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Ultraviolet light efficacy for microbial inactivation on fruit juices, nectars and apple cider

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Abstract
Ultraviolet (UV) light can inactivate microorganisms, reducing the microbial load in air, on hard surfaces and in thin layer of liquid food. It can also eliminate pathogens from potable water and fruit juices. Responsible for the inactivation of microorganisms is the UV-C part of UV light spectrum (200–280 nm with the maximum at 254 nm), also called germicidal UV light. This technology has already been approved as alternative treatment to thermal pasteurization of fresh juices, U.S. Food and Drug Administration setting the regulation of achieving a minimum 5-log reduction of pathogens. Extensive research over the last years showed that UV light technology is suitable for the preservation of fruit juices, nectars and apple cider. This paper reviews available literature data of the application of UV light treatment for the preservation of fruit juices, nectars, blended fruit juices and related products such as apple cider.

Keywords: ultraviolet light, germicidal, inactivation, microorganisms, fruit juices, nectars, apple cider, model solution.

1. Introduction

Currently, the heat treatment is still the most common, available and best understood method of inactivation of microorganisms and enzymes, thereby prolonging the shelf life of food. However, heat processing may cause significant changes in the quality and organoleptic characteristics of food. The increasing interest of the consumers for fresh-like, minimal processed food products and the negative attitude to the addition of preservatives chemically synthesized in food has led to the development of alternative methods of processing. Non-thermal processing methods include high hydrostatic pressure or high pressure processing (HPP) [1] pulsed electric fields (PEF) [2, 3], ultrasound technology [4], ultraviolet (UV) light treatment [5-7] and combinations of these [8-11].

The use of UV light for water sterilisation and wastewater disinfection [12-17], air treatment [18-20] and decontamination of surfaces and packaging in the food industry [5, 21] has been well known for decades and is continuously developed [22-25].

Quintero-Ramos et al. (2004) has shown that outbreaks involving fruit juices have increased consumers' concerns related to the safety of fruit juices [26]. In this case of particular interest is the acid resistance of *E. coli* O157:H7 and *Salmonella* spp., which are able to survive in highly acidic liquids [27, 28].

Usually, fruit juices have pH values between 3.3 and 4.1 [29] and have not been considered potential vectors for foodborne pathogens. However, the increased resistance of newly emerged pathogens such as some strains of *E. coli* O157:H7 has led to foodborne outbreaks even in pasteurised fruit juices [26]. Excessive application of thermal treatment or thermal pasteurisation used to cope with this fact had detrimental effects on organoleptic and nutritional qualities of juices. Therefore new alternative nonthermal processing methods were investigated, including HPP, PEF and UV light treatment, as has

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been mentioned above. Many researchers have showed that nonthermal processing technologies are able of increasing the shelf life of liquid foods [5, 6, 26, 30]. The advantage of nonthermal processing methods is the minimal processing of foods with reduced loss of nutrients, as well as fewer changes in physical and chemical properties [26].

In 1997, the U.S. Food and Drug Administration (FDA) has regulated that juice producers should achieve a minimum 5-log reduction of pathogen for any juice they produce. This new regulation has increased the interest in studying the factors that influence pathogenic microorganisms' reduction [31]. Later, the use of UV light as alternative treatment to thermal pasteurization of fresh juices has been approved [32]. The Report of the Institute of Food Technologists (IFT) written for FDA stipulated that to achieve microbial inactivation, the UV-C (λ = 254 nm) radiant exposure must be at least 400 J/m^2 in all parts of the product [32].

Extensive research over the last years on the use of UV light in food processing has shown that this technology is suitable for the preservation of fruit juices and related products [33, 34]. UV light treatment can combine the advantage of preserving the fresh-like characteristics of food quality and the effective inactivation of spoilage and pathogenic microorganisms [6, 7]. For instance, UV light technology has been shown to be effective against *E. coli* O157:H7 in fruit juices [35, 33, 36, 7] and apple cider [37], and it neither increases the temperature of the product not produces undesirable organoleptic changes [38].

