excimer) sources are available.

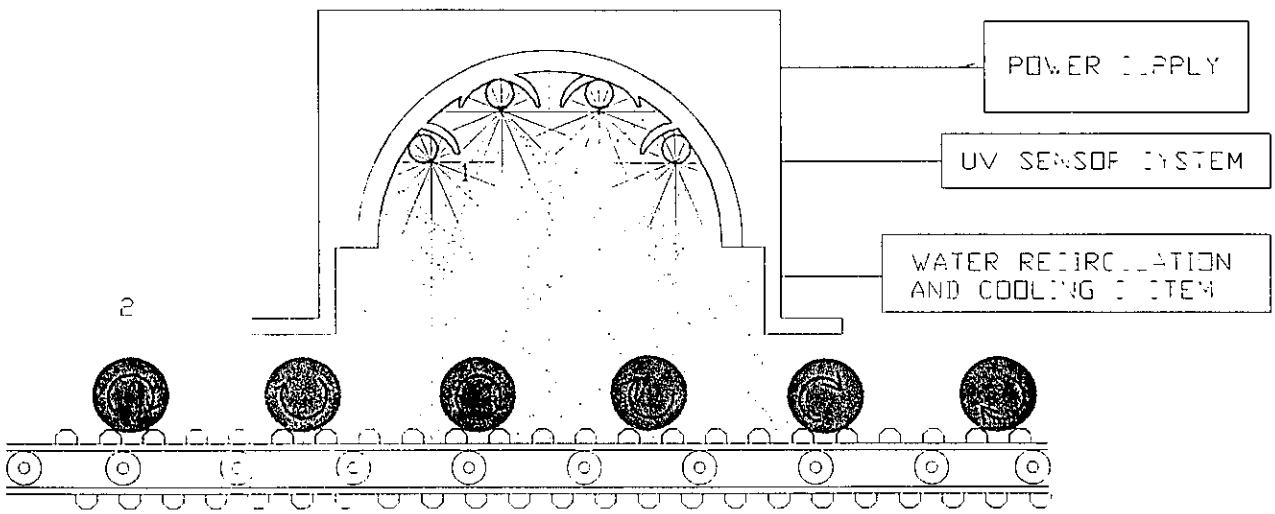
(3) A protective shield to secure personnel and the environment from PUV exposure.

(4) A power supply system to supply electrical power to operate the PUV system ands its accessories.
(5) A PUV sensor to detect and measure energy and fluence levels being delivered onto the treatment area, and

(6) A circulating water cooling system to provide temperature controls to the array of PUV lamp system.

This PUV illumination chamber would also be modular, portable, adaptable to conventional conveyor systems, and user friendly. Maintenance and servicing is expected to be mostly dealing with PUV lamp replacement and electrical systems maintenance.

Figure 18. Conceptual Design for a PUV Prototype System for Decontamination of Fruit Surfaces



(*) PUV system to be modular, portable, and adaptable to current conveyor systems. Shield provides personnel and environmental safety.

APPENDIX 1

TABULATED RESULTS OF

FRUIT QUALITY EXPERIMENTATION

Tables 1A to 22.

TABLE 1A. Quality of 'O'Henry' Peaches after Pulsed UV Treatment and Storage.

Evaluation Time	Treatment	Firmness (Lbs)	SSC (%)	TA (%)	pH	L [1]	Hue ° [2]	Ground Color [3]	External Injury (%)	Decay (%)	Decay Severity [4]
Initial		16.8	13.5	0.70	3.7	50.8	50.7	2.6	0.0	0.0	0.0
15 d	Control	15.6	13.3 b[6]	0.79	3.8	56.9 a	62.1 a	2.9	0.0	0.0	0.0
	PUV 1	15.6	14.2 a	0.78	3.8	54.6 ab	56.3 b	2.9	0.0	0.0	0.0
	PUV 2	15.2	14.4 a	0.78	3.8	53.1 b	54.1 b	3.2	0.0	0.0	0.0
	LSD	NS[5]	0.91	NS	NS	2.67	5.67	NS	NS	NS	NS
15 d + 5 d	Control	1.9	14.6	0.64	3.9 b	53.2	60.3	4.0	0.0	0.0	0.0
	PUV 1	2.0	14.8	0.67	3.9 b	54.5	58.6	4.0	0.0	0.0	0.0
	PUV 2	1.8	14.7	0.63	4.0 a	52.2	53.2	4.0	0.0	0.0	0.0
	LSD	NS	NS	NS	0.06	NS	NS	NS	NS	NS	NS
30 d	Control	15.3	14.7	0.70	3.9	52.4	52.2	3.5	0.0	4.2	0.04
	PUV 1	14.5	14.9	0.67	3.9	52.0	51.0	3.5	0.0	0.0	0.0
	PUV 2	14.6	15.4	0.69	4.0	51.9	53.1	3.5	0.0	0.0	0.0
	LSD	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
30 d + 5 d	Control	1.8	15.3	0.60	4.0 a	49.0	40.0	4.0	0.0	0.0	0.0
	PUV 1	1.8	15.4	0.64	4.0 a	47.0	37.6	4.0	0.0	4.2	0.08
	PUV 2	1.9	15.0	0.62	3.9 b	48.9	39.9	4.0	0.0	0.0	0.0
	LSD	NS	NS	NS	0.04	NS	NS	NS	NS	NS	NS

[1] L value, indication of lightness: 0= black, 100= white
[2] Hue angle attributed to colors as red (0°), yellow (90°), green (180°), blue (270°) or in between any adjacent color pair.
[3] Ground color scale: 1=Green, 2= Light Green, 3=Light Yellow, 4= Yellow
[4] Decay severity scale: 0=None, 1=Slight, 2=Moderate, 3=Severe
[5] NS= Not significant
[6] Means followed by different letters are statistically different at 5% level.

