Journal of the Science of Food and Agriculture *J Sci Food Agric* **80**:637–645 (2000)

Review

Existing and potential applications of ultraviolet light in the food industry – a critical review

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Abstract: Short-wave ultraviolet light (UVC, 254 nm) can reduce dramatically the microbial load in air or on hard surfaces free from food residues, and can eliminate pathogens from potable water filtered to remove organic residues and 'clumps' of bacteria. More recently, approval of the Food and Drug Administration (USA) has been sought for a system for the destruction of pathogenic bacteria in fruit juices using UVC, and the same approach could perhaps be applied to remove spoilage organisms from cider or wines. In contrast, long-wave UV light (UVA, >320 nm) has limited microbiocidal properties, and for practical applications its effectiveness has to be enhanced by the presence of photosensitive compounds (eg furocoumarins) that will diffuse into a microbial cell prior to irradiation. The penetration of UVA into water is better than that of UVC, and its bacteriocidal action in the presence of photosensitisers can be rapid. However, pure furocoumarins are expensive and their addition to foodstuffs might be questioned on safety grounds.

Keywords: ultraviolet light; microbiocidal action; furocoumarins; water and fruit juice treatments

INTRODUCTION

Food safety is one of the most important issues facing the food manufacturing and service industries, for as consumers demand an increasing variety of ready-to-eat meals or dishes on a menu, so the risk of microbial contamination of an ingredient or the finished meal increases. The application of HACCP (hazard analysis critical control point) systems, heat treatments and efficient cold chains helps to reduce the opportunities for pathogenic micro-organisms to gain access to a food and/or grow to levels that will pose a risk from infection or toxin production, but, even so, the number of incidents of food-borne disease continues to rise in most industrialised countries.

Reversing this trend will not be easy, and yet many restaurants serve hundreds of meals per day without incident, and many food factories have equally commendable records with respect to hygiene. Obviously there may be many reasons why a particular company exposes the consumer, on occasions, to microbiologically unsafe products, but any procedure that could help to improve the situation must be welcome. One such procedure could involve the irradiation of food contact surfaces, rinsing water for food or process plant or air over a food preparation area with short-wave ultraviolet (UV) light, for the equipment is relatively inexpensive, the technique is, subject to certain safety precautions, easy to use and the radiation is lethal to most types of micro-organism. Whether the technique could or should be more widely applied in food preparation or production areas is a matter for speculation, as are the possible beneficial roles of long-wave UV light. Consequently, the aim of this present review is to consider some of the current applications of UV radiation in the food industry, and attempt to assess whether the microbiocidal effects of UV should be exploited further.

NATURE OF UV RADIATION

Ultraviolet (UV) light occupies a wide band of wavelengths in the non-ionising region of the electromagnetic spectrum between X-rays (200 nm) and visible light (400 nm). For practical purposes the UV spectrum can be subdivided into three regions:

- short-wave UV (UVC) with wavelengths from 200 to 280 nm;
- medium-wave UV (UVB) with wavelengths from 280 to 320 nm;
- long-wave UV (UVA) with wavelengths from 320 to 400 nm.

The intensity of UV radiation is expressed as irradiance or intensity flux ($W\,m^{-2}$), while the dose,

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(*Received 29 September 1999; revised version received 10 December 1999; accepted 4 January 2000*)

which is a function of the intensity and time of exposure, is expressed as radiant exposure (J m^{-2}).[1]

SOURCES OF UV RADIATION

Solar radiation

The sun emits radiation across a wide range of wavelengths, but the relative intensities of ultraviolet radiation reaching the earth's surface depend, to a considerable extent, on attenuation by the atmosphere through absorption and scattering. UVC is completely absorbed in the upper and middle atmospheres by ozone and molecular oxygen, but, while UVB is similarly attenuated, some UVB does reach the surface—much to the delight of sunbathers! However, UVA is barely affected, and hence the terrestrial environment is exposed mainly to ultraviolet radiation between 290 and 400 nm.[2] The intensity flux of UVA is about 35–50 W m^{-2} at sea level,[3] and under these conditions a dose of 200 kJ m^{-2} will be delivered over about 1 h of exposure. As a consequence, potentially lethal photoproducts can be formed at a considerable rate, and life in the open air would not be possible without the action of repair processes that ensure a drastic reduction in the damage caused by UVA.[4]

Artificial sources

Long-wave UV lamps

The light from mercury vapour lamps can be filtered to remove the visible spectrum and give an emission that is primarily UVA.[5]

Medium-wave UV lamps

Mercury vapour lamps are sometimes designed with pressures that produce maximum radiation in the UVB region, and using glass bulbs that freely transmit this energy.

