Novel Industrial UV-C System for Preservation of Fruit and Vegetable Juices

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Abstract
A novel industrial UV-C system was developed by AseptoRay Ltd. according to regulatory requirements and tested for preservation of a variety of categories of fruit and vegetable juices. The effects of 100% lamp energy output were measured on the reduction of indicator organisms, natural juice microflora, physical, quality, nutritional and sensory attributes. The AseptoRay unit was able to achieve a range of logarithmic count reduction (LCR) of the *E. coli* indicator organism between 5.0 and 8.1 in fruit juices at the flow rate of 1000 L h-1. According to the effects on natural microflora, the AseptoRay UV-C treatment of juices potentially can provide shelf lives of juice products during refrigerated storage similar to that for products treated with high pressure with no effects on the juice's essential attributes.

Introduction

The growing consumption of fruit and vegetable juices has been attributed to the perceived health benefits of reduced calories and the "all natural," "made of organic ingredients" message based on high contents of enzymes, vitamins, nutrients and bioactive constituents. To achieve these attributes, the juice products are minimally processed using cold-pressing extraction methods and preserved through treatment by novel, non-thermal processing methods such as high hydrostatic pressure, pulsed electric fields or UV light.

Ultraviolet-C (UV-C) light at 254 nm is an alternative non-thermal processing technology that has been approved by the US FDA and Health Canada for the pasteurization and shelf life extension of juice products (Health Canada 2003, US FDA 2001). UV-C light treatment is a less expensive and energy saving continuous process that is effective against all food borne pathogens, natural microbiota, moulds and yeasts and extends the shelf life of juices and nut-based beverages with minimum impact on quality and nutritional attributes while using various types of packaging (Koutchma et al. 2016).

The regulatory approval of UV-C light emitted by low-pressure mercury lamps at 253.7 nm for juice products, and the growing premium juice market, opened new opportunities for the development and commercialization of novel UV-C systems. However, to achieve high-performance efficacy of UV-C light in products with low UV transmission (UVT), such as fresh, non-clarified juices, new engineering approaches have been developed that differ from those normally employed for water treatment. Due to UVT challenge, UV-C systems use thin film laminar, annular turbulent or Dean flow regimes in coiled tubes to treat fluids, such as juice suspensions (Koutchma et al. 2016). To address this challenge, a novel UV-C commercial unit has been specifically developed for treatments of low UVT and opaque juices and other beverages.

AseptoRay's industrial UV-C unit (MGT Industries Ltd. Ma'alot-Tarshiha, Israel) consists of the following major modules: (1) inlet valve, (2) product pump, (3) main control board, (4) ballasts board, (5) air vent, (6) reactor chamber, (7) balance tank, (9) recirculation valve, (10) product valve, (11) skid and (12) rector fan (see Figure 1).

