

# **CONSULTATIONS AND WORKSHOPS**

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## **Benefits and Risks of the Use of Chlorine-containing Disinfectants in Food Production and Food Processing**

**Report of a Joint FAO/WHO Expert Meeting**

Ann Arbor, MI, USA, 27–30 May 2008



**Food and Agriculture  
Organization of  
the United Nations**



**World Health  
Organization**

### ***1.6.2 Disinfection of food contact surfaces using non-chlorine-based alternative compounds***

Several non-chlorine-based alternative biocidal compounds are utilized to disinfect hard non-porous food contact surfaces. They have functions and target microorganisms similar to those of chlorine-based compounds.

#### **1.6.2.1 Alternative compounds used**

The most widely used inorganic peroxide on food contact surfaces is hydrogen peroxide. Organic peroxygen compounds used for the sanitization of food contact surfaces include peroxyacetic acid, peroxyoctanoic acid and mixtures of the two. Hydrogen peroxide is widely used for sterilization of equipment and containers in aseptic packaging for foods and drinks. In the USA, it is approved by the USFDA for this application (USFDA, 1990). Peroxyacetic and peroxyoctanoic acids are widely used to disinfect food contact surfaces. Peroxyacetic acid has application as well for use as a commercial sterilant in aseptic packaging operations.

Iodophors, which are mixtures of iodine and surface-active agents that act as carriers and solubilizers for the iodine, are commonly used on food contact surfaces in the beverage industry.

Also commonly used on food contact surfaces are QACs. QACs approved as no-rinse disinfectants for food contact surfaces include the “second generation” QAC, *n*-alkyldimethylbenzylammonium chloride; the “third generation” dual QACs, *n*-alkyldimethylbenzylammonium chloride and *n*-alkyldimethylethylbenzylammonium chloride; the “fourth generation” twin or dual chain QACs, didecyldimethylammonium chloride and dioctyldimethylammonium chloride; and “fifth generation” mixtures of fourth-generation and second-generation QACs.

Ozone is a powerful and naturally unstable oxidizing gas that, when dissolved in water, is used for the sanitization of food contact surfaces. Because of its instability, it must be produced on site at the food processing facility.

Peroxyacetic and/or peroxyoctanoic acids, QACs and ozonated water may be applied to conveyor belts and slicers during processing.

#### **1.6.2.2 Treatment conditions**

Treatment conditions for the application of non-chlorine-based alternatives to food contact surfaces are presented in Table 1.13. Generally, environmental, application and regulatory conditions are similar to those applicable to the use of chlorine-based compounds on food contact surfaces, described above.

#### **1.6.2.3 Effectiveness of alternative compounds**

As with the chlorine compounds, these alternative compounds are generally effective if food contact surfaces are sufficiently prepared (i.e. cleaned and rinsed) prior to the application of the biocide. Appropriate design and maintenance of processing equipment are also essential to ensure contact between the active chemical and the target microorganisms.

**Table 1.13. Treatment conditions for alternative compounds applied to food contact surfaces prior to operation**

Compound	Application	Exposure time	Concentration (mg/kg) <sup>a</sup>	pH	Temperature (°C)
Peroxyacetic acid	No-rinse disinfection <sup>b</sup>	1 min	Up to 315	3–4.5	12–21
	Disinfection	10 min	Up to 2320	3–4.5	12–21
	Commercial sterilization	Up to 20 s		3–4.5	40–60
Peroxyoctanoic acid	No-rinse disinfection	1 min	Up to 122	1.5–2	12–21
	Disinfection	10 min	Up to 547	1.5–2	12–21
Hydrogen peroxide	Commercial sterilization	3–7 s	35%	2–3.5	21
Iodophor	No-rinse disinfection	1 min	Up to 25	2–5	12–21
	Disinfection	10 min	Up to 75	2–5	12–21
QACs	No-rinse disinfection	1 min	Up to 200 (1st–4th generation); up to 400 (5th generation)	7–8	12–21
	Disinfection	10 min	800–1200	7–8	12–21
Ozonated water	No-rinse disinfection	1 min	1.5–4	6–8.5	12–21

<sup>a</sup> Unless otherwise specified.