TABLE 1B. Quality of 'Autumn Flame' Peaches after Pulsed UV Treatment and Storage.

Evaluation Time	Treatment	Firmness (Lbs)	SSC (%)	TA (%)	pH	External Injury (%)	Decay (%)
15 d + 5 d	Control	1.5	9.7	0.68	3.9	0.0 b[2]	0.0
	PUV 3	1.5	10.6	0.72	4.0	55.6 a	0.0
	LSD	NS[1]	NS	NS	NS	11.1	NS

[1] NS= Not significant
[2] Means followed by different letters are statistically different at 5% level.

TABLE 2. Respiration rate and ethylene production of 'O'Henry' peaches after pulsed UV treatment and storage.

	CO_2 Production ($ml \cdot kg^{-1} \cdot h^{-1}$)				C_2H_4 Production ($\mu l \cdot kg^{-1} \cdot h^{-1}$)		
	Initial	15 d	30 d		Initial	15 d	30 d
Treatment							
Control	3.3	3.3	4.4		25.0	24.2	33.2
PUV 1	3.6	3.6	4.6		29.1	28.8	35.6
PUV 2	3.6	3.6	4.4		24.1	22.9	45.0
LSD	NS[1]	NS	NS		NS	NS	NS
Day							
0	2.3 e[2]	2.2 e	--		1.5 c	1.5 c	--
1	2.9 d	2.8 d	4.9 a		13.6 b	13.1 b	7.5 c
2	3.5 c	3.5 c	--		36.5 a	35.2 a	--
3	4.2 b	4.2 b	4.4 b		36.9 a	36.2 a	36.6 b
5	4.6 a	4.6 a	4.9 a		41.9 a	40.5 a	69.6 a
LSD	0.25	0.26	0.4		6.70	7.80	8.7

[1] NS= Not significant
[2] Means followed by different letters are statistically different at 5% level.

TABLE 3. Quality of 'August Red' nectarines after pulsed UV treatment and storage.

Evaluation Time	Treatment	Firmness (Lbs)	SSC (%)	TA (%)	pH	L [1]	Hue ° [2]	Ground Color [3]	External Injury (%)	Ext. Inj. Severity [4]	Decay (%)	Decay Severity [5]
Initial		11.6	14.3	1.10	3.7	54.5	53.9	3.8	0.0	0.0	0.0	0.0
15 d	Control	11.5	15.8	1.20	3.7	51.8	48.9	4.0	50.0 b[7]	0.5 c	0.0	0.0
	PUV 1	10.6	15.6	1.10	3.7	53.3	52.7	4.0	95.8 a	1.4 b	0.0	0.0
	PUV 2	11.5	15.3	1.00	3.7	49.1	48.5	4.0	95.8 a	2.1 a	0.0	0.0
	LSD	NS[6]	NS	NS	NS	NS	NS	NS	20.0	0.4	NS	NS
15 d + 5 d	Control	2.2	15.5 b	0.87	3.8	51.5	46.9	4.0	37.5 b	0.4 c	58.3	1.5
	PUV 1	1.9	16.5 a	0.94	3.8	47.6	43.8	4.0	83.3 a	1.3 b	58.3	1.3
	PUV 2	2.1	15.8 ab	0.91	3.8	49.0	44.7	4.0	100 a	1.9 a	62.5	1.2
	LSD	NS	0.81	NS	NS	NS	NS	NS	21.5	0.43	NS	NS
30 d	Control	12.6	17.0 a	1.30	3.7 b	52.9	52.5	4.0	58.3 b	0.7 c	0.0	0.0
	PUV 1	12.3	16.2 ab	0.99	3.8 a	50.9	47.6	4.0	95.8 a	1.3 b	0.0	0.0
	PUV 2	11.6	15.8 b	1.00	3.8 a	53.9	56.5	4.0	91.7 a	1.9 a	0.0	0.0
	LSD	NS	0.89	NS	0.06	NS	NS	NS	21.1	0.45	NS	NS
30 d + 5 d	Control	5.7	19.2 a	0.86	3.9	47.7	41.1 b	4.0	37.5 b	0.5 b	29.2 b	0.4 b
	PUV 1	5.9	18.0 b	0.79	3.9	51.1	49.5 a	4.0	97.6 a	1.7 b	50.0 ab	0.6 ab
	PUV 2	5.0	17.4 b	0.78	3.9	51.7	53.1 a	4.0	100.0 a	2.1 a	62.5 a	0.9 a
	LSD	NS	0.92	NS	NS	NS	7.70	NS	19.25	0.43	29.3	0.42

[1] L value, indication of lightness: 0= black, 100= white
[2] Hue angle attributed to colors as red (0°), yellow (90°), green (180°), blue (270°) or in between any adjacent color pair.
[3] Ground color scale: 1=Green, 2= Light Green, 3=Light Yellow, 4= Yellow
[4] External injury severity scale: 0=None, 1=Slight, 2=Moderate, 3=Severe
[5] Decay severity scale: 0=None, 1=Slight, 2=Moderate, 3=Severe
[6] NS= Not significant
[7] Means followed by different letters are statistically different at 5% level.

TABLE 4. Respiration rate and ethylene production of 'August Red' nectarines after pulsed UV treatment and storage.

	CO_2 Production ($ml \cdot kg^{-1} \cdot h^{-1}$)				C_2H_4 Production ($\mu l \cdot kg^{-1} \cdot h^{-1}$)		
	Initial	15 d	30 d		Initial	15 d	30 d
Treatment							
Control	3.3 b[2]	4.6	5.3		13.8	4.6	0.8
PUV 1	3.6 ab	4.6	5.4		18.4	5.4	0.8
PUV 2	4.0 a	5.2	5.8		17.6	7.3	1.8
LSD	0.49	NS[1]	NS		NS	NS	NS
Day							
0	1.6 d	--	--		0.4 c	--	--
1	2.2 c	3.3 b	3.9 c		0.9 c	1.5 b	0.3 b
2	2.5 c	--	--		5.2 c	--	--
3	5.4 b	5.4 a	3.4 b		29.9 b	3.1 b	0.8 b
5	6.4 a	5.8 a	9.2 a		46.5 a	12.6 a	2.3 a
LSD	0.30	0.61	0.38		6.92	5.52	1.15

[1] NS= Not significant
[2] Means followed by different letters are statistically different at 5% level.

