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Effect of UV light on food quality and safety

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Abstract. The recent years have seen a great number of instances when ultraviolet (UV) radiation was used in the preservation process of all sorts of foods. Since the purine and pyrimidine bases of DNA and RNA absorb well the 254 nm radiation, its application with the use of a correct dosage can result in disinfections of various orders of magnitude. It can be particularly effective in cases where technology does not allow a more intensive heat treatment. When used properly, UV treatment can be a competitive procedure in the case of foodstuffs where the large surface area allows for UV rays to penetrate the entire volume of the substance. Incorrectly applied UV treatment may change the composition of foods. Free-radical as well as photochemical reactions can digest the proteins, damage the antioxidants, oxidize the lipids, make changes to the colour

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and substance, and produce undesirable flavourings and odorous substances. Some vitamins are particularly sensitive to UV irradiation in the course of which losses could reach even 50%. Photosensitive water-soluble vitamins are vitamin C, B_{12}, B_6, B_2 and folic acid, while vitamins A, K and E are the fat soluble sensitive to light, carotene being the only provitamin with such properties. On the other hand, UV treatment can be a useful tool of food safety because of the photosensitivity of fungal toxins.

1 Introduction

The internationally accepted definition of pasteurization is as follows: "All methods and procedures, or the combination of these, applied on foodstuffs to reduce the number of pathogenic microorganisms relevant to human health to a level where, under normal conditions of production, transport, and storage, they cannot constitute a danger to humans." Treatment with UV rays is also in correspondence with the above definition provided it complies with the conditions outlined. There is broad consensus that both traditional and novel pasteurization procedures need to be validated, and it must be made certain that these methods will indeed lead to the destruction of the pathogenic microorganisms most relevant in terms of human health, which are followed by the authorities' (in the USA: *NACMCF – National Advisory Committee on Microbiological Criteria for Foods*, 2005) licensing procedures for the different foodstuffs.

UV radiation is a non-ionizing radiation from whose spectrum (140–400 nm) the wavelengths between 250 and 280 nm can be utilized as a germicide since the light of this wavelength can be absorbed by both nucleic acids and most proteins containing aromatic amino acids as well, the subsequent transformation having the potential to destroy microorganisms. UV lamps have been widely used before for purposes of air sterilization as well as for late-winter skin treatment of infants and young children because exposure to UV light leads to the synthetization of vitamin D, a necessary circumstance for optimal development. UV radiation can be used for the sterilization of air spaces and surfaces, its applicability being, however, limited by the fact that its energy decreases quadratically as distance from the light source grows and that it has a low penetrating capability. Caution is recommended during its application as it is harmful to the eyes and may cause conjunctivitis or even skin cancer when used in large doses (*Koutchma et al.*, 2009).

In food production, UV light is used to increase the shelf life of foods and

reduce the number of pathogenic microorganisms. UV treatment was applied with good results in increasing the shelf life of fruit juices, various drinks, vegetables, fruits, meat, poultry and seafood products, destroying the pathogenic microorganisms found therein and reducing maturation intensity. The question arises, on the other hand, as to what changes can occur in the composition of foods upon UV treatment. How does photodegradation affect organic molecules? What changes can photochemical reactions trigger that may ultimately have a negative impact on quality and nutritional value? Vitamins with a high structural diversity are of particular interest, most of them being potentially sensitive to UV light by virtue of their structure (*Koutchma et al.*, 2009).

2 Effects of UV-treated milk on microorganisms

Fruit juices and milk are perhaps the two food categories that permit the most efficient studying of UV treatment effects on microorganisms as both of these categories make laminar as well as turbulent flow possible, allowing for the entire volume of the liquid to be exposed to UV treatment.

Upon exposure of goat's milk to 15.8 mJ/cm^2 cumulative UV radiation, the amount of Listeria *monocytogenes* decreased by 5-$\log_{10}$. Applying an UV treatment of 15 kJ/litre on cow's milk reduced the number of coliform bacteria by three orders of magnitude, but there was no significant decrease in the case of spores (*Matak et al.*, 2005). Under laboratory conditions, when using tubes permeable to UV light and applying static mixing, UV treatment was not efficient enough against *Mycobacterium avium subsp. paratuberculosis* as the rate of decrease was only half an order–one order of magnitude upon treatment with a dose of 1 J/ml. Using a special mixing device and the same level of irradiation improved the rate of decrease to 2.5–3.3-$\log_{10}$ (*Altic et al.*, 2007).