<sup>b</sup> Limited to the application of USEPA-registered sanitizers for food contact surfaces.

The effectiveness of peroxyacetic and peroxyoctanoic acids has been reviewed (Block, 2001; Cords et al., 2005). Their efficacy is influenced by numerous factors, including concentration, contact time, temperature and pH of the use solution. Other factors include the presence of organic material and, to a lesser extent, the impact of hard water salts. Organic peroxygen compounds achieve a broad spectrum of activity over a broader pH range than hypochlorous-generating chlorine compounds. Antimicrobial activity has been observed to diminish above pH 7 (Cords et al., 2005). The effect of pH may be a result of the shifting of the equilibrium action of the peroxygenated compounds in a use solution. Peroxyacetic and peroxyoctanoic acids exhibit significant bactericidal activity at low temperatures, a characteristic that lends itself to wide use in food and beverage processing environments, including broad applications in clean-in-place systems. The presence of organic material has less impact on the efficacy of these organic peroxygen compounds compared with chlorine (Block, 2001). Holah et al. (1990) evaluated 12 commonly used surface disinfectants using bacterial biofilms developed on stainless steel. The authors concluded that peroxyacetic acid was the most effective of the compounds tested. Similar results were observed in studies reported by Stopforth et al. (2002), Krysinski, Brown & Marchisello (1991) and Carpentier & Cerf (1993), in which peroxyacetic acid was compared with other biocides. Fatemi & Frank (1999) presented similar results using organic challenges.

Iodine, unlike chlorine, is bactericidal over a fairly broad pH range against a wide spectrum of microorganisms, including yeasts and moulds. Iodophors may also provide a weak acid rinse for mineral buildup control and are less irritating to the skin than chlorine (Cords et al., 2005). In many cases, iodophors are effective at much lower concentrations than chlorine (Gershenfeld & Witlin, 1955; Trueman, 1971). Lindsay & von Holy (1999) investigated the effectiveness of an iodophoric preparation at 35 mg/l as iodine to reduce

populations of planktonic and sessile *Bacillus subtilis* and *Pseudomonas fluorescens*. The iodophor performed as well as the peroxyacetic acid-based and chlorhexidine-based sanitizers also analysed. Iodophors do not lose antimicrobial efficacy as rapidly as chlorine in the presence of organic material (Cords et al., 2005). This is especially true at low pH (Davis, 1962). At higher pH, an organic matter effect becomes apparent. Generally, iodophors are more adversely affected by hard water salts than chlorine, and the degree of influence depends on the specific type of iodophor being evaluated.

Because of the diversity of QACs commercially available, general statements regarding the effectiveness of QACs and the environmental conditions that influence them are difficult. The pH, temperature, organic matter and water hardness may all influence activity. Much of the early research that examined the effect of hydrogen ion concentrations on the antimicrobial activity of QACs suggests that maximum efficacy is exhibited in the alkaline pH range (Soike, Miller & Elliker, 1952). However, further work has indicated that the effect of pH may vary with bacterial species, with Gram negatives being more susceptible to QACs in the acid pH range and Gram positives in the alkaline pH range (Cords et al., 2005). QACs are generally not as effective as chlorine, iodophors or peroxyacids at cold temperatures. The activity of various QAC formulations against bacterial biofilms was studied by Krysinski, Brown & Marchisello (1991). The residual activity of QACs has been noted (Cords et al., 2005) and is an attribute often sought after by food processors.

Ozone is a powerful broad-spectrum biocide. Reviews of the applicability of ozonated water in food processing suggest the range of ozone concentrations needed to achieve effective sanitization of a food contact surface is 1.5–4 mg/kg (Kim, Yousef & Dave, 1999; Weavers & Wickramanayake, 2001). Ozone is quite unstable and has limited solubility in water at high temperature and pH.

#### 1.6.2.4 Limitations of alternative compounds

The general limitations of the alternative compounds in terms of their ability to effectively sanitize or disinfect food contact surfaces are similar to those described above. Additionally, each alternative biocide may be associated with limitations specific to its chemical nature.