TABLE 5. Quality of 'Heritage' raspberries after pulsed UV treatment and storage.

Evaluation Time	Treatment	Firmness ($g \cdot mm^{-1}$)	SSC (%)	TA (%)	pH	L [2]	Hue ° [3]	External Injury (%)	Berry Leakage (%)	Decay (%)	Decay Severity [4]
Initial			9.0	1.40	3.4	30.1	25.6	0.0	0.0	0.0	0.0
6 d	Control	24.7	9.4	1.30 b	4.0	29.4 a	23.0 a[6]	0.0	0.0	0.0 b	0.0 b
	PUV 1	24.1	9.3	1.35 b	3.6	29.2 a	22.4 b	0.0	0.0	2.7 ab	0.03 ab
	PUV 2	23.5	9.6	1.43 a	3.6	28.3 b	20.9 c	0.0	0.0	8.3 a	0.08 a
	LSD	NS[5]	NS	0.07	NS	0.59	0.57	NS	NS	6.2	0.062
6 d + 3 d	Control	22.4	8.7	1.08	3.8	27.6 b	20.1 a	0.0	0.0	100.0	2.33
	PUV 1	22.3	8.5	1.12	3.8	28.1 a	20.9 a	0.0	0.0	100.0	2.32
	PUV 2	20.4	9.1	1.14	3.8	28.4 a	21.0 b	0.0	0.0	100.0	2.44
	LSD	NS	NS	NS	NS	0.63	0.84	NS	NS	NS	NS
9 d	Control	--[1]	9.5	1.50 a	3.6 b	27.8 c	21.4	0.0	0.0	29.2	0.30
	PUV 1	--	9.6	1.49 a	3.6 b	28.4 b	21.0	0.0	0.0	23.6	0.24
	PUV 2	--	8.8	1.33 b	3.7 a	29.0 a	21.3	0.0	0.0	25.0	0.25
	LSD	--	NS	0.12	0.9	0.52	NS	NS	NS	NS	NS
9 d + 3 d	Control	--	9.5	1.24	4.1	29.0 a	21.3 a	0.0	0.0	100.0	2.57 a
	PUV 1	--	9.1	1.16	3.8	28.1 b	19.5 b	0.0	0.0	100.0	2.19 b
	PUV 2	--	9.1	1.23	3.8	28.4 ab	18.3 c	0.0	0.0	100.0	2.29 b
	LSD	--	NS	NS	NS	0.74	0.81	NS	NS	NS	0.24

[1] Too much decay and fruit to soft to measure firmness mechanically.
[2] L value, indication of lightness: 0= black, 100= white
[3] Hue angle attributed to colors as red (0°), yellow (90°), green (180°), blue (270°) or in between any adjacent color pair.
[4] Decay severity scale: 0=None, 1=Slight, 2=Moderate, 3=Severe
[5] NS= Not significant
[6] Means followed by different letters are statistically different at 5% level.

TABLE 6. Quality of 'Red Globe' grapes after pulsed UV treatment and storage.

Evaluation Time	Treatment	Firmness ($g \cdot mm^{-1}$)	SSC (%)	TA (%)	pH	L [1]	Hue ° [2]	External Injury (%)	Decay (%)	Decay Severity [3]
Initial		188.9	16.1	0.57	3.7	35.4	93.0	0.0	0.0	0.00
15 d	Control	193.2 a[5]	15.7	0.67	3.8	34.8	54.5	0.0	1.4	0.01
	PUV 1	181.9 b	15.9	0.70	3.8	35.0	60.6	0.0	0.0	0.00
	PUV 2	185.2 ab	15.8	0.69	3.8	35.0	48.9	0.0	0.0	0.00
	LSD	9.25	NS[4]	NS	NS	NS	NS	NS	NS	NS
15 d + 5 d	Control	192.2 ab	15.6	0.68	3.8	34.9	96.9	0.0	25.0	0.25
	PUV 1	183.8 b	15.4	0.69	3.8	34.7	73.1	0.0	20.8	0.29
	PUV 2	197.5 a	15.6	0.66	3.8	34.0	73.4	0.0	23.6	0.28
	LSD	9.95	NS	NS	NS	NS	NS	NS	NS	NS
30 d	Control	182.8 a	15.6	0.71	3.8	35.2	79.3	0.0	4.1 b	0.04 b
	PUV 1	174.5 b	15.3	0.68	3.8	34.9	66.5	0.0	8.3 ab	0.08 ab
	PUV 2	167.3 b	14.9	0.68	3.8	34.8	70.1	0.0	16.7 a	0.17 a
	LSD	8.41	NS	NS	NS	NS	NS	NS	9.75	0.095
30 d + 5 d	Control	160.4 b	15.9	0.64	3.7	32.5	27.1	0.0	20.8	0.21
	PUV 1	159.9 b	15.3	0.71	3.8	32.9	19.3	0.0	29.2	0.29
	PUV 2	168.2 a	15.1	0.66	3.7	32.5	19.0	0.0	29.2	0.33
	LSD	7.9	NS	NS	NS	NS	NS	NS	NS	NS

[1] L value, indication of lightness: 0= black, 100= white
[2] Hue angle attributed to colors as red (0°), yellow (90°), green (180°), blue (270°) or an intermediate between any adjacent pair of these colors.
[3] Decay severity scale: 0=None, 1=Slight, 2=Moderate, 3=Severe
[4] NS= Not significant
[5] Means followed by different letters are statistically different at 5% level.