This latter finding also draws attention to the fact that the dosage of UV light is not the sole determining factor in reducing the number of germs, but apparatus design is of crucial importance as well. Recently, UV reactors operating in continuous current mode have been developed primarily for the pasteurization of fruit juices, thus avoiding the formation of turbidity during treatment. According to one technological procedure, laminar flow is applied forming an extremely thin layer of film that reduces the path of UV light in the substance, thus allowing the light to permeate the entire volume of the substance (*Koutchma et al.*, 2004). Another solution is the application of a turbulence that allows the total amount of the substance to get in the im-

mediate proximity of the light source, likewise enabling the light to permeate all particles of the substance. These devices are currently being tested, in the course which flow rates, turbulence, or the level of UV irradiation are optimized.

In order for the conditions to be normalized during UV treatment, experimenters must succeed in exposing all areas of the liquid – whether it is a laminar or a turbulent flow – to a sufficient dose of UV light that is capable of destroying the microorganisms. A spiral tubular reactor could offer such a solution (*Koutchma et al.*, 2007), making possible that all of the treated liquid gets the optimal UV dose (*Forney & Pierson*, 2004; *Forney et al.*, 2004).

In the May 2011 issue of New Scientist, heat pasteurization was considered an alternative method (*Gupta*, 2011). According to the report, introducing pasteurization has significantly cut down the number of foodborne diseases despite not destroying all bacteria. At the same time, however, it reduces the nutritional value of milk, which is most significant in proteins and vitamins. Since this is especially the case with colostrum, it has been tested whether the UV treatment of colostrum would lead to the desired microbe-destroying effect without the drastic decrease of its immunological value. The question has been raised as to whether or not UV treatment can serve as an alternative for pasteurization in the case of colostrum.

In their experiments, they attempted to pasteurize colostrum with UV light on a farm keeping dairy cows, as it is widely known that immunoglobulins in colostrum condense due to heat and become immunologically worthless to the calf. A similar situation prevails during the pasteurization of mother's milk by heat treatment for the composition of mother's milk, considering its protein fractions, is similar to that of the bovine colostrum. In carrying out the procedure, the basic assumption was that although the applied dose of UV light would not destroy the bacteria completely, it would render them unable to reproduce due to the damage caused in their DNA, while the applied energy would not damage the immunoglobulins, which would preserve their ability to provide passive immunity to the calf.

To serve the purposes of the experiment, a device was constructed in which threaded tubes encircled the UV lamps, allowing the total amount of the turbulently flowing milk to receive the UV treatment. Upon treatment, part of the microorganisms was destroyed, but the proteins were not significantly damaged. Nonetheless, supervisory bodies contend that there are still plenty of experiments to be carried out in order to prove the applicability of this procedure for the preservation of mother's milk (*Gupta*, 2011).

Pereira et al. (2014) treated colostrum and milk with UV light in an at-

tempt to find out the degree to which bacteria would be destroyed and what changes would occur in the nutritional value of colostrum and milk, particularly in its immunoglobulin G content. Their experiments were driven by a USDA statement that 58% of the calves in the US are given unpasteurized colostrum and milk to drink, which carries the risk of infection. In the course of the experiment, both the milk samples and the colostrum were exposed to a continuous UV radiation of 45 J/cm^2. Prior to UV treatment, the colostrum as well as the sterile milk samples were inoculated with *Listeria innocua*, *Mycobacterium smegmatis*, *Salmonella serovar typhimurium*, *Escherichia coli*, *Staphylococcus aureus*, *Streptococcus agalactiae* and *Acinetobacter baumannii* microorganisms. The IgG content of the treated and untreated samples was continuously determined with the ELISA method.

It has been established that UV treatment significantly reduced microbial count in milk (log CFU/ml) in the case of *Listeria monocytogenes* (a decrease of 3.2 ± 0.3 log CFU/ml), *Salmonella* spp. (3.7 ± 0.2 log CFU/ml), *Escherichia coli* (2.8 ± 0.2 log CFU/ml), *Staph. aureus* (3.4 ± 0.3 log CFU/ml), *Streptococcus* spp. (3.4 ± 0.4 log CFU/ml), and *A. baumannii* (2.8 ± 0.2 log CFU/ml). UV treatment did not result in a significant decrease in the case of *M. smegmatis* (1.8 ± 0.5 log CFU/ml), whereas with colostrum significant decrease was observed for *Listeria* spp. (1.4 ± 0.3 log CFU/ml), *Salmonella* spp. (1.0 ± 0.2 log CFU/ml), and *Acinetobacter* spp. (1.1 ± 0.3 log CFU/ml), but for *E. coli* (0.5 ± 0.3 log CFU/ml), *Strep. agalactiae* (0.8 ± 0.2 log CFU/ml), and *Staph. aureus* (0.4 ± 0.2 log CFU/ml) the decrease did not reach one order of magnitude. The UV treatment of colostrum resulted in an average of 50% decrease in IgG content.