This paper aims to evaluate available literature data and provide a general review of the application of UV light treatment for the preservation of liquid foods obtained from fruits: fruit juices, nectars, blended fruit juices and related products such as apple cider.

2. Ultraviolet light

UV light occupies a small band of electromagnetic radiation found in nature. It is situated between visible light and X-rays, having wavelengths between 10 nm and 400 nm. UV light spectrum has frequencies invisible to humans and visible to some birds and insects.

Because these frequencies are higher than those that human eye indentifies as the violet colour, they are called "ultraviolet".

Found in sunlight, UV light is also emitted by electric arcs and specialised lights such as mercury lamp and black lights. It determines many substances to glow or become fluorescent and can cause chemical reactions.

According to ISO 21348-2007, standard on determining solar irradiances, the range of UV wavelengths used in experiments is situated between 200 and 400 nm and is divided in three parts: UV-A, UV-B and UV-C (Table 1).

Table 1. Division of electromagnetic spectrum of experimental UV light (from [39])

Name	Abbreviation	Wavelength range, in nm	Energy, in eV/ photon	Alternative names
Ultraviolet C	UV-C	200 – 280	4.42 – 12.40	Short wave, germicidal
Ultraviolet B	UV-B	280 – 315	3.94 – 4.43	Medium wave
Ultraviolet A	UV-A	315 – 400	3.10 – 3.94	Long wave, black light

UV-C (200–280 nm) found in sunlight is completely absorbed in the upper and middle parts of atmosphere by ozone and molecular oxygen. It contains short UV waves and is called the germicidal domain because it effectively inactivates microorganisms [23, p. 2].

UV-B (280–315 nm) contains medium UV waves. A smaller fraction of this region (295–297 nm) is responsible for the formation of vitamin D in all organisms that make this vitamin, including humans. UV-B light is attenuated in a similar way as UV-C light, being absorbed by the ozone layer in proportion of around 97%. A small part of UV-B light reaches the surface of the Earth and would cause much damage to living organisms such as skin burns and possibly lead to skin cancer. Consequently, the atmosphere acts as a filter media of UV light and after that, only about 3% of the total energy of sunlight at the zenith is UV, this fraction decreasing at other sun angles.

Finally, UV-A (315–400 nm) contains long UV waves and is normally responsible for changes in human skin called tanning.

3. Mechanism of microbial inactivation by UV light

UV light is lethal to most types of microorganisms found in air, water or on hard surfaces. Cells inactivation is based on the damage of nucleic acid under UV light action, thus microorganisms can not further replicate. The nucleic acid is either deoxyribonucleic acid (DNA) or ribonucleic acid (RNA). Most cells have the nucleus composed of double stranded DNA. DNA contains the information necessary for the synthesis of ribosomal, transfer and messenger RNA, all involved in the metabolic processes of synthesis within the cell [23, p. 69].

Nucleic acids are long-chain macromolecules consisting of sequencing of nucleotides. Each nucleotide contains a sugar phosphate and a nitrogenous base. These bases are of two types: purines and pyrimidines. Purine bases are the same in both DNA and RNA: adenine and guanine. Pyrimidine bases are different: thymine and cytosine in DNA, uracil and cytosine in RNA. Adenine pairs with thymine in DNA and with uracil in RNA, while quinine pairs with cytosine in both nucleic acids [40, p. 5, 14].

Nucleic acids absorb UV light from 200 to 310 nm. Absorbed UV light causes breaking of some bonds and the formation of pyrimidine dimers which are bonds between adjacent pairs of thimine or cytosine pyrimidines on the same DNA or RNA strand. These dimmers prevent cells from replicating, so microorganisms become inactive and unable to proliferate [23, p. 71].