TABLE 7. Respiration rate of 'Red Globe' and 'Thompson Seedless' grapes after pulsed UV treatment and storage.

	Red Globe				Thompson Seedless		
	CO_2 Production ($ml \cdot kg^{-1} \cdot h^{-1}$)				CO_2 Production ($ml \cdot kg^{-1} \cdot h^{-1}$)		
	Initial	15 d	30 d		Initial	15 d	30 d
Treatment							
Control	1.0 b[2]	1.2 b	1.0		2.0 b	2.5	2.4
PUV 1	1.2 b	1.2 b	1.1		2.4 ab	3.7	3.0
PUV 2	1.4 a	1.5 a	1.1		2.8 a	2.9	2.6
LSD	0.2	0.2	NS[1]		0.5	NS	NS
Day							
0	1.4 a	--	--		2.2 c	--	--
1	1.3 b	1.4 b	1.2 a		3.1 a	3.0 b	2.5 b
2	1.2 c	--	--		2.5 b	--	--
3	1.1 d	1.5 a	1.1 b		2.3 c	3.4 a	2.7 a
5	1.0 e	1.0 c	1.0 c		1.9 d	2.6 c	2.8 a
LSD	0.05	0.08	0.06		0.13	0.2	0.13

[1] **NS= Not significant**
[2] **Means followed by different letters are statistically different at 5% level.**

TABLE 8. Quality of 'Thompson Seedless' grapes after pulsed UV treatment and storage.

Evaluation Time	Treatment	Firmness ($g \cdot mm^{-1}$)	SSC (%)	TA (%)	pH	L [2]	Hue ° [3]	External Injury (%)	Shatter (%)	Rachis Brown (%)	Rachis Brown Severity [4]	Decay (%)	Decay Severity [5]
Initial		201.4	17.4	0.50	3.8	48.3	117.7	0.0	6.0	4.17	0.04	0.00	0.0
15 d	Control	203.1 a	18.3 a[7]	0.78	3.9	46.3	115.4	0.0	11.0	50.0 b	0.58	0.0	0.0
	PUV 1	180.6 c	17.9 ab	0.75	3.8	46.6	115.5	0.0	8.0	66.7 ab	0.79	0.0	0.0
	PUV 2	190.5 b	17.4 b	0.73	3.8	45.3	116.3	0.0	15.0	79.2 a	0.92	0.0	0.0
	LSD	9.71	0.54	NS[6]	NS	NS	NS	NS	NS	28.20	NS	NS	NS
15 d + 5 d	Control	181.7 b	17.9	0.58	3.8 b	48.0 a	116.4 a	0.0	46.0	100.0	2.17	100.0	2.1
	PUV 1	197.7 a	18.3	0.57	3.8 b	47.0 b	114.2 b	0.0	63.0	100.0	2.29	100.0	2.4
	PUV 2	203.7 a	18.0	0.54	3.9 a	47.2 b	112.9 c	0.0	53.0	100.0	2.21	100.0	2.3
	LSD	8.82	NS	NS	0.07	0.80	0.96	NS	NS	NS	NS	NS	NS
30 d	Control	185.6 a	18.2	0.63	3.8	46.2	117.8	0.0	45.0	75.0 b	0.9 b	54.2 b	0.6 b
	PUV 1	186.0 a	18.5	0.62	3.8	46.2	117.1	0.0	55.0	100.0 a	1.3 a	83.3 a	1.0 a
	PUV 2	175.9 b	18.7	0.62	3.8	45.6	117.3	0.0	57.0	100.0 a	1.3 a	54.2 b	0.7 ab
	LSD	8.65	NS	NS	NS	NS	NS	NS	NS	15.3	0.34	14.3	0.37
30 d + 5 d	Control	--[1]	17.8 b	0.58	3.86 b	46.4 a	119.2 a	0.0	65.0 b	100.0	2.2 b	100.0	2.4
	PUV 1	--	18.5 a	0.58	3.93 a	44.7 b	114.5 b	0.0	78.0 a	100.0	2.8 a	100.0	2.7
	PUV 2	--	18.5 a	0.57	3.90 ab	45.7 a	114.1 b	0.0	81.0 a	100.0	2.8 a	100.0	2.8
	LSD	--	0.40	NS	0.05	0.84	1.0	NS	11.0	NS	0.30	NS	NS

[1] Too much decay to measure firmness mechanically.
[2] L value, indication of lightness: 0= black, 100= white
[3] Hue angle attributed to colors as red (0°), yellow (90°), green (180°), blue (270°) or an intermediate between any adjacent pair of these colors.
[4] Rachis browning severity scale: 0=None, 1=Slight, 2=Moderate, 3=Severe
[5] Decay severity scale: 0=None, 1=Slight, 2=Moderate, 3=Severe
[6] NS= Not significant
[7] Means followed by different letters are statistically different at 5% level.

TABLE 9. Quality of 'Thompson Seedless' grapes after pulsed UV treatment and storage.

Evaluation Time	Treatment	Firmness ($g \cdot mm^{-1}$)	SSC (%)	TA (%)	pH	L [1]	Hue° [2]	External Injury (%)	Shatter (%)	Rachis Brown (%)	Rachis Brown Severity [3]	Decay (%)	Decay Severity [4]
Initial		201.4	17.4	0.50	3.8	48.3	117.7	0.0	6.0	4.17	0.04	0.00	0.0
15 d + 5 d	Control	--	17.9	0.52	3.9	45.5	115.3	0	68.0	100	3.0	100	3.0
	PUV 3	--	18.2	0.51	3.9	44.8	116.4	0	75.0	100	3.0	100	2.88
	LSD	--	NS[5]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[1] L value, indication of lightness: 0= black, 100= white
[2] Hue angle attributed to colors as red (0°), yellow (90°), green (180°), blue (270°) or an intermediate between any adjacent pair of these colors.
[3] Rachis browning severity scale: 0=None, 1=Slight, 2=Moderate, 3=Severe
[4] Decay severity scale: 0=None, 1=Slight, 2=Moderate, 3=Severe
[5] NS= Not significant

TABLE 10. Quality of 'Granny Smith' apples after pulsed UV treatment and storage.