Short-wave UV lamps

Mercury lamps designed to produce energy in the germicidal region (254 nm) are electrically identical to fluorescent lamps, but they lack the phosphor coating, and the use of glass allows the transmission of UVC. It should be noted that radiation below 260 nm will produce ozone which has to be monitored to prevent a hazard to health; a working atmosphere should not contain more than 0.2 mg l^{-1} of air.

SHORT-WAVE UV RADIATION (UVC)

Impact on living cells

UV radiation in the range of 250–260 nm is lethal to most micro-organisms, including bacteria, viruses, protozoa, mycelial fungi, yeasts and algae. The relationship between germicidal effect and wavelength is illustrated in Fig 1, which shows the maximum effect at 254 nm and a fall to practically zero at 320 nm; in fact, the effectiveness at 320 nm is 0.4% of the peak value.

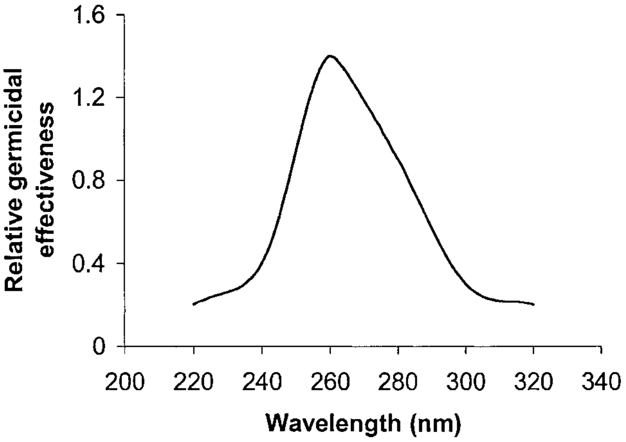


Figure 1. Direct lethality of UV wavelengths (after Ref 6).

The damage inflicted by UVC probably involves specific target molecules,[7] and a dose in the range from 0.5 to 20 J m^{-2} leads to lethality by directly altering microbial DNA through dimer formation. The main types of photoproduct in UV-irradiated DNA are cyclobutyl-type dimers (pyrimidine dimers), pyrimidine adducts and DNA–protein cross-links.[4] Purines are approximately 10-fold more resistant to photochemical alteration than are the pyrimidines, and because of this difference in sensitivity it has been implied that the photochemistry of the purines is not important biologically; by the time a significant amount of purine damage has occurred, the cells would have been inactivated by pyrimidine damage anyway.[8]

Once the DNA has been damaged, the micro-organisms can no longer reproduce and the risk of disease arising from them is eliminated. Temperatures between 5 and 37 °C have little, if any, influence on the microbiocidal action of radiation,[9] but moisture exerts a very marked effect. Where bacteria are suspended in air, an increase in relative humidity results in a greatly reduced death rate, especially at humidities greater than about 50%. Similarly, bacteria suspended in a liquid medium are much more resistant than those suspended in air, even after making allowance for the absorption of the medium.

Practical applications

The applications of the germicidal effects of UV fall into three broad categories: (a) inhibition of micro-organisms on surfaces; (b) destruction of micro-organisms in air; (c) sterilisation of liquids.

Disinfection of surfaces

The first category under this heading includes the sterilisisation of packaging materials, eg containers, wrappers or bottle caps, by arranging appropriate lamps over conveyors. The success of this application depends on the material surfaces being clean and free from any dirt which would absorb the radiation and hence protect the bacteria.

During the manufacture of aseptically filled UHT dairy products, for example, UV sterilisation has been applied to the foil caps of HDPE bottles[10] and to cartons for liquid products.[11] Similarly, the Hamba BK10010/10 has been used for aseptic yoghurt filling, and all the packaging materials, eg plastic cups and aluminium foil lids, are sterilised using UVC lamps working at 100–200 mW cm^{-2};[12] the shelf-life of fruit yoghurt packaged in containers sterilised by UVC lamps was extended by about 2 weeks at 5–7 °C. The disinfection of working surfaces in food preparation areas could merit serious assessment as well, but the limiting factor could be the presence of irregularities which would protect bacteria from incident UV.