However, damage of nucleic acid does not totally kill the cells. This means that cells are unable to replicate but they still experience metabolism and other cell functions. Some of the damages of nucleic acid can be repaired by enzyme mechanisms within the cell. Therefore microorganisms can repair themselves using either light repair mechanism called photoreactivation, or dark repair mechanism. After reactivation, microorganisms become again able to cause illnesses. Consequently, the UV treatment has to provide enough dosage of UV light to ensure that nucleic acid is damaged beyond the stage where it can be repaired [41, 23, p 71].

4. UV light inactivation of microorganisms in liquid foods obtained from fruits

UV light, with some precautions, is easy to use and lethal to most types of microorganisms [5]. The highest germicidal effect is produced by short-wavelength UV (UV-C) between 250 and 270 nm [12]. Low pressure mercury lamps generate UV light with 254 nm wavelength. They are used for disinfection of surfaces, water and some food products leading to the maximum inactivation effect.

Bintsis et al. (2000) showed that bacteria suspended in air are more sensitive to UV-C than those in water due to the different penetration capacity of UV light through different media. The penetration depth of UV-C light through liquids is very low, with the exception of clear water. It depends on the type of liquid, its UV-C absorptivity, content of soluble solids in the liquid and amount of suspended matter in the liquid. The intensity of penetration of the UV-C light in the liquid varies inversely with the amount of soluble solids. Suspended particles may also block the incidence of light on the microorganisms [5]. The effect of particles, as small as they are, is shielding the cells of microorganisms [42].

UV light has been used to reduce the microbial load of several types of microorganisms in some liquid foods. The most studied microorganism is *Escherichia coli* followed by other bacteria species such as *Listeria innocua*, *Yersinia pseudotuberculosis*, *Bacillus subtilis*, *Staphylococcus aureus*, yeast *Saccharomyces cerevisiae*, undefined moulds and protozoan *Cryptosporidium parvum*.

E. coli was first identified as a foodborne pathogen in 1982 and is recognised as a significant cause of foodborne illness [43]. It has a great ability to contaminate different products and survive in food: yogurt [44], mayonnaise [45], deer jerky [46], fruit juices [7, 9, 35, 36, 47-50] and apple cider [26, 33, 37, 51-53].

4.1. UV light inactivation of microorganisms in fruit juices

Among fruit juices, apple juice has been the most widely used as a medium to evaluate the microbial inactivation by UV light treatment since it is readily available, easily contaminated with microorganisms and it can be produced as clear apple juice, thus increasing the depth of UV light penetration [7, 9, 34-36, 47-50].

Other investigated juices were: orange juice [34, 36], tropical juice [34], multifruit juice [36], guava and pineapple juice [34], apple and cranberry juice blend [10]. Moreover, Keyser at al. (2008) used for investigation strawberry and mango nectars [34].

The target microorganism of many investigations was *E. coli* O157:H7 selected for its high probability to produce food-borne illnesses. Whereas *E. coli* O157:H7 is pathogenic, many researchers used in their studies other microorganisms which are non-pathogenic and have similar UV sensitivity for example *E. coli* K12 [33, 34, 49, 54, 49, 55] and *E. coli* ATTC 11775 [47].

Ngadi et al. (2003) studied the inactivation with UV light of *E. coli* O157:H7 in apple juice. The result was 4.5-log reduction for a UV light dose of 300 mJ/cm^2 and a liquid medium depth of 1 mm. Bacterial inactivation increased at 4.8-log as the UV dose increased. When a UV dose of 390 mJ/cm^2 and a medium depth of 3.5 mm were used, the inactivation did not exceed 3.5-log showing that medium transparency to UV influences the efficacy of microbial inactivation [35].

Oteiza et al. (2005) extended the study with UV-C light at 254 nm to different fruit juices (apple, orange and multifruit) with different absorptivities inoculated with *E. coli* ATCC 25922 and *E. coli* O157:H7 (EDL 933) varying the liquid film thickness and agitation rate. Stirring the juices exposed to UV light and reducing the film thickness to 0.7 mm produced the highest bactericidal effect. Another conclusion of this study was the linear relationship between the decimal reduction time (*D* value) and the absorbance of the medium [36].