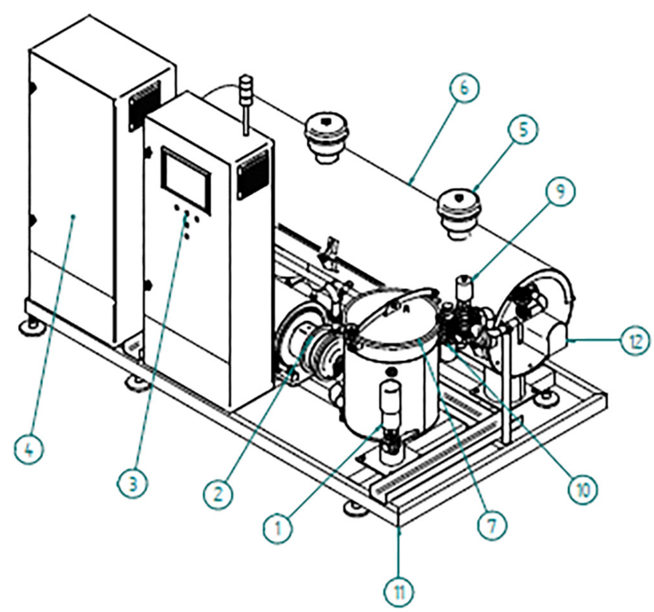

Figure 1. Schematic drawing of AseptoRay's industrial UV-C processing unit

The UV-C chamber of the unit contains UV-C transparent food grade approved polymer tubing that is surrounded by low-pressure amalgam lamps. The unit delivers light photons to the entire sample volume when it is pumped in turbulent flow through the tubing. The use of food-grade polymer tubing in food processing facilities ensures that safety and HACCP requirements are met by eliminating the hazards associated with the use of glass. The UV-C dose level can be adjusted for each individual product based on their absorption and rheological characteristics and microbial reduction requirements. Temperature sensors control air and product temperatures in the UV-C chamber, whereas UV-C sensors monitor the incident intensity of UV-C light and absorbed light that is delivered to the treated product. The size and geometry of the tubing along with product flow rate, create a turbulent flow regime with effective spontaneous mixing. There are no moving parts in the system's UV-C chamber.

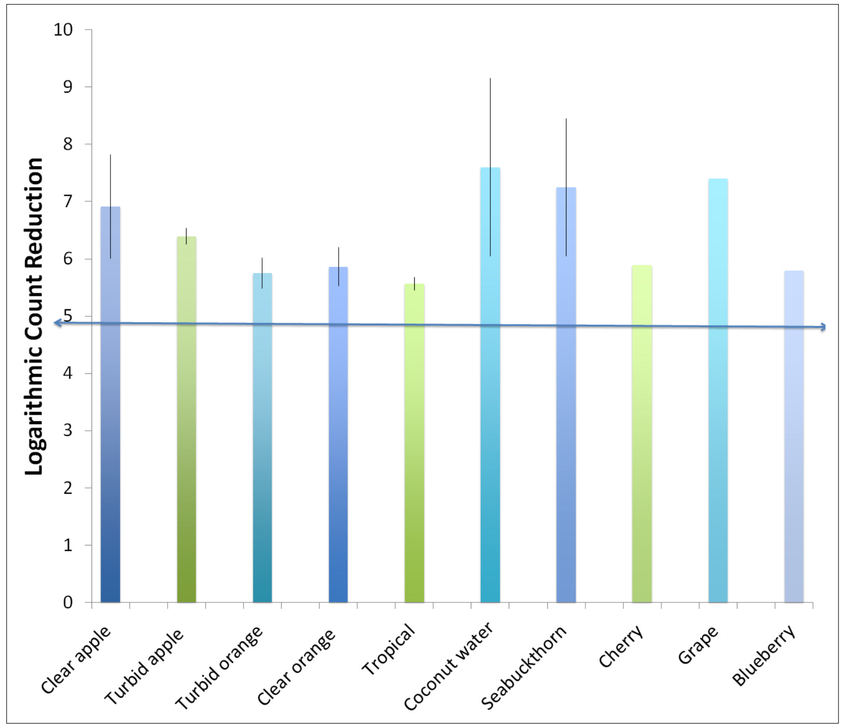

Figure 2. The efficacy of AseptoRay 1000 UV-C System for reduction of *E. coli* bacteria in fruit juices

Microbiological effects

To test performance efficacy of the AseptoRay UV-C unit, numerous microbiological tests were conducted to determine the effect of UV-C dose on the natural microbiota, such as the aerobic and anaerobic total counts, lactic acid bacteria, coliforms, yeasts and moulds, that can affect the storage stability of the juices. Additionally, tests for evaluating compliance with HACCP 5-log reduction requirements with regards to pertinent pathogenic organisms were performed.

A variety of juice products, black and green tea inoculated with a different type of bacteria (*Escherichia coli* ATCC 35218, yeasts and *Bacillus Atropheus* spores) were treated with three models of the AseptoRay UV system processing at throughput of 1000 L h^{-1} (4.4 gpm), 3000 L h^{-1} (13.2 gpm) and 8000 L h^{-1} (35.2 gpm). *E. coli* ATCC 35218 has been used as an indicator bacterium because its UV sensitivity is lower than that of common pathogenic bacteria (Orlowska et al. 2014).

Particularly, the tests were conducted using 10 types of high-acid juices (pH < 4.6), such as apple juice (clear and turbid), orange juice (clear and turbid), tropical juice, cherry blueberry juice, cranberry and grape juice. Additionally, four types of low-acid juices (pH > 4.6) and beverages were tested, such as coconut water, sea buckthorn juice, wheatgrass juice, celery, carrot juice and black tea.