Evaluation Time	Treatment	Firmness (Lbs)	SSC (%)	TA (%)	pH	L [1]	Hue ° [2]	External Injury (%)	Ext. Injury Severity [3]	Decay (%)
Initial		19.0	9.4	1.00	3.5	60.9	117.1	0.0	0.0	0.0
15 d	Control	18.5	10.3	1.17	3.5	60.7	117.6	0.0	0.0	0.0
	PUV 1	18.6	10.3	1.13	3.5	60.0	117.5	0.0	0.0	0.0
	PUV 2	18.8	10.5	1.15	3.4	59.5	117.4	0.0	0.0	0.0
	LSD	NS[4]	NS	NS	NS	NS	NS	NS	NS	NS
15 + 5 d	Control	17.6	10.9	1.14	3.5	60.5	117.1	0.0	0.0	0.0
	PUV 1	17.6	11.1	1.11	3.5	60.3	117.0	0.0	0.0	0.0
	PUV 2	17.6	10.6	1.12	3.5	60.3	116.7	0.0	0.0	0.0
	LSD	NS	NS	NS	NS	NS	NS	NS	NS	NS
30 d	Control	18.7	10.5 ab	1.15	3.5	60.3	116.7	0.0	0.0	0.0
	PUV 1	18.4	10.4 b[5]	1.19	3.5	60.4	117.2	0.0	0.0	0.0
	PUV 2	18.8	11.0 a	1.19	3.5	60.0	116.7	0.0	0.0	0.0
	LSD	NS	0.55	NS	NS	NS	NS	NS	NS	NS
30 + 5 d	Control	18.1	10.8	1.05	3.5	58.8	115.4	0.0 b	0.0 b	0.0
	PUV 1	18.5	10.8	1.08	3.5	60.6	116.8	0.0 b	0.0 b	0.0
	PUV 2	18.2	11.2	1.10	3.5	60.0	116.6	4.1 b	0.0 b	0.0
	PUV 3	18.2	11.3	1.11	3.5	59.8	116.0	45.8 a	0.5 a	0.0
	LSD	NS	NS	NS	NS	NS	NS	15.0	0.2	NS

[1] L value, indication of lightness: 0= black, 100= white
[2] Hue angle attributed to colors as red (0°), yellow (90°), green (180°), blue (270°) or an intermediate between any adjacent pair of these colors.
[3] External Injury severity scale: 0=None, 1=Slight, 2=Moderate, 3=Severe
[4] NS= Not significant
[5] Means followed by different letters are statistically different at 5% level.

TABLE 11. Respiration rate and ethylene production of 'Granny Smith' apples after pulsed UV treatment and storage.

	CO_2 Production ($ml \cdot kg^{-1} \cdot h^{-1}$)				C_2H_4 Production ($\mu l \cdot kg^{-1} \cdot h^{-1}$)		
	Initial	15d	30d		Initial	15d	30d
Treatment							
Control	0.8 b[2]	0.8 b	0.95 b		0.6	0.20	1.49
PUV 1	0.9 ab	0.9 ab	1.05 a		0.7	0.22	1.48
PUV 2	1.1 a	1.0 a	1.13 a		0.6	0.30	1.84
PUV 3	0.9 ab	--	1.11 a		0.6	--	1.92
LSD	0.24	0.17	0.09		NS[1]	NS	NS
Day							
0	0.9 b	--	--		0.1 c	--	--
1	0.9 b	1.0 a	1.2 a		0.1 c	0.3 a	1.0 b
2	0.8 b	--	--		1.8 a	--	--
3	0.8 b	0.9 a	0.9 c		1.1 b	0.1 b	1.3 b
5	1.1 a	0.8 b	1.1 b		0.1 c	0.3 a	2.9 a
LSD	0.17	0.11	0.07		0.12	0.05	0.5

[1] NS= Not significant
[2] Means followed by different letters are statistically different at 5% level.

TABLE 12. Quality of 'Red Delicious' apples after pulsed UV treatment and storage.

Evaluation Time	Treatment	Firmness (Lbs)	SSC (%)	TA (%)	pH	L [1]	Hue ° [2]	External Injury (%)	Decay (%)
Initial		17.6	12.2	0.28	3.9	34.7	24.2	0.0	0.0
15 d	Control	16.9	13.2	0.31 a[4]	3.9	34.2	24.5	0.0	0.0
	PUV 1	17.0	13.4	0.28 b	3.9	35.2	26.0	0.0	0.0
	PUV 2	16.8	13.1	0.31 a	3.9	34.2	24.6	0.0	0.0
	LSD	NS[3]	NS	0.029	NS	NS	NS	NS	NS
15 + 5 d	Control	16.7	14.2	0.26 ab	3.9	35.3	26.5	0.0	0.0
	PUV 1	16.8	13.9	0.27 a	3.9	33.9	23.8	0.0	0.0
	PUV 2	16.7	13.9	0.25 b	3.9	34.1	25.5	0.0	0.0
	LSD	NS	NS	0.021	NS	NS	NS	NS	NS
30 d	Control	17.3	13.5	0.30	3.8 b	36.8 a	25.8	0.0	0.0
	PUV 1	17.1	13.4	0.29	3.9 a	34.8 ab	22.8	0.0	0.0
	PUV 2	17.1	13.9	0.29	3.9 a	33.9 b	22.9	0.0	0.0
	LSD	NS	NS	NS	0.03	2.75	NS	NS	NS
30 + 5 d	Control	16.4	14.0	0.29	4.0	34.7	26.2	0.0	0.0
	PUV 1	16.4	14.3	0.28	4.0	34.0	25.2	0.0	0.0
	PUV 2	17.1	14.1	0.26	4.0	35.0	27.2	0.0	0.0
	LSD	NS	NS	NS	NS	NS	NS	NS	NS

[1] L value, indication of lightness: 0= black, 100= white
[2] Hue angle attributed to colors as red (0°), yellow (90°), green (180°), blue (270°) or in between any adjacent color pair.
[3] NS= Not significant
[4] Means followed by different letters are statistically different at 5% level.