Short-wave UV can also be employed to treat the surface of an actual food. For example, it has been used to control food spoilage micro-organisms such as *Bacillus stearothermophilus* in thin layers of sugar[13] or *Pseudomonas* spp on the surface of meat.[14] However, meat that has been exposed directly to UV light sometimes develops off-flavours, and a similar problem has been encountered with milk. It has been suggested that these undesirable flavours arise owing to absorption of ozone and oxides of nitrogen, as well as to direct photochemical effects on the lipid fractions of milk or meat. These latter effects can be reduced by filtering-out the shorter wavelengths or covering the product with a layer of inert gas prior to irradiation,[9] but in any event there appears to be no evidence that any of the photoproducts are harmful to humans.

Fresh fish is another product with a superficial flora of *Pseudomonas* spp, and Huang and Toledo[15] demonstrated the effectiveness of reducing initial bacterial counts, using UVC irradiation, in prolonging the storage life of fish. Kuo *et al*[16] showed that UVC radiation is effective in reducing the total aerobic and mould counts, along with *Salmonella typhimurium*, on the surfaces of egg shells; this latter treatment may be of little practical use, as the more important pathogen with respect to hen's eggs, ie *Salmonella enteritidis*, would be inside the egg and protected by the shell. In the baking industry, contamination of fresh products with mould spores has always been a problem, but, with bread, irradiation of the loaves as they emerge from the oven is reported to extend significantly their shelf-lives.[6]

A combination of UVC radiation and heat has been suggested by Tanaka and Kawaguchi[17] for the production of high-quality raw meat. More specifically, the same authors envisaged that: (a) retail portions of meat could be vacuum-packed using a membrane that transmits UVC; (b) the surface of the meat would be sterilised with UVC; (c) the membrane would then be heat-shrunk using water at temperature sufficient to kill any bacteria that had survived the UV treatment; and (d) the meat would then be cooled rapidly to maintain quality.

Given the growing demand for 'organic' foods, the potential use of UVC as an alternative to fungicides for the control of post-harvest diseases of stored vegetables such as carrots has attracted attention.[18] For example, a pre-storage treatment of carrots with UVC induces the accumulation of the phytoalexin 6-methoxymellein (an isocoumarin), and this change increases tissue resistance to fungal pathogens.

Disinfection of air

In hospitals, UVC lamps have been used to create a curtain or barrier of radiation through which air must pass before reaching patients sensitive to infection, and UV radiation at 254 nm and 0.25 W m^{-2} has been used in the United States since the 1930s to decrease the number of air-borne bacteria in operating theatres.

For the handling of sensitive foodstuffs, a system which combines a laminar flow of air through filters to remove particles of size $> 0.1\,\mu$m, and the use of UV radiation to kill any live micro-organisms that remain, has been suggested for the provision of clean sterilised air in the workplace.[19] Similarly, the microbiological quality of mechanically peeled fruit and vegetables is improved when UV-treated air is blown through the peeling unit counter-current to the flow of product.[20] The microbiological quality of air in cold stores can also be improved using an air sterilisation unit,[21] and the same technique has been applied to the air in egg hatching cabinets.[22]

Disinfection of liquids

Treatment with UVC is one of the simplest and most environmentally friendly ways of destroying a wide range of micro-organisms in water.[23,24] It has been used to disinfect sewage effluent, drinking water and water for swimming pools, and the combination of UV and ozone has a very powerful oxidising action which can reduce the organic content of water to extremely low levels.[2]

As UVC disinfects without any change in colour, flavour, odour or pH, it is an effective means of ensuring that drinking water is microbiologically safe;[25] the normal performance criterion is based on a 99.999% reduction of micro-organisms with a treatment time of < 1 min. The major limitations on the effectiveness of UVC radiation in this context are the following.