The results of juice inoculation tests with *E. coli* ATCC 35218 showed that treatment with AseptoRay unit was capable to achieve a range of logarithmic count reduction (LCR) between minimum of 5.0 in tropical juices and 8.1 in clear apple juice at the flow rate of 1000 L h^{-1}. The LCR of *E. coli* in fruit juices obtained as an average of all tests is shown in Figure 2 demonstrating that the AseptoRay UV system achieved higher than 5 LCR in all tested products.

The UV treatment using AseptoRay1000 system was also effective against *Bacillus Atropheus* spores in sea buckthorn juice and coconut water by achieving average of 5.6 and 5.4 log reduction respectively.

To determine the effect of UV-C treatment at 100% lamp energy output, corresponding to an applied UV energy of 2.93 kJ L^{-1} on the natural microbiota that determines the storage stability of juices, the trials were conducted using cold-pressed green juice blend (GJB) (Biancaniello et al. 2018). The total applied UV-C energy (E_{UV}, J L^{-1}) (Equation (1)) was evaluated based on the number of UV-C sources (N) turned-on with single-source power (P_{UV}, W) and volumetric flow rate of treated juice (Q, $L\ s^{-1}$)

$$E_{UV} = (P_{UV} \times N)/Q \quad (1)$$

GJB contained cucumber, apple, spinach, kale, ginger and lemon juice at pH 3.79, 6.7 °Brix. Microbiological results for aciduric total count (Ac Count), aerobic colony count (ACC), lactic acid bacteria (LAB), coliforms, yeasts, moulds and *E. coli* after exposure of the GJB to UV-C are shown in Table

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1. The treatment at 100% UV-C exposure resulted in similar reductions in aciduric and aerobic total log count reductions of 3.7 and 3.9, respectively. LCRs of approximately 2.1 were observed for both moulds and yeasts. *E. coli*, lactic acid bacteria and coliforms were not detected in any of the GJB UV-C treated samples. UV-C treatments ranging from 0.2 – 3.6 kJ L^{-1} have led to 1.0 – 3.0 log count reductions for these microorganisms in fruit juices.

Table 1. Log (CFU/g) and LCR of aciduric total count, aerobic colony count, lactic acid bacteria, coliforms, yeasts, moulds and *E. coli*, of untreated and treated GJB at 100% UV-C energy output with a commercial UV-C unit at 1000 L h^{-1}.

	Log (CFU/g) Untreated	Log (CFU/g) Treated	LCR
Aciduric total count	6.39 ± 0.7^{a}	2.7 ± 0.1^{b}	3.7 ± 0.1
Aerobic total count	6.8 ± 0.2^{a}	2.88 ± 0.04^{b}	3.9 ± 0.2
Lactic acid bacteria	4.6 ± 0.04	ND	>3
Coliforms	3.4 ± 0.05	ND	>2
Yeasts	4.0 ± 0.5^{a}	1.91 ± 0.05^{b}	2.1 ± 0.7
Moulds	4.5 ± 0.25^{a}	2.4 ± 0.1^{b}	2.1 ± 0.2
*E. coli**	ND	ND	ND

* Not detected = ND

Note: Different superscript letters in the same row indicate a significant difference between means (p <0.05).

Efficacy of UV-C vs. high hydrostatic pressure processing (HPP)

The microbial efficacy of UV-C in GJB at 100% energy output was compared with HPP treatment at 600 MPa for five min that is used as standard industrial practice. The effects of both treatments on natural microflora (Ac count, ACC, LAB and coliforms) were measured as LCR in GJB immediately after cold-pressing operation. UV-C system cleaning in place (CIP) was performed to ensure no cross contamination. The results of LCR shown in Figure 3 on page 11 demonstrated higher or similar efficacy of AseptoRay system at 100% energy output in reduction of ACC, LAB and coliforms.

Effects on quality, nutrients, vitamins and sensory

In terms of UV-C effects on physical parameters and the quality of green juice blend, there was little to no change in the measured parameters. Identical values for total soluble solids, pH and titratable acidity were found for the untreated and treated GJB. No significant change ($p > 0.05$) in viscosity was detected in the treated samples. L*, *a**, *b** and ΔE for darkness/brightness, redness/greenness, yellowness/ blueness and total colour difference respectively have been evaluated. A colour difference scale based on ΔE values (not noticeable = 0 to 0.5, slightly noticeable = 0.5 to 1.5, noticeable = 1.5 to 3.0, well noticeable = 3.0 to 6.0, greatly noticeable = 6.0 to 12.0) was adapted from (Koutchma et al. 2016).