Donaghy et al. (2009) studied the destruction of the various strains of *Mycobacterium avium ssp. paratuberculosis* (Map) in milk as an effect of UV treatment. Milk treated at ultrahigh temperature was inoculated with various strains of *Mycobacterium avium ssp. Paratuberculosis* and then treated with UV light of 0–1836 mJ/ml in a 20 litre reactor. Following treatment, the microorganisms were grown in an appropriate culture medium, and then their number was determined. It has been established that destruction took place at an order of magnitude of 0.1–0.6 $\log_{10}$. They concluded that UV radiation treatment alone is not suitable for the destruction of pathogenic microorganisms, so it is advisable to be combined with other procedures. They take the view that milk is an inappropriate medium because UV rays can find their way and take effect with difficulty through the opaque liquid. In one of their studies, *Donahue et al.* (2012) ascertain that heat treatment significantly reduces total germ count in colostrum, while its IgG content barely undergoes

any change at all. First-milking colostrum was heated to 60 °C and kept in a pasteurizer tank for 60 minutes, and then the total germ count and immunoglobulin G content of colostrum were determined. After analysing 266 unique colostrum samples, they pointed out that due to heat treatment the total germ count of colostrum and the number of coliforms decreased by 2.25 $\log_{10}$ and 2.49 $\log_{10}$ respectively, but this heat treatment had only a slight impact on the IgG concentration of colostrum. They found that heat treatment of colostrum at 60 °C for a period of 60 minutes makes it possible to reduce the number of microorganisms by two orders of magnitude, while the IgG concentration of the colostrum suffers only minimal changes, and such a heat-treated colostrum can be applied safely to provide passive immunity to the calf.

Teixeira et al. (2013) studied the effects of heat and ultraviolet light on colostrum and hospital milk and analysed the impact of these treatments on calves' health and the growth parameters. The declared aim of the study was to examine the effects of heat and UV treatment on the total microbial count of milk, on the immunoglobulin G and lactoferrin concentration, and on calves' health, growth, and blood serum IgG level. Part of the colostrum samples was heat treated at 63 °C for 60 minutes, whereas another part of them was exposed to UV radiation of 45 J/cm^2, and test results were then compared to untreated milk samples. One part of hospital milk samples was heat treated at high temperature (72 °C) and for a short time (15 seconds), while the other part was exposed to UV radiation of 45 J/cm^2, and test results were then compared to untreated milk. They showed that heat treatment reduced the number of microorganisms more efficiently than UV treatment and that both IgG and lactoferrin concentration were significantly lower in treated milk when compared to raw milk. A comparison of hospital milk samples demonstrated that high-temperature heat treatment reduced the concentration of lactoferrin as compared to raw or UV-treated milk. An analysis of the IgG concentration of calves' blood serum showed that none of the treatment types had a significant effect thereon.

Singh & *Ghalya* (2006) studied the efficiency of cheese whey sterilization by applying 5–70 ml/min flow time in a traditional and a spiral UV reactor. Test results in the traditional reactor failed to get close to a 100% efficiency, but attempts made in the spiral reactor approximated this level when flow rate ranged between 35 and 40 ml/min. In the case of both reactors, they managed to balance the lowering of treatment temperature by increasing the flow rate. 100% efficiency could only be achieved with an extremely long (45 and 240 minutes) flow time.

Further developing their methodology (*Singh & Ghalya*, 2007), they designed an UV spiral reactor for the sterilization of cheese whey, and then compared its antimicrobial effect with that of a traditional UV reactor. Both reactors were tested at equal volumes and at different (5, 10, 15, 20, 25, 30, 35, 40, 50, 60 and 70 ml/min) flow rates. It was found that despite the turbid nature of whey both reactors could be used with great efficiency for sterilization. Technical problems occurring in the spiral reactor were much fewer in number than in its traditional variant.