The study of Gabriel (2012) determined and compared the heat and UV light inactivation rates in apple juice of individual and composited inocula of different strains of *E. coli* O157:H7 (CR-3, MN-28 and HCIPH 96055) and juice spoilage yeast strains (*Debaryomyces hansenii*, *Clavispora lusitaniae*, *Torulaspora delbrueckii*, *Pichia fermentans* and *Saccharomyces cerevisiae*). Spoilage yeasts (*D* = 6.38–11.04 min) were found to be generally more UV-C resistant than *E. coli* O157:H7 (D = 0.5–2.76 min), while the opposite was observed in terms of thermal resistance (*E. coli D* = 0.9–4.43 min; yeast *D* = 0.03–6.10 min). These results may be useful to select appropriate target microorganism in further studies [7].

Guerrero-Beltrán & Barbosa-Canovás (2005) aimed to study the microbial reduction of *Saccharomyces cerevisiae*, *Listeria innocua* (ATCC 51742) and *Escherichia coli* (ATCC 11775) inoculated separately and as a mixture in apple juice. The reduction log obtained after 30 min of UV treatment with doses between 75 and 450 kJ/m^2 at different juice flow rates (0.073–0.548 L/min) was 1.34 ± 0.35 for *S. cerevisiae*, 4.29 ± 2.34 for *L. innocua* and 5.10 ± 1.12 for *E. coli*. The average D_{UV} values obtained for each microorganism were: 23.1–40.5 for *S. cerevisiae*, 8.2–20.6 for *L. innocua* and 6.0–17.7 for *E. coli*. The higher D_{UV} values obtained for *S. cerevisiae* demonstrate that this yeast was more resistant to the UV light treatment than bacteria *L. innocua* and *E. coli*. High microbial reduction was also obtained when a mixture of microorganisms was inoculated in apple juice: less than 10 CFU/mL (no growth) for *S. cerevisiae*, 190 CFU/mL for *L. innocua* and 200 CFU/mL for *E. coli* after UV treatment [47].

The influence of UV light and PEF on microbial inactivation of natural microbial count in fresh apple juice was investigated by Noci et al. (2008) resulting in a 2.2 and 5.4 log reduction respectively [50].

Keyser et al. (2008) examined apple juice inoculated with *E. coli* K12 as surrogate for *E. coli* O157:H7, other fruit juices (orange juice, tropical juice, guava-and-pineapple juice) and nectars (strawberry and mango) pursuing UV inactivation of aerobic plate counts (APC) and yeasts and moulds (YM) [34].

Other bacteria subjected to UV light in fruit juices were: *Listeria innocua* ATCC 51742 [47], *Yersinia pseudotuberculosis* and *Y. pestis* [55] and *Staphylococcus aureus* (SST 2.4) [9]. All these bacteria are pathogenic with the exception of *Y. pestis*, a surrogate of *Y. pseudotuberculosis*. The inactivation of *S. aureus* decreased linearly as the exposure time increased and after exposing the apple juice for 30 min to UV, 2.2 log reductions were achieved.

Table 2 presents some of the most relevant studies on UV light inactivation of microorganisms in fruit juices.

4.2. UV light inactivation of microorganisms in apple cider

Some researches have examined the efficacy of UV light in the treatment of apple cider.

Harrington and Hills (1968) studied the effect of UV light exposure on spoilage and flavour of fresh cider

subsequent production. They observed that the reduction of total aerobic population was dependent on the clarity of juice and time of UV light treatment. A taste panel found no significant difference between UV treated and not treated apple cider. The reduction of any pathogenic microorganism and the relationship between the clarity of apple cider and the efficacy of UV light treatment were not examined [38].

Apple cider is usually commercialised unpasteurised, its shelf life and preservation relying on product's acidity, refrigeration, and chemical preservatives. However, *E coli* O157:H7 can survive in cider despite its low pH, refrigerated conditions and preservatives addition [56, 57]. Although the producers of apple cider are aware of the risks of unpasteurised apple cider consumption, thermal pasteurisation is not considered attractive due to the high cost of equipment and the potentially negative organoleptic effects. Therefore, the effect of UV light on this pathogenic bacterium was intensely studied.