UV-C treatment in AseptoRay unit had a "noticeable" (1.5 < ΔE < 3.0) effect on the sample treated at 100% output energy. The samples experienced changes to L* and *a** that were both "slightly noticeable" (Δ*a* = -0.69), and a "noticeable" change in *b** (Δb = -1.8). However, there was no clear difference between the treated and untreated juice samples that could be detected by eye. Also, no significant reduction ($p > 0.05$) in protein content, total phenolic content (TPC) or antioxidants activity (ORAC and DPPH) was found for the UV-C treated green juice.

A triangle test was used to determine whether there is a noticeable difference in overall sensory qualities between two control GJB samples and one treated juice sample. A nine-member panel evaluated the differences between untreated GJB and GJB treated at 100% UV energy. The panellists gave four correct and five incorrect responses. These results indicate that there is no significant difference between the treated and untreated GJB.

Also, quality and sensory tests have been carried out to evaluate odour, colour and taste after the UV-C treatment of celery, apple, orange and beat juices, coconut water and tea. The tests were performed using blind triplicate test ABB by a panel of eight to 12 people. No changes were found in all tested juices. Minor change was found in almond nut milk beverage and lemonade juice.

The effects of the AseptoRay UV-C unit on nutritional attributes, such as the level of vitamins A, K, E, C, B2, B6, folic acid and carotenoids were measured in fruit and vegetable juice products that presented green, roots and citrus categories. The untreated products were compared with UV-C treated juice samples using standard methods in the certified laboratory after one pass through the unit at 100% lamp energy output. The results are presented in Table 2 on page 11.

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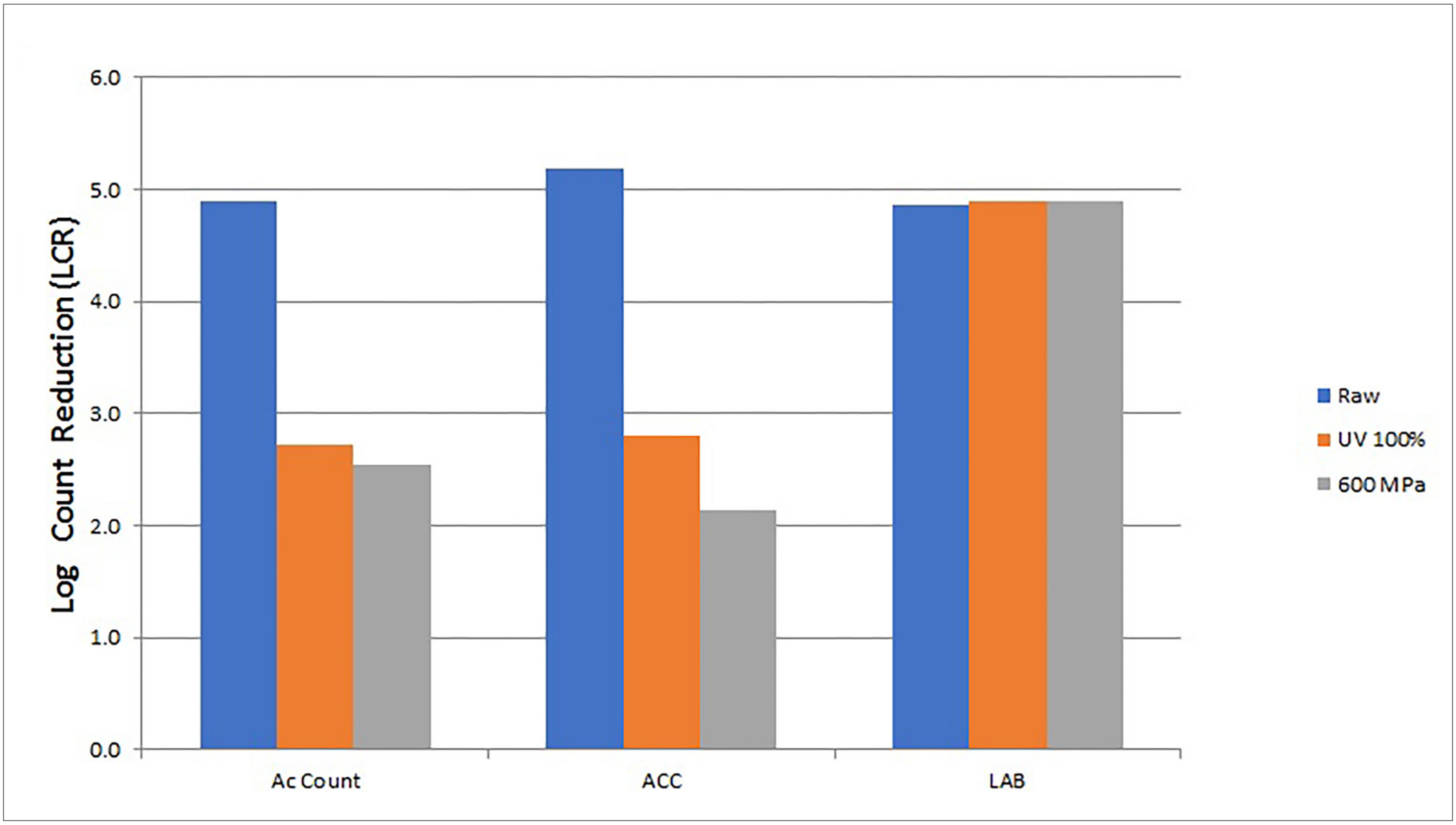