Peroxyacetic and peroxyoctanoic acids are sensitive to metal ions, so the quality of water used in the preparation of working solutions is critical. These biocides are also corrosive to soft metals, such as brass, copper, mild steel and galvanized steel. Corrosivity is accelerated by the presence of high concentrations of chloride in the water (>75 mg/kg). High temperatures will also exacerbate the corrosion rate. Concentrated peroxyacetic acid has a strong, pungent odour.

QACs, when used in mechanical operations, can foam and therefore are not recommended for use in clean-in-place systems. They are also not effective at low temperatures (Cords et al., 2005) and have little tolerance of hard water salts.

A large capital investment is required of food processors implementing the use of ozone for disinfection of their facility. Ozone must be generated and monitored on site. Additionally, many applications require adequate ventilation systems to operate within established exposure limits (e.g. <0.1 mg/l continuous 8 h exposure). Validation that the process is achieving required thresholds of disinfection effectiveness is required.

#### 1.6.2.5 Summary

Active chlorine compounds are broadly used in food processing facilities to disinfect food contact surfaces prior to the beginning of operation. Of the active chlorine compounds,

sodium hypochlorite is the most commonly used. The process is generally effective if surfaces are properly cleaned and prepared before the application of the biocide. Several non-chlorine-based alternative compounds are utilized as well, including peroxyacids, iodophors, QACs and ozonated water.

Additionally, biocides are used to mitigate the accumulation of bacterial populations on food contact surfaces during production. Hypochlorite, ASC, peroxyacids, QACs and ozonated water may be used for this application.

Requirements related to completing the cleaning and disinfection cycle with a potable water rinse vary globally from region to region and from country to country. The final step of the cycle in food processing facilities within the USA is the application of a USEPA-registered no-rinse food contact disinfectant. The practice mandates that treated surfaces be adequately drained prior to production, but it is expected that chemical residues contact food. Potable water rinsing is generally not practised in those applications in which biocides are applied to food contact surfaces (e.g. conveyor belts and slicers) during production. Because this application is practised in close proximity to the contact of the treated surface with food, one can expect chemical residues to come into contact with the food as well. There is, however, little information available regarding the quantification of such residuals on foods.

## **1.7 References**

Andrews L et al. (2002). Chlorine dioxide wash of shrimp and crawfish an alternative to aqueous chlorine. *Food Microbiology*, 19:261–267.

Angulo F (1999). *Use of antimicrobial agents in aquaculture: potential for public health impact*. Atlanta, GA, United States Department of Health and Human Services, Centers for Disease Control and Prevention (<http://www.fda.gov/ohrms/dockets/dailys/00/apr00/041100/c000019.pdf>).

Bagge-Ravn D et al. (2003). The microbial ecology of processing equipment in different fish industries—analysis of the microflora during processing and following cleaning and disinfection. *International Journal of Food Microbiology*, 87:239–250.

Bailey JS et al. (1986). Chlorine spray washing to reduce bacterial contamination of poultry processing equipment. *Poultry Science*, 65:1120–1123.

Bari ML et al. (2008). Hot water treatment to inactivate *Escherichia coli* O157:H7 and *Salmonella* in mung bean seeds. *Journal of Food Protection*, 71:830–834.

Bashor MP et al. (2004). Effects of carcass washers on *Campylobacter* contamination in large broiler processing plants. *Poultry Science*, 83:1232–1239.

Berrang ME, Dickens JA (2000). Presence and level of *Campylobacter* on broiler carcasses throughout the processing plant. *Journal of Applied Poultry Research*, 9:43–47.

Berrang ME, Buhr RJ, Cason JA (2000). *Campylobacter* recovery from external and internal organs of commercial broiler carcass prior to scalding. *Poultry Science*, 79:286–290.