- Lack of penetration: in distilled water, UV radiation at 254 nm will have suffered a 30% loss in intensity 40 cm below the surface, while sea water will cause the same reduction over ~10 cm; a solution of sucrose (10%) or a natural spring water containing high levels of iron will cause the same loss within 5 cm.[25]
- In natural water supplies, any suspended solids must be filtered-out prior to treatment, and occasional 'clumps' of bacteria can pose a similar problem, ie the outer cells protect the more deep-seated ones. However, as small-scale water filtration units have become more efficient, so the ability of UVC systems to generate safe, potable water supplies has improved. In Japan, UVC radiation has been used for disinfection of natural mineral water with

no effect on the mineral content of the water or generation of taints or off-flavours;[26] the eradication of *Enterococcus faecalis* was the essential aim of the latter process.

In some food processing industries the situation may be rather different, and a simple reduction in the microbial load in a water supply may be more than adequate. For example, in the brewing industry a treatment that does not alter the taste or quality of the end-product is essential, and a number of breweries have become major users of UV disinfection systems.[27–29] Dosages in brewery water treatment can be quite high to ensure the absence of any spoilage problems during the early stages of the brewing process, and doses range from 300 to 600 $\mathrm{J\,m^{-2}}$ compared with 200 to 300 $\mathrm{J\,m^{-2}}$ for the treatment of potable water.

Similar applications tend to be limited by the lack of penetration of UVC into liquids containing organic matter, but the disinfection of the brine used to salt Mozzarella cheese has been proposed,[30] thus enabling spent brine to be reused rather than replaced. The brine has to be filtered to remove any cheese residues before treatment, and, after replenishing the level of NaCl, it is pumped back to the storage vats containing the cheese.

The treatment of more opaque liquids is clearly a problem, and yet Lodi *et al*[31] used UVC to reduce the total colony counts in samples of caprine milk by 50–60%, along with a specific fall in coliform counts of 80–90%. However, while these latter reductions could be valuable to prevent on-farm spoilage of milks with high bacterial counts, the presence of 10% of the original coliform populations would still render the milk unacceptable for human consumption. Whether or not the process could be made sufficiently reliable to replace pasteurisation for milk is an open question, but it may be relevant that, at one time, milk in Germany and North America was treated with UVC to enhance the concentration of vitamin D.[32] The most successful system was the Lembke plant in which turbulent flow was achieved by pumping milk at high velocity through transparent tubes of 1 cm diameter, and, as 80% of the UV radiation reached the milk, it was found that over 99% of bacteria initially present in the milk could be destroyed.[32] It is worth noting though that the keeping quality of such milk was worse than that of heat-pasteurised milk, even though the latter had a higher microbial count, and this anomaly was ascribed to the selective survival of coliforms.

More recently, it has been reported that the Food and Drug Administration (USA) is considering allowing UVC to be used to eliminate pathogens from fruit juices.[33] The alleged success of the system depends on ensuring that the flow of the juice is turbulent rather than laminar, holding the temperature of the juice below 5 °C and applying a rigorous HACCP programme. It is suggested also that this 'light-processed' juice retains its levels of vitamins A, B, C and E, and other processors of liquid products may well monitor this development with interest. However, as unpasteurised fruit juice has been recorded as a source of infection from *Escherichia coli* O157,[33] the comments of Burton[32] about the ability of coliforms to survive UCV treatments could be pertinent, as could earlier reports on the treatment of cider[34] and maple syrup.[35] In both cases the authors recorded reductions in microbial counts following UVC treatments, but no attempt appears to have been made to identify which genera survived.

One final barrier to the use of UVC for destroying pathogens in liquids appears to be the absence of any test to confirm that a specified treatment has taken place. Thus pasteurised milk can be subjected to the classic alkaline phosphatase test,[36] other heat treatments below 100 °C can be monitored by the acid phosphatase test,[37] but how can a Public Health Authority check a UVC-treated product? The author of Ref 33 suggests that records of product flow rates and UV emissions should be sufficient to ensure product integrity, but then a chart from a temperature recorder does not confirm that raw milk is not contaminating pasteurised product through a damaged gasket.