During the sterilization process of cheese whey, *Mahmoud & Ghalya* (2005) studied – at different values of fluid thickness and after different retention times – the obstructions formed in an UV tubular reactor as well as the composition of the substance responsible for the clogging. Substances precipitated on UV lamps significantly reduced sterilization efficiency. A close correlation was found between the degree of obstruction and the applied temperature. 63.5–77.2% of protein, 12.6–16.5% of fat, and 6.5–9.5% of minerals were measured in the dry matter content of the substance causing the blockage, which values were about 1%, 0.5%, and 0.4%, respectively, in the case of whey. Upon reducing the layer thickness of whey, the amount of precipitated matter increased. High temperature and low pH were favourable to precipitation, whose mechanism was explained with adsorption and direct exchange. It was established that contact between the flowing substance and the quartz wall must be reduced as that may also be the agent responsible for precipitation during the UV sterilization process.

3 Effects of UV irradiation on fungal toxins

Toxins are secondary metabolites of microscopic fungi, representing serious food and feed safety hazard for both humans and animals (*Beardall & Miller*, 1994) and resulting in a disease called mycotoxicosis. Although these compounds are generally heat-stable molecules, for example, the aflatoxins are decomposed only above 268–269 °C (*Peng et al.*, 2018), a specific wavelength of light sources can result degradation. Even the sunlight is useful for decreasing their concentration – direct solar irradiation applied on poultry feed for 3–30 hours resulted in a 25–60% decrease of aflatoxin B_1 (*Herzallah et al.*, 2008), but the UV light has a stronger decomposing effect of mycotoxins due their photosensitivity. *Murata et al.* (2008) evaluated the effect of mild and strong (0.1 and 24 mW/cm^2) UV irradiation at a 254 nm wavelength on toxin-contaminated feed samples and found that even a low dose of

irradiation totally decomposed the initial 30 mg/kg zearalenone (ZEN) and deoxynivalenol (DON) concentration after 60 minutes, while a higher dose resulted in a more rapid elimination. *Murata et al.* (2011) also evaluated the 1.5 mW/cm^2 intensity UV-C treatment at the same wavelength on artificially DON-contaminated corn silage and found a 21–22% decrease after a 30- and 60-min. treatment. *Jajic et al.* (2016) confirmed the DON-decreasing effect of both UV-A and UV-C radiation on naturally contaminated maize but underlined that the change is not consistent, maybe due to the uneven toxin distribution; therefore, the results of the evaluation on artificially contaminated solid samples and contaminated homogeneous solutions can be taken into account only to a limited degree on natural solid samples. They found the UV-A treatment much more effective than UV-C. Aflatoxins have been referred to as UV-resistant toxins for a long time because the 254-nm wavelength irradiation was found to have no effect, but *Patras et al.* (2017) applied medium-pressure UV lamp light in the 200 to 360 nm wavelength region in different doses (from 0 to 4.88 J/cm^2) on aflatoxins dissolved in pure water and found that the highest dose resulted 67%, 30%, and 98% reduction for AFG_1, AFB_2 and AFB_1, respectively, and noted that aflatoxins had an absorption maximum at 320 nm. *Dong et a*l. (2010) made similar examinations on patulin-contaminated apple cider with 14.2 to 99.4 mJ/cm^2 UV-C treatment, found rapid decrease in toxin content (9.4 to 43.4% decrease within 15 s), and observed that the dose–effect connection is strongly linear.

4 Effects of UV irradiation on the quality of milk and dairy products

It is common knowledge that milk and dairy products are highly sensitive to UV irradiation since quality deterioration occurs very quickly if kept for a longer period of time in a glass recipient or in a translucent polycarbonate packaging, whereas opaque multilayer packaging protects them against deterioration. Milk can very easily produce foul-smelling compounds that remind us of burning protein, but a cabbage-like taste can also be easily formed as well as the oxidation of fats and unsaturated phospholipids, which occurs during the photochemical reaction and leads to the development of oxidized flavour (*Spikes*, 1981).

With milk, it is well known that upon UV treatment its vitamin D content increases in the transformation of 7-dehydrocholesterol into vitamin D. In addition to this useful transformation, a great number of valuable compo-

nents can deteriorate on this wavelength and foul-smelling products can be generated. It has also been found, however, that the treatment increasing the vitamin D content of milk does not reduce the concentration of carotene, vitamin A, thiamine, and riboflavin.