Ozone is extremely reactive and would be expected to react with most components of food (e.g. proteins, fatty acids, vitamins, etc.) that contained unsaturation or were oxidizable. There are reports that, under laboratory conditions, hypobromous acid reacts with proteins, peptides and amino acids, producing brominated tyrosine and short-lived *N*-brominated species, such as bromamines and bromamides. Hawkins & Davies (2005) reported that greater than 40% of hypobromous acid generated in the presence of bovine serum albumin is converted to short-lived bromamides and bromamines. Above 4 °C, these protein-derived *N*-bromo compounds decompose rapidly (either directly or through the formation of free radicals) by a number of pathways, including oxidation of tyrosine, formation of carbonyl moieties in proteins, and rearrangement and fragmentation of proteins. Although bovine serum albumin and fish muscle proteins are not identical, they contain tyrosine. There would, however, be variation in the quantities of the reaction products owing to the macromolecular configuration of the individual proteins. Given the reactive nature of hypobromous acid and the *N*-bromo compounds and the variation of the chemical composition of protein chains and their macromolecular configuration, small quantities of numerous compounds would be expected. However, specific compounds or classes of compounds have not been identified. Although brominated tyrosine is expected to be stable under these conditions, the data by Hawkins & Davies (2005) indicate that the concentration of these brominated compounds in fish and seafood would be insignificant.

### **2.10.3 Summary**

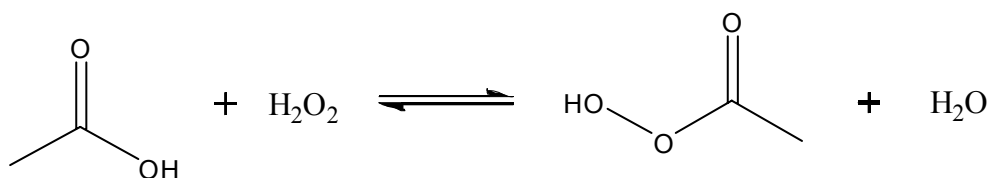
Ozone and its rapid decomposition limit its reactivity to the surface of foods. The quantities of oxidation products resulting from the treatment of seafood and fish would be small compared with those resulting from oxidation due to the cooking of food; however, brominated DBPs could be formed with available bromide.

## **2.11 Peroxyacids and peroxides**

A number of oxygen-based alternatives to chlorine-containing disinfectants are currently being used in the processing of fresh meat, poultry, fish and fresh and processed fruits and vegetables. They include hydrogen peroxide and peroxyacids, as well as ozone (see section 2.10). Peroxy compounds are a group of peroxide compounds containing at least one pair of oxygen atoms (-O-O-) bonded by a single covalent bond. Peroxides may be divided into two groups: inorganic and organic peroxy compounds.

### **2.11.1 Chemistry of peroxyacids and hydrogen peroxide**

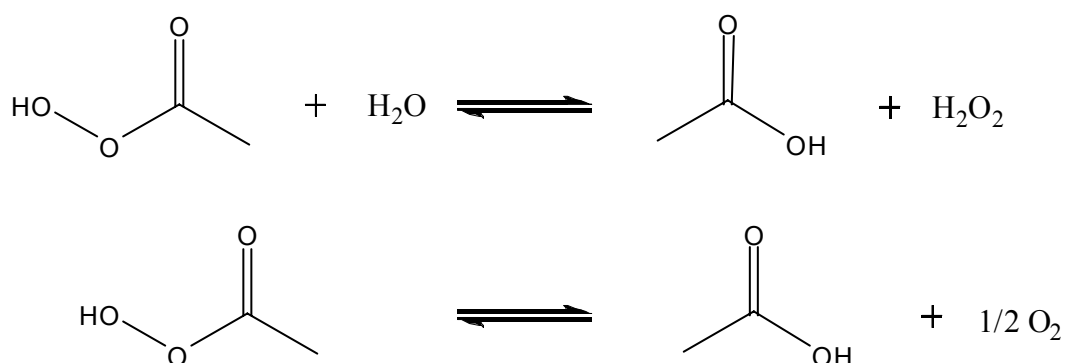
JECFA recently evaluated peroxyacid-based antimicrobials containing 1-hydroxyethylidene-1,1-diphosphonic acid (HEDP) (C<sub>2</sub>H<sub>8</sub>O<sub>7</sub>P<sub>2</sub>; CAS No. 2809-21-4) as a stabilizer (FAO, 2004; FAO/WHO, 2005). The following is a summary of the chemistry of the peroxyacid antimicrobial washes from these reports. Peroxyacid antimicrobial solutions are typically prepared by mixing aqueous hydrogen peroxide (4–12%) (CAS No. 7722-84-1) and aqueous acetic acid (40–50%) (CAS No. 64-19-7), which results in an equilibrium mixture of acetic acid, peroxyacetic acid (CAS No. 79-21-0), hydrogen peroxide and water (Figure 2.7).