LONG-WAVE UV RADIATION (UVA)

Impact on living cells

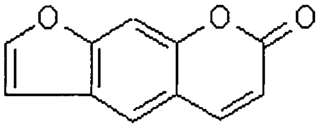
As UVA is poorly absorbed by living cells compared with UVC, little attention has been paid to any potential biocidal role. However, remedies of sunlight and herbs have been used for thousands of years to treat dermatological conditions such as psoriasis, a practice that confirms that some penetration of the skin cells does occur. Similarly, UVA does affect microbial cells, but it is far less effective than UVC. For example, the incident energy required to bring about a 50% reduction in microbial counts was 5 $\mathrm{J\,m^{-2}}$ using UVA, whereas UVC achieved the same impact with only $10^{-5}\,\mathrm{J\,m^{-2}}$.[38] Nevertheless, given that UVA is much safer for an operator to use than UVC, eg less risk of damage to the eyes if protective goggles are defective, interest in the sterilising effect of UVA has recently been revived.

The mode of action of UVA within cells is significantly different from that of UVC,[39] and the most likely effect(s) of UVA on micro-organisms are through:

(a) membrane damage—unsaturated fatty acids are readily oxidised to hydroperoxides, thus inducing changes in membrane permeability;[40]

(b) an oxygen-dependent reaction involving endogenous photosensitizing pigments—this mechanism involves the absorption of light by chromophores, resulting in their excitation, followed by reaction with oxygen to form active oxygen species or H_2O_2 which may be the primary agents of cell damage;[3,7,40] the latter compound has been implicated as H_2O_2 pretreatment of cells of *E coli* induced resistance to UVA, probably because a repair system specific to oxidative damage was induced.[41]

A large number of compounds commonly present in micro-organisms have been suggested as possible endogenous target molecules, but the low lethality of UVA against micro-organisms means that it has little practical value unless the rate of kill can be enhanced by means of exogenous photosensitisers absorbed into the cell.[42] One group of compounds that meet this requirement are the tricyclic furocoumarins (see Fig 2), which are formed by the fusion of a furan ring with a coumarin molecule.[44] In general, Gram-negative bacteria are more resistant to hydrophobic antimicrobial substances (eg furocoumarins) than are Gram-positive species, principally because the outer cell membrane of the former contains lipopolysaccharides which can delay, or perhaps prevent, the entry of hydrophobic molecules into the cell.[45,46] Consequently, it may be that the hydrophobic furocoumarins are largely retained in the outer cell membrane of Gram-negative bacteria, and cannot diffuse into the cell to react with the DNA.[47] In addition, since the effectiveness of furocoumarins as antimicrobial agents depends on contact with the DNA, their distribution within a cell and interactions with other components (ie proteins) may also influence their antimicrobial activity.[48]



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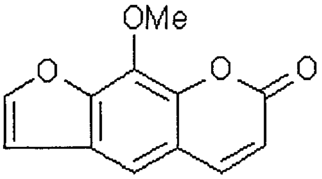

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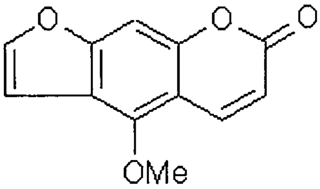

(III)

Figure 2. Chemical structure of some linear furocoumarins: (I) psoralen; (II) bergapten; (III) xanthotoxin (after Ref 43).

Potential use of the UVA/furocoumarin system

Antimicrobial activity

The furocoumarins are best known for their use in medicine, and a combination treatment involving 8-methoxypsoralen and sunlight/UVA radiation has found success in the control of psoriasis.[49] In a different context, Lin *et al*[50] employed 5 μg ml^{-1} of 8-methoxypsoralen with UVA to kill bacteria in human platelet concentrates required for transfusions.

Unlike the situation where UVA stimulates endogenous target molecules, the activated furocoumarins form cross-links between complimentary strands of DNA, so preventing the strands from replicating.[43] In addition, UVA plus furcoumarin produces DNA monadducts which damage both eucaryotic and bacterial cells, but the relative lethal impacts of cross-link formation or monoadduct action may vary.[51] The amount of furocoumarin needed to stimulate this reaction is very small, and, in a model food system under UVA illumination, Ulate-Rodriguez *et al*[52] tested the antimicrobial properties of linear furocoumarins at levels of 2–53 μg ml^{-1} against *Listeria monocytogenes, E coli* O157:H7 and *Micrococcus luteus. L monocytogenes* was inhibited, but *E coli* O157:H7 and *M luteus* were found to be more resistant; considerable variation in sensitivity has been found even with a single species.[6] More recently, Bintsis (unpublished) found that *L innocua, E coli* and *Staphylococcus aureus* suspended in tubes of Maximum Recovery Diluent (MRD Code No CM733, Unipath Ltd, Basingstoke, Hants, UK) (5.0×10^6 colony-forming units (cfu) in 10 ml) were inactivated rapidly by UVA and psoralen (see Table 1), whereas *Yarrowia lipolytica* and *Debaryomyces hansenii* (5.0×10^5 cfu in 10 ml) were slightly more resistant.