Matak et al. (2005) attempted to reduce the population of *Listeria monocytogenes* in goat's milk by applying UV treatment. Certain types of goat's cheese are made of raw milk, which increases the products' food safety risk. Gourmets continuously look for these products in the supermarkets, which makes risk reduction a significant issue. As the U.S. Code of Federal Regulations and the Pasteurized Milk Ordinance strictly sets out the rules for pasteurization, UV treatment could serve as an alternative to heat treatment, while those substances responsible for the gourmets' preference for goat's cheese would not be damaged. In the course of the experiment, fresh goat's milk was inoculated with 10^7 CFU/ml of *Listeria monocytogenes* (L-2289) and then treated with UV light using a dosage ranging between 0 and 20 mJ/cm^2. They managed to achieve a decrease of more than 5 $\log_{10}$ when the cumulative UV dose reached 15.8 mJ/cm^2. Their experiment clearly indicated that UV treatment is appropriate for reducing the number of *Listeria monocytogenes* by several orders of magnitude.

Exposing goat's milk to UV treatment of 15.8 mJ/cm^2, thiobarbituric acid test was used to measure the oxidative and hydrolytic degradation processes. They found that UV treatment increased the amount of thiobarbituric acid–active compounds and the degree of acidity. It has been shown that not only lipase activity but UV treatment was also responsible for the increased amount of free fatty acids and that the amounts of pentane, hexane, and heptane also increased owing to UV treatment; what is more, treatment performed at 254 nm caused the milk to smell like cabbage (*Matak et al.*, 2007).

Lu et al. (2011) developed a new technology for reducing the bacterial count of milk. In the process, milk was transferred through a quartz spiral helical tube while being blasted with UV rays and radio frequency radiation of 2.65 MHz. It was found that decrease in microbial count is significantly affected by flow rate, the internal diameter of the quartz tube, the UV light sources of various quality, and the different types of bacteria. According to them, the apparatus functioning with electrodeless UV lamp was more efficient in destroying microorganisms compared to the traditional, low-pressure, high-intensity mercury-vapour lamp. When the UV dose reached 21.3 mJ/cm^2 at a 28.8 litre/hour flow rate and at 1.5 mm diameter, total bacteria count decreased by 6 $\log_{10}$. Upon repeating their experiment with milk and applying a dose of 21.3 mJ/cm^2, total bacteria count decreased by 3–4 $\log_{10}$ orders of

magnitude in the case of microorganisms such as *Salmonella* and *Shigella* spp., *Listeria monocytogenes*, *Staphylococcus* spp., *Enterobacteriaceae*, lactic acid bacteria, or pseudomonades. It has been found that electrodeless UV source is less energy consuming, requires less space, and its operation is much simpler too than with heat treatment. They came to the conclusion that this new technology is viable and can replace heat treatment methods.

5 Effects of UV irradiation on food composition

In summary, it can be said that properly applied UV treatment can be a competitive method for decreasing the number of harmful microbes in foods if we do not wish to use thermal processes. At the same time, UV treatment may adversely affect food composition since a number of harmful photochemical reactions may be activated following the formation of free radicals, which may reduce the number of valuable food components (*Lu et al.*, 2011). Undesirable reactions reduce vitamin content, digest proteins, destroy antioxidants, oxidize lipids, cause changes to substance and colour, and leave undesirable smells (*Koutchma et al.*, 2002; *Adhikari & Koutchma*, 2002).

UV treatment of citrus fruits can modify their taste and reduces β-carotene as well as vitamin A and C content in all fruit and vegetable juices (*Guerrero-Beltrán & Barbosa-Cánovas*, 2006). The aforementioned call our attention to the fact that UV radiation treatment adopted for microbial inactivation must have an intensity that will cause minimal changes to the nutritional value and palatability of foods (*Noci et al.*, 2008).

Photochemical reactions have the greatest impact on the components that are capable to absorb UV light such as vitamin A, riboflavin, vitamin C, and a few food colourings. Others have reported that vitamin A and β-carotene decreased only when food was irradiated with visible light. With liquid milk, the oxidation of ascorbic acid in the presence of riboflavin was activated by superoxide anion (*Koutchma & Shmats*, 2002).

UV treatment may have significant effects in the case of foodstuffs containing large amounts of unsaturated fatty acids when these, affected by free radicals, oxidize, thus producing a rotten smell and reducing antioxidant effect. We have no data as to whether any toxic substances are produced upon UV treatment that may present a risk to human health (*Koutchma et al.*, 2009).