**Figure 2.7. Peroxyacid formation from hydrogen peroxide**

These antimicrobial washes may sometimes contain 3–10% octanoic acid (CAS No. 124-07-2), which, when treated with hydrogen peroxide, produces an equilibrium mixture of octanoic acid and peroxyoctanoic acid (CAS No. 33734-57-5). The peroxyacid solutions are typically sold as concentrates and are diluted with water to a total peroxyacid concentration of 80–200 mg/kg.

Peroxyacids are inherently unstable and decompose into non-toxic chemicals in the presence of heat, acids and certain transition metal ions (e.g. copper). Two mechanisms for the decomposition are 1) hydrolysis to their corresponding organic acid and hydrogen peroxide and 2) decomposition to their corresponding organic acid and oxygen (Figure 2.8) (FAO, 2004). The hydrogen peroxide in these solutions decomposes into water and oxygen. To counteract the deleterious effects of metal ions, manufacturers incorporate <1% HEDP as a chelating agent. Unlike hydrogen peroxide and the peroxyacids, HEDP is stable and is expected to remain in the antimicrobial wash and on food after treatment.



**Figure 2.8. Decomposition equilibria of peroxy compounds**

### 2.11.2 Application and fate in foods

Given the highly reactive nature of the peroxyacids and hydrogen peroxide, these compounds are not expected to be present on foods at the time of consumption. However, their breakdown products (e.g. acetic acid or octanoic acid) and residual HEDP would be expected residues on foods that are not washed, peeled or further processed before consumption. HEDP residues will remain on foods that are not washed or further processed. Being less reactive than hypochlorite, peroxyacids may survive longer in contact with organic matter and may penetrate biofilms more effectively; however, they are also lesser biocides than hypochlorite.

The peroxyacids would be expected to react with components of food (e.g. proteins, fatty acids, vitamins). However, the data available to JECFA on the TBARS values (as a measure of the oxidation of fatty acids) and fatty acid profiles of raw and cooked poultry and beef indicated that there were no significant differences between treated and control samples.

In the USA, the use of peroxyacid disinfectants on poultry carcasses and red meat is currently authorized; the maximum concentration of peroxyacids is 220 mg/kg as peroxyacetic acid, the maximum concentration of hydrogen peroxide is 85 mg/kg and the maximum concentration of HEDP is 11 mg/kg (USFDA, 2009). The use of peroxyacid disinfectants in wash water and chilling water for fruits and vegetables is authorized in the USA, with a limit of HEDP of 9.6 mg/kg. The worst-case scenario that was estimated for leafy greens was 0.53 mg/kg as HEDP (USFDA, 2007a). The use of peroxyacid disinfectants in water and ice used to commercially process fish and seafood is also authorized in the USA, with a limit of HEDP of 10 mg/kg in the wash water and ice. Given that 1 kg of fish retains approximately 9 g of water, the residue level of HEDP on fish would be around 90 µg/kg fish (USFDA, 2007b).

### **2.11.3 Summary**

The only chemical residue in food resulting from the use of peroxyacid disinfectants in food processing is HEDP.