Wright et al. (2000) investigated the efficacy of UV light for reducing a mixture of acid-resistant *E. coli* O157:H7 in unpasteurized apple cider at 254 nm with dosage ranging from 9.4 to 61.0 mJ/cm^2. They observed that *E. coli* was killed exponentially with UV doses between 4.0 and 6.5 mJ/cm^2. UV-C light significantly reduced *E. coli* O157:H7 inoculated in apple cider with a mean of 3.81-log CFU/ml when treated in thin film continuous flow. The best reduction was obtained when apple cider contained very low initial levels of yeasts and moulds (1 log CFU/ml) and was treated with the highest UV dosage (61.0 mJ/cm^2), the inactivation being of 5.4 log CFU/ml [37].

Koutchma et al. (2004) used the bacterium *E coli* K-12 as surrogate for *E. coli* O157:H7. They achieved only a 3.8-log reduction for *E coli* K-12 in apple cider due to the influence of the turbidity of the cider on the effectiveness of the treatment. A 5-log reduction was achieved in cider containing low initial levels of yeasts and moulds with high UV doses and low flow rates [33]. However, Duffy et al. (2000) and Quintero-Ramos et al. (2004) have demonstrated at least a 5-log reduction of *E. coli* ATCC 25922, a surrogate for O157:H7 in multiple trials using the CiderSure^{TM} UV light equipment working with doses of UV-C light (λ = 254 nm) up to 18.681 mJ/cm^2 [26, 51].

Hanes et al. (2002) demonstrated the effectiveness of UV light for inactivating *Cryptosporidium parvum* in fresh apple cider. They obtained more than 5-log reduction with UV-C light (λ = 254 nm) dose of 14.32 mJ/cm^2 and exposure time of 1.2–1.9 s [52].

Basaran et al. (2004) analyzed the effect of different apple cultivars upon the UV inactivation of *E. coli* O157:H7 strains (933, ATCC 43889, ATCC 43895) in unfiltered apple cider using UV-C light (λ = 254 nm) dose of 14 mJ/cm^2. *E. coli* O157:H7 ATCC 43889 showed the most sensitivity to UV treatment with an average reduction of 6.63-log compared to 5.93-log for other two strains. The same strain was reduced with 7.19-log in Rome cider, this being the highest log reduction seen. Among the apple cultivars, an average log reduction range of 5.78 (Red Delicious) to 6.74 (Empire) was observed [53].

Table 3 summarizes some of the most relevant studies on UV light inactivation of microorganisms in apple cider.

4.3. UV light inactivation of microorganisms in model solutions

In order to study the influence of individual physical and chemical factors of liquids on the UV light inactivation of microorganisms, model fluids were used. Thus, Koutchma *et al*. (2004) examined the inactivation of *E. coli* K-12 (ATCC 25253) in model solutions based on malate buffer to simulate the content in L-malic acid and to adjust the pH accordingly, and added caramel to provide extremes of absorbance, and sucrose to simulate soluble solids of apple juice/cider [33].

Similar model solutions (Table 3) were used in other studies: malate buffer pH 3.0 and 5.0, 10, 15, 20 and 25°Brix sucrose, and 0.13% caramel [49], model caramel solutions [55]. The researches reveal that factors unique to juice, such as pH and concentration in Brix degrees did not show large effects on UV treatment when tested individually. The absorbance seems to be the single factor affecting the efficacy of UV light inactivation in apple juice and cider. Increasing the absorbance of solutions resulted in lower inactivation of *E. coli* bacteria. For instance, for the lowest absorbance of 0.13% caramel solution and one pass of fluid through UV reactor at lowest flow rate of 57 ml/s a reduction of bacterial population of 4.3-log was achieved in the work of Koutchma et al. (2004).