TABLE 13. Respiration rate and ethylene production of 'Red Delicious' apples after pulsed UV treatment and storage.

	CO_2 Production ($ml \cdot kg^{-1} \cdot h^{-1}$)				C_2H_4 Production ($\mu l \cdot kg^{-1} \cdot h^{-1}$)		
	Initial	15 d	30 d		Initial	15 d	30 d
Treatment							
Control	1.3 b[2]	1.9	1.8		3.8	16.8	29.0
PUV 1	1.6 ab	2.0	1.7		2.6	17.4	22.9
PUV 2	1.9 a	2.0	1.7		2.0	16.8	21.3
LSD	0.37	NS[1]	NS		NS	NS	NS
Day							
0	1.4 e	--	--		0.3 b	--	--
1	1.7 b	3.3 a	1.5 b		0.5 b	5.4 c	11.3 c
2	1.8 a	--	--		1.7 b	--	--
3	1.5 d	1.1 c	1.8 a		2.9 b	15.0 b	25.4 b
5	1.6 c	1.5 b	1.8 a		8.5 a	30.7 a	36.5 a
LSD	0.10	0.18	0.08		2.8	5.3	2.90

[1] NS= Not significant
[2] Means followed by different letters are statistically different at 5% level.

TABLE 14. Quality of 'Fuji' apples after pulsed UV treatment and storage.

Evaluation Time	Treatment	Firmness (Lbs)	SSC (%)	TA (%)	pH	L [1]	Hue ° [2]	Ground Color [3]	External Injury (%)	Decay (%)
Initial		16.0	14.2	0.48	3.9	64.2	83.4	2.2	0.0	0.0
15 d	Control	17.2	14.5	0.49	3.9 b[5]	61.5	73.8	2.0	0.0	0.0
	PUV 1	17.0	15.3	0.47	3.9 b	64.5	80.6	2.0	0.0	0.0
	PUV 2	16.8	14.6	0.47	4.0 a	64.3	81.8	2.0	0.0	0.0
	LSD	NS[4]	NS	NS	0.04	NS	NS	NS	NS	NS
15 d + 5 d	Control	17.5 ab	14.7 b	0.44	3.9	68.2	91.0	2.9	0.0	0.0
	PUV 1	16.9 b	15.4 ab	0.45	3.9	67.7	88.5	2.8	0.0	0.0
	PUV 2	17.9 a	15.6 a	0.47	3.9	68.3	93.8	2.8	0.0	0.0
	LSD	0.64	0.82	NS	NS	NS	NS	NS	NS	NS
30 d	Control	16.6	14.9	0.45	4.0	66.3	83.6	2.1	0.0	0.0
	PUV 1	17.1	15.2	0.46	4.0	66.5	86.6	2.1	0.0	0.0
	PUV 2	16.7	15.1	0.47	4.0	67.7	91.4	2.1	0.0	0.0
	LSD	NS	NS	NS	NS	NS	NS	NS	NS	NS
30 d + 5 d	Control	17.6	15.5	0.45	4.0	68.3	88.2	2.4	0.0	0.0
	PUV 1	18.0	15.5	0.44	4.0	67.2	91.0	2.3	0.0	0.0
	PUV 2	17.9	15.4	0.46	4.0	69.4	93.1	2.3	0.0	0.0
	LSD	NS	NS	NS	NS	NS	NS	NS	NS	NS

[1] L value, indication of lightness: 0= black, 100= white
[2] Hue angle attributed to colors as red (0°), yellow (90°), green (180°), blue (270°) or an intermediate between any adjacent pair of these colors.
[3] Ground color scale: 1=Green, 2= Light Green, 3=Light Yellow, 4= Yellow
[4] NS= Not significant
[5] Means followed by different letters are statistically different at 5% level.

Table 15. Respiration rate and ethylene production of 'Fuji' apples after pulsed UV treatment and storage.

	CO_2 Production ($ml \cdot kg^{-1} \cdot h^{-1}$)				C_2H_4 Production ($\mu l \cdot kg^{-1} \cdot h^{-1}$)		
	Initial	15 d	30 d		Initial	15 d	30 d
Treatment							
Control	1.8	1.4	1.0		0.4	1.1	0.6
PUV 1	1.9	1.4	1.0		0.6	1.0	0.4
PUV 2	1.9	1.4	1.0		0.4	0.9	0.4
LSD	NS[1]	NS	NS		NS	NS	NS
Day							
0	1.6 d[2]	--	--		0.3 c	--	--
1	2.0 b	1.0 c	1.0		0.3 c	1.1	0.25 b
2	2.2 a	--	--		0.5 b	--	--
3	1.7 c	1.6 b	1.0		0.5 b	0.9	0.5 a
5	1.7 c	1.7 a	1.0		0.7 a	1.1	0.6 a
LSD	0.08	0.06	NS		0.1	NS	0.19

[1] **NS= Not significant**
[2] **Means followed by different letters are statistically different at 5% level.**

TABLE 16. Quality of 'Bosc' pears after pulsed UV treatment and storage.