Figure 3. The efficacy of the AseptoRay UV system compared to HPP treatment for LCR of natural microflors in a green blend juice

Table 2. Vitamin and carotenoid (beta carotene) content in three juice categories in undreated and UV-C treated products

	Juice	Greens	Roots	Citrus
Nutrient	# of passes	1	1	1
Vitamin A (total)	Untreated (RE/100 g) Treated (RE/100 g)	28 28	108 128	3* 5*
Vitamin A (beta carotene)	Untreated (*µ*g/100 g) Treated (*µ*g/100 g)	169 165	647 736	20 29
Vitamin K	Untreated (*µ*g/100 g) Treated (*µ*g/100 g)	6.9* 10.5*	< 10 < 10	< 10 < 10
Vitamin E	Untreated (mg/100 g) Treated (mg/100 g)	0.14 0.13	0.17 0.16	0.24 0.24
Vitamin C	Untreated (mg/100 g) Treated (mg/100 g)	3.9 3.9	2.7 2.8	54.9 52.6
Folic acid	Untreated (*µ*g/100 g) Treated (*µ*g/100 g)	5.1* 3.7*	2.4 2.4	34.0 34.4
Vitamin B2	Untreated (mg/100 g) Treated (mg/100 g)	0.02 0.02	0.02 0.02	0.01 0.01
Vitamin B6	Untreated (mg/100 g) Treated (mg/100 g)	0.06* 0.08*	0.06 0.06	0.03 0.03

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The uncertainties analysis for the tests was provided by the certified laboratory that presented data with 95% confidence limit. According to the analysis of uncertainties and discussions with the laboratory, it can be concluded that there is no significant difference in the overall nutritional profile of the juices pre- and post-UV treatment at 100% lamp energy output.

> UV-C treatment of a cold-pressed acidified green juice at applied UV energy of 2.93 kJ L^{-1} led to a reduction in natural microbiota, yeasts and moulds.

Conclusions

The industrial AseptoRay1000 UV system at operating UV energy level of 2.93 kJ L^{-1} and flow rate of 1000 L h^{-1} proved to be efficient in achieving 5-log microbial reduction of indicator organisms in high-acid fruit juice products. These processing conditions were effective in reducing counts for spores, such as *Bacillus atropheus*, in low-acid products. Also, UV-C treatment of a cold-pressed acidified green juice at applied UV energy of 2.93 kJ L^{-1} led to a reduction in natural microbiota, yeasts and moulds without significantly altering physical, quality, nutritional and sensory parameters and had similar effectiveness with industrial HPP treatment. The lower initial investment, operating costs, packaging flexibility and size requirements associated with industrial UV-C treatment show the feasibility of this technology as the primary non-thermal processing alternative for the premium fruit and vegetables juice category. ■

References

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