Table 2. Studies on UV light inactivation of microorganisms in fruit juices

Food / support material	Type of UV light conditions	Microorganism(s)	Inactivation result	References
Apple juice				
Fresh apple juice	UV-C λ = 254 nm 30 W, 30 min	Natural microbial count	2.2 log	Noci *et al*., 2008
Apple juice	UV-C λ = 254 nm 1 mm liquid depth 300 mJ/cm^2	*E. coli* O157:H7	4.5-log	Ngadi et al., 2003
Apple juice pH = 3.47	UV-C λ = 254 nm 0 – 6 J/cm^2	*E. coli* O157: H7 (EDL 933) *E. coli* ATCC 25922	5D reduction for 1 mm thick film and 0.1 J/cm^2	Oteiza *et al*., 2005
Clear apple juice (pH 3.68, 12°Brix)	UV-C 254 nm 1.5 min	*E. coli* O157:H7	D = 2.64–2.76 min	Gabriel, 2012
Apple juice	UV-C λ = 254 nm 4 – 24 mJ/cm^2	*E. coli* O157: H7 (DHS1, ATCC 35150, 960218 and H3482)	0.406 – 0.551 log/(mJ/cm^2)	Murakami *et al*., 2006
Pasteurised apple juice	UV-C λ = 254 nm 8 LP mercury lamps 8 × 39 W = 312 W	*E. coli* K-12 (ATCC 25253)	3.8-log	Koutchma et al., 2004
Apple juice a = 0.9 mm^{-1}	12 LP mercury lamps 12 × 42 W = 504 W Turbulent conditions Flow rates: 32 l/min 75 l/min Almost seven passes	*E. coli* K-12 (ATCC 25253)	More than 5 log	Koutchma *et al*., 2004
Apple juice	UV-C λ = 254 nm 2 – 100 mJ/cm^2 0.1 – 1.0 mm	*E. coli* K12	0.055 – 0.215 log/(mJ/cm^2)	Murakami *et al*., 2006
Apple juice	UV-C λ = 254 nm 12, 15.4, 16 mW/cm^2	*E. coli* K12 (ATCC 25253)	5.3-log	Ye *et al*., 2007
Apple juice	UV-C λ = 254 nm 1377 J/L	*E. coli* K12	7.42 log	Keyser et al., 2008
Apple juice	UV-C λ = 254 nm 75–450 kJ/m^2	*E. coli* ATTC 11775 *Listeria innocua* ATCC 51742	D = 6.0–17.7 min D = 8.2–20.6 min	Guerrero-Beltrán & Barbosa-Canovás, 2005
Apple juice	UV-C λ = 254 nm 12, 15.4, 16 mW/cm^2	*Yersinia pseudotuberculosis* *Yersinia pestis* 1122	4.9-log 4.4-log after 6 h	Ye *et al*., 2007
Apple juice reconstituted from concentrate	UV-C λ = 254 nm 4 mm liquid depth 30 W UV light bulb 5–30 min, 20°C	*Staphylococcus aureus* (SST 2.4)	2.2-log	Walkling-Ribeiro et al., 2008
Apple juice	UV-C λ = 254 nm 75–450 kJ/m^2	*Saccharomyces cerevisiae*	D = 23.1–40.5 min	Guerrero-Beltrán & Barbosa-Canovás, 2005
Clear apple juice (pH 3.68, 12°Brix)	UV-C λ = 254 nm 8.0 min	Spoilage yeasts: *Debaryomyces hansenii* *Clavispora lusitaniae* *Torulaspora delbrueckii* *Pichia fermentans* *Saccharomyces cerevisiae*	 D = 8.27 min D = 9.78 min D = 9.39 min D = 11.04 min D = 6.38 min	Gabriel, 2012