## **2.12 Quaternary ammonium compounds (including cetylpyridinium chloride)**

Quaternary ammonium compounds, commonly referred to as QACs or Quats, are widely used as surface sanitizers in hospital settings, nurseries (Rutala, 2005) and food processing facilities. QACs are organically substituted ammonium compounds in which the nitrogen atom has a valency of five. They have the general structure  $R_4N^+X^-$ , where the Rs can be numerous alkyl or alkylbenzyl moieties, including several different groups in the same molecule, and the X is a halide ion, often chloride. They are ionic and water soluble. However, their solubility can be affected by water quality factors (e.g. hard water) and pH. They are commonly used on food contact surfaces, and several are registered as “no-rinse sanitizers” (Cords et al., 2005), which would be indicative of a regulator’s conclusions of their low toxicity under those conditions of use and residue transport. No-rinse sanitizers for food contact surfaces include the “second-generation” QAC, *n*-alkyldimethylbenzylammonium chloride; the “third-generation” dual QACs, *n*-alkyldimethylbenzylammonium chloride and *n*-alkyldimethylethylbenzylammonium chloride; the “fourth-generation” twin or dual-chain QACs, didecyldimethylammonium chloride and dioctyldimethylammonium chloride; and “fifth-generation” mixtures of fourth-generation and second-generation QACs. They are also common components of antiseptic hand soaps (Sattar, 2004).

### **2.12.1 Cetylpyridinium chloride**

CPC is a QAC found in an anhydrous form ( $C_{21}H_{38}NCl$ ; CAS No. 123-03-5) or as cetylpyridinium chloride monohydrate ( $C_{21}H_{38}NCl \cdot H_2O$ ; CAS No. 6004-24-6). CPC has been approved for food contact use in the USA (USFDA, 2004b) as an antimicrobial agent to treat the surface of raw poultry carcasses only in systems that collect and recycle solution that is not carried out of the system with the treated poultry carcasses. CPC should be applied at a maximum level of 0.66 g/kg of raw poultry carcass as a fine mist spray of an ambient-temperature aqueous solution to raw poultry carcasses prior to immersion in a chiller. The aqueous solution should also contain propylene glycol at a concentration 1.5 times that of the CPC. The requirement for collection of the solution is due to the fact that water from poultry processing may be recycled into animal feed. Water retention in poultry carcasses may be



The mean potential exposure to ethyl lauroyl arginate in consumers only ranged from 0.11 mg/kg bw per day in the elderly to 0.83 mg/kg bw per day in children aged 1.5–4.5, whereas high potential exposure (97.5th percentile in consumers only) ranged from 0.37 mg/kg bw per day in the elderly to 2.89 mg/kg bw per day in children aged 1.5–4.5. EFSA concluded that, based on the data available, the average dietary exposure to ethyl lauroyl arginate across Europe would be unlikely to exceed 1 mg/kg bw per day, and high-level exposure (at the 97.5th percentile) would be unlikely to exceed 3 mg/kg bw per day.

#### ***Risk characterization***

JECFA concluded that some estimates of high-percentile dietary exposure to ethyl lauroyl arginate exceed the ADI of 0–4 mg/kg bw, but recognized that these estimates were highly conservative and that actual intakes were likely to be within the ADI. Therefore, no health concerns were identified.

### **3.1.3.3 Ozonated water**

#### ***Introduction***

Because of its reactivity, the toxicity of ozone is mostly related to its reaction products, especially after oral exposure. The presence of bromide ion in the aqueous solution treated with ozone may lead to the formation of, for example, hypobromite ion, bromate ion, bromoform and other brominated THMs, dibromoacetonitrile (DBAN) and dibromoacetone (IPCS, 2000). Aldehydes, ketones, ketoacids and carboxylic acids may also be formed by ozonation.

The use of ozone in disinfection of drinking-water is described in IPCS (2000) and WHO (2006a), but no toxicity or risk characterization of ozone itself is given in these documents. Therefore, no evaluations of the toxicity of ozone from oral exposure have been found.

A review of available chemical data supports the hypothesis that rapid decomposition of ozone and its breakdown products limits their reactivity to the surface of food, and residues often will be removed by washing or peeling before eating or volatilized and decomposed during cooking.

#### ***Toxicological data***

No evaluations of the toxicity of ozone from oral exposure have been found (see section 3.1.4.1 for bromate).

#### ***Dietary exposure***

No dietary exposure to ozone is expected (see section 3.1.4.1 for information on exposure to bromate).

#### ***Risk characterization***

As there is no direct dietary exposure to ozone, no health concerns were identified.