Evaluation Time	Treatment	Firmness (Lbs)	SSC (%)	TA (%)	pH	External Injury (%)	Decay (%)	Decay Severity [1]
Initial		15.8	13.6	0.22	4.3	0.0	0.0	0.0
15 d	Control	14.9	13.7	0.25	4.3	0.0	0.0	0.0
	PUV 1	14.5	13.6	0.23	4.3	0.0	0.0	0.0
	PUV 2	14.3	13.6	0.24	4.3	0.0	0.0	0.0
	LSD	NS[2]	NS	NS	NS	NS	NS	NS
15 d + 5 d	Control	6.5	14.6	0.19	4.6	0.0	5.6	0.06
	PUV 1	7.2	14.8	0.22	4.6	0.0	0.0	0.0
	PUV 2	6.7	15.1	0.19	4.6	0.0	5.6	0.06
	LSD	NS	NS	NS	NS	NS	NS	NS
30 d	Control	12.7	14.1	0.22	4.4	0.0	0.0	0.0
	PUV 1	12.4	13.8	0.19	4.4	0.0	0.0	0.0
	PUV 2	12.4	13.7	0.19	4.4	0.0	0.0	0.0
	LSD	NS	NS	NS	NS	NS	NS	NS
30 d + 5 d	Control	8.2	15.1	0.20	4.5 b[3]	0.0	0.0	0.11
	PUV 1	7.5	14.7	0.18	4.6 a	0.0	0.0	0.0
	PUV 2	7.9	14.9	0.19	4.4 c	0.0	0.0	0.0
	LSD	NS	NS	NS	0.1	NS	NS	NS

[1] Decay severity scale: 0=None, 1=Slight, 2=Moderate, 3=Severe
[2] NS= Not significant
[3] Means followed by different letters are statistically different at 5% level.

TABLE 17. Respiration rate and ethylene production of 'Bosc' pears after pulsed UV treatment and storage.

	CO_2 Production ($ml \cdot kg^{-1} \cdot h^{-1}$)				C_2H_4 Production ($\mu l \cdot kg^{-1} \cdot h^{-1}$)		
	Initial	15 d	30 d		Initial	15 d	30 d
Treatment							
Control	1.1	1.6	2.3		8.2	25.6	36.0
PUV 1	1.1	1.6	2.3		4.5	28.0	33.0
PUV 2	1.3	1.7	2.2		9.0	29.6	31.9
LSD	NS[1]	NS	NS		NS	NS	NS
Day							
0	1.2 b[2]	--	--		0.34 d	--	--
1	1.1 c	1.3 c	1.3 c		1.27 d	12.3 b	20.7 c
2	1.1 c	--	--		4.02 c	--	--
3	1.1 c	1.5 b	2.0 b		9.00 b	34.0 a	28.8 b
5	1.5 a	2.0 a	3.5 a		21.7 a	37.0 a	51.3 a
LSD	0.09	0.10	0.23		2.05	5.65	4.5

[1] NS= Not significant
[2] Means followed by different letters are statistically different at 5% level.

TABLE 18. Quality of 'Hayward' kiwifruit after pulsed UV treatment and storage.

Evaluation Time	Treatment	Firmness (Lbs)	SSC (%)	TA (%)	pH	External Injury (%)	Decay (%)
Initial		**6.6**	**9.1**	**1.95**	**3.5**	**0.0**	**0.0**
15 d	Control	4.4 ab	11.5	1.85	3.6	0.0	0.0
	PUV 1	5.5 a[2]	11.7	1.87	3.6	0.0	0.0
	PUV 2	4.0 b	11.9	1.77	3.6	0.0	0.0
	LSD	1.29	NS[1]	NS	NS	NS	NS
15 d + 5 d	Control	3.3 a	12.1 b	1.69 a	3.7	0.0	0.0
	PUV 1	2.3 b	12.3 b	1.55 b	3.7	0.0	0.0
	PUV 2	2.3 b	13.0 a	1.48 b	3.7	0.0	0.0
	LSD	0.70	0.59	0.13	NS	NS	NS
30 d	Control	4.0	12.3 b	1.70	3.6	0.0	0.0
	PUV 1	4.7	12.4 ab	1.73	3.6	0.0	0.0
	PUV 2	4.0	13.0 a	1.73	3.6	0.0	0.0
	LSD	NS	0.58	NS	NS	NS	NS
30 d + 5 d	Control	2.9 ab	12.8	1.52	3.7	0.0	0.0
	PUV 1	3.1 a	12.6	1.57	3.7	0.0	0.0
	PUV 2	2.3 b	13.1	1.44	3.7	0.0	0.0
	LSD	0.66	NS	NS	NS	NS	NS

[1] NS= Not significant
[2] Means followed by different letters are statistically different at 5% level.

TABLE 19. Respiration rate and ethylene production of 'Hayward' kiwifruit after pulsed UV treatment and storage.

	CO_2 Production ($ml \cdot kg^{-1} \cdot h^{-1}$)			C_2H_4 Production ($\mu l \cdot kg^{-1} \cdot h^{-1}$)		
	Initial	15 d	30 d	Initial	15 d	30 d
Treatment						
Control	1.9	2.6	1.0	0.07	2.2	0.04
PUV 1	2.0	1.3	1.0	0.06	1.2	0.04
PUV 2	2.0	1.3	2.3	0.05	0.07	1.00
LSD	NS[1]	NS	NS	NS	NS	NS
Day						
0	2.2 b[2]	--	--	0.05 cd	--	--
1	2.3 b	0.2 a	1.9 a	0.06 bc	0.3	0.04
2	2.6 a	--	--	0.07 ab	--	--
3	1.4 c	1.7 b	1.2 b	0.08 a	1.2	0.12
5	1.2 d	1.3 c	1.2 b	0.04 d	2.0	0.91
LSD	0.19	0.31	0.58	0.015	NS	NS

[1] NS= Not significant
[2] Means followed by different letters are statistically different at 5% level.

TABLE 20. Quality of 'Eureka' lemons after pulsed UV treatment and storage.