Other juices				
Orange juice pH = 3.53	UV-C λ = 254 nm 0–6 J/cm^2	*E. coli* ATCC 25922 *E. coli* O157: H7 (EDL 933)	5D reduction for 0.7 mm thick film and 0.55 J/cm^2	Oteiza *et al*., 2005
Orange juice	UV-C λ = 254 nm 1607 J/L	APC* YM**	0.3 log 0.3 log	Keyser et al., 2008
	UV-C λ = 254 nm 1377 J/L	APC YM	0.89 log 0.30 log	Keyser et al., 2008
Tropical juice	UV-C λ = 254 nm 1607 J/L	APC YM	0.5 log -	Keyser et al., 2008
	UV-C λ = 254 nm 1607 J/L	APC YM	0.59 log 0.72 log	Keyser et al., 2008
Multifruit juice pH = 3.76	UV-C λ = 254 nm 0 – 6 J/cm^2	*E. coli* ATCC 25922 *E. coli* O157: H7 (EDL 933)	3 log decrease for 0.7 mm thick film and 0.55 J/cm^2	Oteiza *et al*., 2005
Guava-and-pineapple juice	UV-C λ = 254 nm	APC YM	3.31 log CFU/ml 4.48 log CFU/ml	Keyser et al., 2008
Strawberry nectar	UV-C λ = 254 nm 2065.5 J/L	APC YM	1.32 log CFU/ml 2.45 log CFU/ml	Keyser et al., 2008
Mango nectar	UV-C λ = 254 nm 1377 J/L	APC YM	1.4 log CFU/ml 2.8 log CFU/ml	Keyser et al., 2008

* APC – Aerobic plate count
** YM – Yeasts and moulds

Table 3. Studies on UV light inactivation of microorganisms in apple cider

Food / support material	Type of UV light conditions	Microorganism(s)	Inactivation result	References
Unpasteurized apple cider	UV-C λ = 254 nm 9,402–61,005 μW/cm^2	*E. coli* O157:H7	3.81 log	Wright et al., 2000
	0.061 mJ/cm^2	*E. coli* O157:H7	5.4 log	
Apple cider	UV-C λ = 254 nm 14 mJ/cm^2	*E. coli* O157:H7 933 strain ATCC 43889 ATCC 43895	5.25 – 7.19-log 5.93-log 6.63-log 5.93-log	Basaran et al., 2004
Apple cider	UV-C λ = 254 nm	*E. coli* ATCC 25922	5–8.5 log	Duffy *et al*., 2000
Fresh apple cider	UV-C λ = 254 nm 14.32 mJ/cm^2 1.2–1.9 s	*Cryptosporidium parvum* oocysts	More than 5 log	Hanes *et al*., 2002
Apple cider pH = 3.0–4.4 Apple cider	UV-C λ = 254 nm 1.8–18.681 mJ/cm^2	*E. coli* ATCC 25922	0.35–6.05 log	Quintero-Ramos *et al*., 2004
Pasteurised apple cider	UV-C λ = 254 nm 8 lamps × 39 W = 312 W	*E. coli* K-12 (ATCC 25253)	3.8 log	Koutchma et al., 2004
	UV-C λ = 254 nm 12 lamps × 42 W = 504 W	*E. coli* K-12 (ATCC 25253)	More than 5 log	Koutchma et al., 2004
Apple cider	UV-C λ = 254 nm 34,000 mJ/cm^3	*E. coli*	4.7 log	Geveke, 2005