6 Measuring the effects of UV treatment

Effects of UV treatment to food quality can be measured by drawing conclusions from the organoleptic properties (appearance, colour, fragrance, smell, texture, and flavour) and by determining the colour, pH, and chemical composition, including first of all vitamins, which are perhaps the most sensitive to UV treatment. Our examination must also comply with the sample type we intend to evaluate as different foods are not equally sensitive to UV light (*Heiss & Radtke*, 1968). Sour cream, whipped cream, dried vegetable soup powder, butter, margarine, and mayonnaise proved to be the most sensitive to sunlight and fluorescent light, and so these gave off an unpleasant smell after a short period of UV treatment. 1–3 days of irradiation was necessary for sugar, chocolate, cheese, bacon, raw sausage, green beans, and salty peanuts to undergo visible changes. Rice and potato chips making up the third group showed significant changes only after 4–7 days, while 10–30 days were necessary for pastries, almond, and split peas to show such changes. These changes are, of course, affected by the wavelength of UV light to which the given food shows sensitivity, the transparency of packaging, and treatment temperature (*Koutchma et al.*, 2002).

7 The photodegradation of organic molecules

In direct photochemical reactions, light energy gets directly absorbed, after which the chemical reaction as well as the changes in food composition take place. The chemical reaction is dependent on the photon's energy and light exposure time. The energy of a 254 nm UV photon corresponds to 472 Joules, which can be suitable both for loosening the bond between the O-H, C-C, C-H, C-N, H-N and S-S and for the activation of various chemical reactions. In the case of indirect photochemical reactions, there are one or two components in the system that are sensitive to light exposure, which then launch a series of reactions that can yield several kinds of products.

Direct photochemical reactions depend on the wavelength of the adopted light for that will determine the photon's energy and the wavelength of light which the molecule in question will be able to absorb. Once the photon has been absorbed, the molecule enters an excited state and undergoes a photochemical change during which it may dissociate into radicals, may isomerize, dimerize, or form ions. Free radicals and ions are particularly reactive intermediates that can enter into fast, additional reactions with other food components, in which end-products are created.

Photo-oxidation is one of the most sensitive reactions to light. In the course of this, photosensitive intermediate products get from ground state to a short-lived excited state and then transform into long-lived intermediates. In the following, these will transform into end-products either in free-radical reactions by way of hydrogen/electron transfer or through energy transfer. In this process, hydrogen peroxide or superoxide anion is produced, for instance, which are able to react with many kinds of food components (*Koutchma et al.*, 2009).

Nucleic acids are especially great absorbers of 254 nm UV light. Only purine and pyrimidine bases absorb in DNA and RNA, while the structural framework of nucleic acids, the phosphodiester bonds, do not absorb at this wavelength. Those components are sensitive to 254 nm that contain conjugated bonds such as compounds containing aromatic and double rings, while disulphide bridges are also sensitive absorbents. Proteins are sensitive to this wavelength only if they contain amino acids with aromatic rings (phenylalanine, tyrosine, tryptophan) or if they have a disulphide (S-S) bridge. Vitamins A, B_{12} (cyanocobalamin) and D, folic acid, vitamins B_2 (riboflavin or lactoflavin) and E (tocopherols), the aforementioned tryptophan, unsaturated fatty acids in oils and fats, and the unsaturated fatty acids of phospholipids are all extremely sensitive to UV light. Literature data suggest that the structure of vitamin D can change upon exposure to UV light, and intermediate superoxide radicals can also enter into reaction with vitamin K (*Spikes*, 1981). Visible light does not affect ascorbic acid, but it strongly absorbs UV light at 254 nm; at this wavelength, plant pigments too are highly light absorbent.

In assessing the effects of UV light, a problematic issue may be that the absorption of the various light-sensitive compounds was studied in clear solutions, but there are very limited data on transformations in complex matrices such as foods. Generally speaking, organic molecules containing unsaturated bonds are strong UV absorbents. The longer the system of conjugated bonds is, the higher the wavelength will be at which maximum absorption takes place. Heterocyclic aromatic compounds such as purine and pyrimidine bases and, e.g., aromatic side-chain amino acids show strong absorption at 254 nm, with maximum absorption values sometimes reaching above 300 nm (*Spikes*, 1981).

Carbohydrates are not particularly sensitive to light, but some carbohydrate derivatives, such as sugar alcohols or saccharic acids, can be sensitive to light, and upon its absorption the fragmentation of polysaccharides can take place, thus changing, for instance, the properties of fruits and vegetables. Research indicate that UV light accelerated the oxidation of fats and oils.