Evaluation Time	Treatment	SSC (%)	TA (%)	pH	L [1]	Hue ° [2]	External Injury (%)	Ext. Injury Severity [3]	Decay (%)	Decay Severity [4]
Initial		7.6	7.23	3.16	77.7	92.1	0.0	0.0	0.00	0.0
15 d	Control	7.7	7.09	3.4 a[6]	78.0 a	91.3 a	0.0 b	0.0 b	5.6	0.1
	PUV 1	7.7	7.22	3.3 b	74.6 b	86.5 b	94.0 a	2.2 a	0.0	0.0
	PUV 2	7.9	7.46	3.3 b	73.3 c	86.0 b	100.0 a	2.2 a	0.0	0.0
	LSD	NS[5]	NS	0.02	1.16	1.27	9.12	0.47	NS	NS
15 d + 5 d	Control	7.6	7.47	3.3 a	78.6 a	92.0 a	0.0 b	0.0 b	0.0	0.0
	PUV 1	7.7	7.69	3.2 b	72.8 b	83.1 b	100.0 a	2.9 a	0.0	0.0
	PUV 2	7.8	7.55	3.2 b	72.8 b	83.0 b	100.0 a	2.9 a	0.0	0.0
	LSD	NS	NS	0.01	1.04	1.16	8.76	0.13	NS	NS
30 d	Control	7.8	7.14	3.2 a	77.6 a	90.4 a	0.0 b	0.0 c	0.0	0.0
	PUV 1	7.7	7.05	3.2 a	73.6 b	84.5 bc	100.0 a	2.5 b	0.0	0.0
	PUV 2	8.0	7.44	3.2 a	72.3 c	82.2 c	100.0 a	2.8 a	0.0	0.0
	LSD	NS	NS	0.01	1.18	1.53	8.76	0.28	NS	NS
30 d + 5 d	Control	8.2	7.39	3.2 a	76.2 a	89.0 a	5.5 b	0.0 b	5.6	0.2
	PUV 1	8.2	7.23	3.2 a	76.2 a	89.0 a	100.0 a	2.8 a	5.6	0.2
	PUV 2	8.1	7.23	3.1 b	70.9 b	81.6 b	100.0 a	2.8 a	11.1	0.3
	LSD	NS	NS	0.01	2.48	2.12	9.12	0.26	NS	NS

[1] L value, indication of lightness: 0= black, 100= white
[2] Hue angle attributed to colors as red (0°), yellow (90°), green (180°), blue (270°) or an intermediate between any adjacent pair of these colors.
[3] External injury severity scale: 0=None, 1=Slight, 2=Moderate, 3=Severe
[4] Decay severity scale: 0=None, 1=Slight, 2=Moderate, 3=Severe
[5] NS= Not significant
[6] Means followed by different letters are statistically different at 5% level.

TABLE 21. Respiration and ethylene production of 'Eureka' lemons after pulsed UV treatment and storage.

	CO_2 Production ($ml \cdot kg^{-1} \cdot h^{-1}$)				C_2H_4 Production ($\mu l \cdot kg^{-1} \cdot h^{-1}$)		
	Initial	15 d	30 d		Initial	15 d	30 d
Treatment							
Control	0.76 c[2]	0.55	0.62		0.05	0.02	0.16
PUV 1	1.11 a	0.73	0.64		0.11	0.02	0.08
PUV 2	0.92 b	0.71	0.63		0.08	0.02	0.08
LSD	0.16	NS[1]	NS		NS	NS	NS
Day							
0	0.83 b	--	--		0.01 c	--	--
1	1.11 a	0.81 a	0.72 a		0.15 a	0.02 b	0.09
2	0.91 b	--	--		0.07 b	--	--
3	0.84 b	0.63 b	0.59 b		0.09 b	0.02 b	0.18
5	0.97 ab	0.55 b	0.58 b		0.08 b	0.03 a	0.05
LSD	0.20	0.11	0.07		0.05	0.006	NS

[1] NS= Not significant
[2] Means followed by different letters are statistically different at 5% level.

TABLE 22. Weight loss (%) of different commodities after pulsed UV treatment and storage. Weight loss presented as 24 h values.

		Pome Fruits				Berry Fruits				Stone Fruits		Citrus
		Granny Smith Apple	Fuji Apple	Red Delicious Apple	Bosc Pear	Thompson Seedless Grape	Red Globe Grape	Hayward Kiwifruit	Heritage Raspberry	August Red Nectarine	O'Henry Peach	Eureka Lemon
Initial	Control	0.087 b	0.58	0.15	0.65	2.84	1.60	0.69	24.45	11.60	8.05	0.80
	PUV 1	0.072 c	0.68	0.15	0.65	2.60	1.56	0.81	29.25	11.80	8.36	0.85
	PUV 2	0.080 bc	0.73	0.16	0.73	2.44	1.57	0.83	25.05	11.82	7.96	0.87
	PUV 3	0.100 a	--	--	--	--	--	--	-	--	--	--
	LSD	0.013	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
15 d	Control	0.082	0.47	0.20	1.57	3.01	1.44	0.79	--	10.19	5.95	0.59
	PUV 1	0.079	0.43	0.23	1.77	2.80	1.29	0.81	--	10.72	6.52	0.65
	PUV 2	0.076	0.38	0.22	1.51	2.68	1.41	0.86	--	10.52	6.72	0.63
	LSD	NS	NS	NS	NS	NS	NS	NS	--	NS	NS	NS
30 d	Control	0.097 b	0.57	0.19	1.80	2.87	1.35	0.63	--	12.51	9.09	0.72
	PUV 1	0.103 ab	0.34	0.21	1.90	2.76	1.46	0.69	--	11.41	9.50	0.81
	PUV 2	0.109 a	0.52	0.19	1.83	3.34	1.40	0.88	--	9.80	8.99	0.75
	PUV 3	0.102 a	--	--	--	--	--	--	--	--	--	--
	LSD	0.010	NS	NS	NS	NS	NS	NS	--	NS	NS	NS