Table 4. Studies on UV light inactivation of microorganisms in model solutions

Food / support material	Type of UV light conditions	Microorganism(s)	Inactivation result	References
Model solution: 3 g/l malic acid, 10–20°Bx sucrose 0.13–0.6% caramel	UV-C λ = 254 nm 8 LP mercury arc lamps 8 × 39 W = 312 W Flow rate = 57 ml/s	*E. coli* K-12 (ATCC 25253)	4.3–5 log	Koutchma *et al*., 2004
0.13% caramel	One pass		4.3 log	
0.4% caramel	Two passes		4.3 log	
0.5% caramel	Three passes		4.3 log	
0.6% caramel	Five passes		5 log	
Model solution: clear malate buffer 0.13–0.6% caramel pH = 3.75	12 LP mercury arc lamps 12 × 42 W = 504 W Turbulent conditions Flow rates: 32 l/min 75 l/min One pass	*E. coli* K-12 (ATCC 25253)	More than 5 log	Koutchma *et al*., 2004
Model apple juice / cider (malate buffer pH 3.0 and 5.0, 10, 15, 20 and 25°Brix sucrose, and 0.13% caramel)	UV-C λ = 254 nm 4.0, 8.0 and 12.0 mJ/cm^2	*E. coli* K-12 (ATCC 35695)	0.71 log per mJ/cm^2 for a* = 6 cm^{-1}	Murakami *et al*., 2006
	0.5, 1.0 and 2.0 mJ/cm^2		0.16-log per mJ/cm^2 for a = 21 cm^{-1}	
Model caramel solutions	UV-C λ = 254 nm 12, 15.4, 16 mW/cm^2	*E. coli* K12 (ATCC 25253)	More than 5-log	Ye *et al*., 2007
		Yersinia pseudotuberculosis	4.9-log	
		Yersinia pestis 1122	4.4-log after 6 h	

* a – absorbance of UV light

Any increase of absorbance required more than one pass of the fluid through UV reactor in order to obtain the same level of inactivation. Thus, increasing the absorbance to 0.6% caramel resulted in a 5-log reduction of initial count of *E. coli* after five passes of model solution through the UV reactor [33].

The conclusion of all work based on model solutions is that absorbance is an important factor in UV inactivation, since the presence of solid particles could provide a means of shielding microorganisms from the UV treatment.

4. Conclusion

The interest in UV light treatment increased with the growing need of microbiologically safe food, and responds to the demands of the consumers for food with more natural texture and flavours.

UV radiation was successfully used to reduce the microbial load in different fruit juices, mainly apple juice, fruit nectars and apple cider. Clear liquids such as apple juice needed lower doses of UV to reach efficient reduction of microbial load. Other food liquids such as orange juice with pulp and nectars needed higher doses of UV light due to the greater amount of suspended solids and fibres, which protect microorganisms against the action of UV light.

Extensive research over the last years showed that UV light technology is suitable for the preservation of fruit juices, nectars and apple cider combining the inactivation of spoilage and pathogenic microorganisms with the advantage of preserving the fresh-like attributes of treated foods.

Different microorganisms such as pathogenic bacteria (*E. coli* O157:H7, *L. innocua*, *Y. pseudotuberculosis*, *S. aureus*) surrogate bacteria for *E. coli* O157:H7 (*E. coli* K-12, *E. coli* ATCC 25922), spoilage yeasts (*S. cerevisiae*, *D. hansenii*, *C. lusitaniae*, *T. delbrueckii*, *P. fermentans*) and

protozoan *C. parvum* were tested. The resistance of tested microorganisms toward UV-C light significantly varied within species and strain. The minimum 5-log reduction of pathogens regulated by U.S. FDA for fruit juices was achieved in most of the studies. For those situations in which this reduction is not reached, higher dose rates of UV light are necessary. These can be obtained by extension of the time of exposure of food liquid to the UV light or by using a higher intensity of the lamp as well as increasing the turbulent flow of the liquid.

In conclusion, UV light technology is able to ensure the safety of fruit juices, nectars and cider, especially in combination with good manufacturing practices or other minimal processing technologies; therefore is a promising, lower-cost alternative to thermal pasteurisation.

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Abbreviations

APC – Aerobic plate count
D value – decimal reduction time, min
DNA – deoxyribonucleic acid
FDA – Food and Drug Administration
HPP – high pressure processing
PEF – pulsed electric fields
RNA – ribonucleic acid
UV – ultraviolet
YM – Yeasts and moulds

Compliance with Ethics Requirements

Authors declare that they respect the journal's ethics requirements. Authors declare that they have no conflict of interest and all procedures involving human and/or animal subjects (if exists) respect the specific regulations and standards.

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