These figures confirm that the UVA/furocoumarin system can have a dramatic microbiocidal impact. However, it was recorded in a separate trial (no micro-organisms present) that the loss of irradiance through

Table 1. Inactivation of different types of micro-organism following a 60 s treatment with UVA[a]/psoralen (5 μg ml^{-1})

Micro-organism	*% killing*
Listeria innocua	99.8
Escherichia coli O157:H7	99
Staphylococcus aureus	99.9
Debaryomyces hansenii	97.5
Yarrowia lipolytica	82.7

[a] The experiment was performed with a Black-Ray Display Lamp (XX-15BLB) (Ultraviolet Products, Cambridge, UK) with the surface of the liquid at a distance of 10 cm from the lamp. At 10 cm the intensity was 45 W m^{-2}.

MRD was 34% over 5 cm, while in a simulated cheese brine including casamino acids (1.0%), lactose (0.5%) and NaCl (6.0%) the loss was approximately 95% over 5 cm. As neither tap water nor sucrose solutions (<10%) caused any loss of irradiance under the same conditions, it may be the peptides and amino acids in the MRD and brine that absorbed the radiation. For practical applications this point needs further study, because it has been reported elsewhere that UVA has the advantage over UVC in that amino acids do not absorb UV at wavelengths > 300 nm.[4]

Potential applications in food processing

Natural furocoumarins have been isolated from five plant families, namely the *Umbelliferae* (eg celery, parsley and parsnip), *Rutaceae* (eg bergamot fruit and lime), *Moraceae* (eg fig), *Leguminosae* and *Orchidaceae*. Typical concentrations of furocoumarins are shown in Table 2, and, while psoralen is the most photoreactive, it is likely that initial addition rates could be calculated on the basis of total furocoumarins; the wide variation in concentrations within the same species is a reflection of differences between cultivars, season/location of collection and method(s) of analysis. However, it should be borne in mind that if the UVA/furocoumarin system was to be used rather than UVC to sanitise a cheese brine, for example, each litre of cheese brine would have to be dosed with a minimum of 5000 μg of furocoumarin prior to irradiation, so that some of the concentrations in parsley or celery are clearly too low to be of practical or economic value. Furthermore, a number of studies have highlighted the fact that handlers of celery are prone to light-induced dermatitis due to UVA/furocoumarin interactions.[63–65] Consequently, although it might be attractive from a marketing standpoint to employ natural plant materials as a source of furocoumarins, the practical hurdles may prove insurmountable.

Nevertheless, it remains feasible to suggest that a combination of UVA and photosensitisers could be used to increase the shelf-life of perishable products, with the furocoumarins being incorporated, perhaps, into the packaging materials. If these same compounds then diffused into microbial contaminants on the surface of a product, they could be sensitised by natural light.[66] The direct addition of furocoumarins to foods could be a further option, but on the negative side it is important to highlight the facts that: (a) pure furocoumarins such as psoralen are expensive; and (b) although in the treatment of psoriasis the daily dose of 8-methoxypsoralen is about 20 mg, there is a recognised toxicological risk to the patient.[67] In particular, the ingestion of natural furocoumarins has been linked with the onset and/or development of cutaneous carcinomas,[68–70] and hence this risk alone will prevent their commercial exploitation within the food context.

If the phototoxic side-effects could be eliminated, then the UVA/furocoumarin system might be worth further evaluation, and it could be relevant that a number of synthetic furocoumarins are available that have the same therapeutic activity as 8-methoxypsoralen but, at least in mice, induce no toxic or carcinogenic reactions.[68,71,72] At present, the cost of such compounds would prohibit their use as components of any food preservation system.