Of the essential amino acids, histidine, phenylalanine and tryptophan showed significant decomposition levels when exposed to UV light as a result of which their protein structures underwent certain changes that modified the solubility, thermal sensitivity, mechanic properties and enzymatic digestibility of the protein; what is more, in the process of treating milk, for instance, unwanted odorous substances appeared in significant amount.

Thanks to the special pigments, foods take on a characteristic colour which can substantially change upon UV treatment, although it is precisely UV light that promotes the formation of certain pigments.

8 Effects of UV light on vitamin content

UV treatment of vitamins gives us cause for concern since many of the vitamins are sensitive to light, especially to UV radiation. Photosensitive water-soluble vitamins include vitamins C, B_{12}, B_6, B_2 and folic acid, while vitamins A, K and E are among the photosensitive fat-soluble vitamins, carotene being the only provitamin with such properties. Most experiments were performed in the 290–700 nm wavelength range, and very few were carried out in the 240–260 nm range so crucial for disinfection (*Ye*, 2007). Upon examination of the vitamin C content of apple juice before and after UV treatment (254 nm, 25W), they found that UV treatment caused 50% of the original vitamin C content to decompose at the slowest flow rate (*Ye et al.*, 2007). Vitamin C shows maximum absorption at around 260 nm, which is why vitamin C content has significant influence on the absorption of UV rays at this wavelength. Therefore, higher-energy UV rays must be applied in the pasteurization of products enriched with vitamin C. Another experiment showed that vitamin C decomposition takes place according to zero-order reaction and that the death rate for *E. coli* was two and a half times bigger with samples receiving vitamin C supplementation. In the case of apple juice, a correlation was found between vitamin C decomposition, the applied energy and the adopted technology (e.g. flow rate).

In fresh fruit juices, vitamin A plays an important role as well, contributing with 25% to the daily vitamin A requirement. Irradiating apple juice with an UV dose of 200 mJ/cm^2 caused its vitamin A content to decrease to around 50% of the original value, which calls attention to the vitamin-A-damaging effect of UV treatment (*Adhikari & Koutchma*, 2002). Considering that vitamins A and C are the two most essential vitamins in fruit juices, this raises awareness of the fact that UV treatment may cause substantial vitamin loss.

Besides these two vitamins, a 50% decrease was observed with riboflavin and β-carotene content as well, while others reported on a much slighter decrease of 11–16% upon the UV treatment of vitamins C, B_6 and A. The irradiation of a similar dose caused vitamin C to undergo a more significant decomposition than β-carotene (*California Day-Fresh Food Inc.*, 1999).

Summarizing the data obtained, it can be established that UV treatment resulted a decrease of about 30–40% and 18–25% in the vitamin C content of apple juice and carrot juice respectively. In the above cases, the applied irradiation dose was 600 mJ/cm^2 and 1450 J/s respectively (*Koutchma & Shmalts*, 2002).

9 Shelf life and changes in quality due to UV treatment

Effects of UV treatment have been primarily studied in the nowadays very popular fruit juices. The bulk of the dry matter content of fruit juices is carbohydrate, wherefore UV light has no particular effect on these types of foods. UV treatment is first of all applied to extend shelf life – in this process, they analysed how UV light affects aroma, colour and nutrient content (*Tandon et al.*, 2003). Applying UV light of various energy and wavelengths for various durations and at varying temperatures yielded no significant changes in the organoleptic properties of the treated and untreated fruit juices and led to no significant differences between pasteurization with UV light and heat. Following the treatment of orange juice with UV light of 100 mJ/cm^2, the loss of vitamin C was around 17%, just as if pasteurization were performed with heat treatment (*Tran & Farid*, 2004). The amount of total phenolic components in the apple juice significantly decreased due to UV treatment, but this was a slighter decrease compared to a heat treatment of similar efficiency (*Tran & Farid*, 2004).

UV treatment makes changes to enzymatic activity as well. In mango nectar, polyphenol oxidase activity decreased to 19%, and the product kept its bright fresh colour over a long period of time (*Guerrero-Beltrán & Barbosa-Cánovas*, 2006). Another experiment focused around the UV treatment of apple juice and found that total polyphenol amount was significantly reduced, but this decrease was smaller than in the case of heat treatment. UV light did not affect total antioxidant capacity and did not reduce either polyphenol oxidase or peroxidase activity as compared to the corresponding heat treatment. They concluded that UV treatment in no respect caused more negative changes in

composition than the equally efficient mild heat treatment (*Noci et al.*, 2008).