Practical applications of UVA alone

Detection of chemical residues

The principal application of UVA within the food industry has been in relation to quality control, particularly for the detection of aflatoxins from *Aspergillus flavus* or *Aspergillus parasiticus* on various grains and nuts, eg maize, cottonseeds or peanuts, during storage. The aflatoxins have absorption maxima around 360 nm, and while aflatoxin B fluoresces blue at 425 nm, aflatoxin G produces a green–blue emission at 450 nm; these reactions can be employed to detect low levels of aflatoxin.[73] UVA is also reported to degrade aflatoxin M_1 in milk.[74,75]

In some stores and shops it may be necessary to check for the presence of rodents, and while dry rodent urine (fresh) glows blue–white under UVA, older deposits give a yellow–white glow. Rodent hairs also glow blue–white and are easily identified on sacks or intermixed with food grains.[76]

In the dairy industry, fresh deposits of milk-stone—a long-enduring problem—will fluoresce a strong yellow–white/bright blue–white under UVA.[77]

Detection of micro-organisms

The rapid identification of coliform bacteria in water is essential to ensure that public drinking water is safe,

Table 2. Some reported furocoumarin contents in various plants of the *Umbelliferae* and *Rutaceae;* all figures as $\mu g\,g^{-1}$ on a fresh or dry weight basis (see footnotes)

Plant	*Psoralen*[c]	*Xanthotoxin*[c]	*Bergapten*[c]	*Total linear furocoumarins*	*Reference*
Celery[a]	0.01–4.18	0.08–16.86	0.46–28.51	0.56–49.84	3–57
Lime peel[b]	14 ± 2	42 ± 6	1406 ± 18		52
Parsley[b]	32.3–104.7	5.3–53	56.7–479.2	94.3–541.5	47, 58
					52
Parsnip[a]	0.01–10.5	170–682	213–430		58–61
Angelica[a]		427.3	3477.0		59
Heracleum[a]	6.1–6.5	140–150	64–68	220 ± 9	62

[a] Concentration expressed on a fresh weight basis.

[b] Concentration expressed on a dry weight basis.

[c] See Fig 2 for the chemical structure.

and the auto-analysis test is performed in test tubes pre-filled with a powdered, coliform-specific indicator nutrient.[76] After incubation at 35 °C for 24 h, any indicator-positive tube is illuminated with UVA, and fluorescence of the solution indicates the presence of *E coli* and hence a risk of faecal contamination. The bacterium *Pseudomonas aeruginosa* which causes rots in eggs, meat and fish can also be detected by its yellow–green fluorescence under UVA radiation.[76]

In another application a redox dye, 5-cyano-2,3-ditolyl tetrazolium chloride (CTC), has been employed for the direct epifluorescent microscopic enumeration of live bacteria in environmental samples.[78] The CTC competes directly with molecular oxygen as an electron acceptor, and the reducing power generated by the electron transport system converts CTC into its reduced formazan, which accumulates in metabolically active bacteria. When illuminated with long-wave UV (>350 nm), the reduced CTC fluoresces bright red and is easily detected. However, the application of this technique to foods needs to be carefully assessed, as some foods may contain significant levels of natural or artificial quenchers.

In order to reduce the risk of microbial contamination from flying insects, much use is made of traps in which a UVA fluorescent lamp is mounted in a unit containing a high-voltage grid. The insect, attracted by the UVA lamp, flies into the unit and is electrocuted in the air gap between the high-voltage grid and a grounded metal screen. Such units are commonly found in areas where food is prepared and/or sold.[2]

CONCLUSIONS

While the UVA/furocoumarin system has a superficial attraction for sanitising solutions, ie better penetration of the radiation, it has yet to find a commercial niche. By contrast, UVC enjoys a good reputation for sanitising the air or food contact surfaces, and it seems likely that its use will expand as the supporting technology improves. For example, safe drinking water can assured by exposure to UVC systems so long as the associated filtration system is capable of removing all particulates, and recent advances in North America suggest that fluids containing suspended solids can be treated as well. The security offered by this latter system remains under scrutiny, for it is not clear at present whether the radiation levels would be effective if a sample of fruit juice, for example, was contaminated with *E coli* or some other pathogen prior to treatment.

Nevertheless, it is evident that the food industry is faced with two conflicting pressures. On the one hand, there is the need to produce microbiologically 'safe' food, while on the other, consumers are seeking foods with more natural flavours and textures. Consequently, a resurgence of interest in UVC could well be appropriate, for it does seem that UV radiation is one of the least exploited antimicrobial treatments for surfaces and, perhaps, foods themselves.

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