10 Application of continuous and pulsed UV light during food production

Application of UV treatment aimed at extending shelf life and destroying pathogenic microorganisms does not have an unequivocal reception due to the component-damaging and -changing effects of ultraviolet light. In 2000, the U.S. Food and Drug Administration claimed that UV treatment was completely safe and destroyed human pathogenic microorganisms in fruit juices (*US*, *FDA*, 2000a). It has also been established that UV irradiation may cause the decomposition of some components and the creation of others, but these are not dangerous to human health. Fruit juices treated with UV rays were claimed to be at least as safe as the commercially available products not treated with UV rays. However, it has also been made clear that UV treatment may be considered as microbiologically safe only if the number of human pathogenic microorganisms decreases by five orders of magnitude when compared to the control sample. This degree of reduction must be ensured and verified at all times whenever it comes to applications for human use (*US*, *FDA*, 2000b).

In most cases, UV rays are created with low-pressure mercury-vapour lamps, and the liquid is transferred through tubes that permit the full passage of UV rays. As most fruit juices absorb UV rays to the maximum, the greater part of the energy emitted gets absorbed within a few millimetres from the radiation source and does not reach other parts of the food, wherefore the light energy inside the tube will not be enough to destroy the human pathogenic microorganisms. Therefore, it is recommended that there be a turbulent flow in the light-transmitting tube allowing the bulk of the liquid to be in contact with the tube wall, where it can get the radiation dose necessary for the destruction of microorganisms. Compliance with the above conditions helps in destroying pathogenic microorganisms (*US*, *FDA*, 2001).

The intensity of UV radiation necessary for the destruction of human pathogenic microorganisms varies according to the type of liquid and fruit juice, the initial microbial count, the design of the applied apparatus, flow rate, number of lamps and time of irradiation. In view of the aforementioned, authorities do not prescribe a maximum and minimum radiation dose but recommend that maximum safety be achieved in the various applications, i.e. pathogenic microorganisms be destroyed in sufficient amount at all times. It must also be

taken into consideration that the production of UV radiation is also capital intensive, wherefore using a dose that is higher than the optimum can be uneconomical and may contribute to the adverse transformation of certain components.

In 2005, authorities approved the use of pulsed UV treatment in food production, processing and treatment (*US*, *FDA*, 2005). Pulsed UV treatment is safe in the producing, processing and treating of foods if xenon lamps emitting radiation in the range of 200–1.000 nm are used with a pulsing frequency not greater than 2 milliseconds, if the treatment aims at the destruction of the microorganisms on the surface, if the effects of the pulsed UV-light treatment are appropriate, and if total radiation dosage does not exceed 12.0 J/cm^2 (*US*, *FDA*, 2005).

Krishnamurthy et al. (2004) used pulsed UV radiation for the inactivation of *Staphylococcus aureus*. The energy of the pulsed light was 5.6 J/cm^2, and pulsing duration increased up to 30 seconds. This technology yielded a decrease of 7–8 $\log_{10}$ when UV radiation time reached at least five seconds. Sample thickness, exposure time, and treatment method significantly influenced the bactericidal effect. Pulsed UV radiation is considered a potential solution in the destruction of pathogenic microorganisms.

11 How safe is treatment with UV light?

A Canadian institute specialized in the safety of new food products examined how efficient an apparatus suitable for UV treatment is in reducing the microbial count of apple juice as well as of cider. They studied the changes in the composition and organoleptic properties of apple juice and cider upon UV treatment as compared to the control sample and if there was a possibility for the formation of toxic substances during UV treatment (*Health Canada*, 2004). They found that UV treatment had no harmful effect whatsoever on human organism, and it could be used efficiently for reducing the number of microorganisms in both cider and apple juice. Nevertheless, they have also established that UV treatment was not sufficient to completely destroy the microorganisms, particularly when the initial total microbial count was extremely high.

12 Regulating the use of UV light

In the European Union, there is no specific legislation regarding the usage of UV light in food production but only decisions with reference to the irradiation of foods, varying between Member States. Food products for which radiation can be used during their production or storage are now under discussion in the Member States. Radiation is allowed only if it is absolutely necessary in the technological process, if it is useful for the consumers, and if it does not aim at replacing either hygiene and health protection rules or the best practices used in production and agriculture (*Koutchma et al.*, 2009).

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