### **3.1.3.4 Peroxyacids and peroxides**

#### ***Introduction***

Peroxyacid antimicrobial solutions are typically prepared by mixing hydrogen peroxide and acetic acid in aqueous solution, which results in an equilibrium mixture of acetic acid, peroxyacetic acid, hydrogen peroxide and water. Preparations may also contain octanoic acid, which, when treated with hydrogen peroxide, produces an equilibrium mixture

of octanoic acid and peroxyoctanoic acid. As described in chapter 2, peroxyacids decompose to their corresponding organic acid and hydrogen peroxide or oxygen. The hydrogen peroxide in these solutions decomposes into water and oxygen. Preparations may contain 1-hydroxyethylidene-1,1-diphosphonic acid (HEDP), which is stable and is expected to remain in the antimicrobial wash and on food after treatment.

Peroxyacid solutions were most recently evaluated by JECFA in 2005 (WHO, 2006c). JECFA considered that, owing to the high reactivity of peroxyacids and hydrogen peroxide towards organic matter, they would break down into acetic acid, octanoic acid and water, respectively, and therefore be of no safety concern (WHO, 2006c). This is the most recent international evaluation of peroxyacids.

EFSA has also reviewed peroxyacids for treatment of poultry carcasses and concluded that the estimated intakes of residues of peroxyacetic acid, hydrogen peroxide, acetic acid, octanoic acid and HEDP arising from the treatment of poultry carcasses would be of no safety concern (EFSA, 2005).

### *Toxicological data*

In 2005, JECFA considered the safety of antimicrobial solutions using HEDP as a sequesterant or stabilizer and containing three or more of the following components: acetic acid, hydrogen peroxide, octanoic acid and peroxyacetic acid (WHO, 2006c). These solutions are intended to be diluted before use to achieve peroxyacid concentrations in the range 80–220 mg/kg. JECFA concluded that the peroxy compounds in these solutions would break down into acetic acid and octanoic acid and that small residual quantities of these acids on foods at the time of consumption would not pose a safety concern; JECFA therefore focused its evaluation on the residues of HEDP that are anticipated to remain on foods (WHO, 2006c).

JECFA noted that absorption of HEDP from the gastrointestinal tract is very limited and that its metabolism is negligible. HEDP did not show evidence of mutagenic activity. In 90-day toxicity studies in dogs and rats, the NOELs were 250 mg/kg bw per day and 500 mg/kg bw per day, respectively (WHO, 2006c). In reproductive toxicity studies, a NOEL of 50 mg/kg bw per day was identified for both rats and rabbits. HEDP has not shown any evidence of mutagenic activity. Based on the available toxicity data, together with a margin of exposure of >1000 when comparing the highest estimate of intake of HEDP with the starting oral dose of 5 mg/kg bw per day used in clinical treatment of patients with Paget disease, JECFA concluded that HEDP does not pose a safety concern at the concentrations of residue that are expected to remain on foods (WHO, 2006c).

JECFA evaluated acetic acid in 1974, allocating an ADI “not limited”<sup>1</sup> (FAO/WHO, 1974a). This ADI was retained at a subsequent evaluation in 1997 (FAO/WHO, 1999). In evaluating the acceptance of acetic acid, emphasis was placed on its established metabolic pathways (metabolized to carbon dioxide) and its consumption by humans as a normal constituent of the diet. Also in 1997, JECFA concluded that use of octanoic acid as a flavouring agent posed no safety concerns at intakes of up to 63 µg/kg bw per day (FAO/WHO, 1999). JECFA evaluated hydrogen peroxide in 1966 as a preservative and sterilizing agent for use in milk, concluding that it was not possible to set an ADI for humans because of the instability of hydrogen peroxide in contact with food (FAO/WHO, 1966). However, it was noted that hydrogen peroxide may be used only in circumstances where more acceptable methods of milk preservation are not available (FAO/WHO, 1966). This was confirmed in a subsequent evaluation in 1974 (FAO/WHO, 1974b).

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<sup>1</sup> This is a term no longer used by JECFA that has the same meaning as ADI “not specified” (see Annex 4).

### *Dietary exposure*

Human exposure to components of antimicrobial peroxyacid solutions was evaluated by the sixty-third meeting of JECFA (FAO/WHO, 2005). Additionally, an EFSA evaluation was published in 2005. Consistent with what is known about the chemistry of peroxy compounds, no residues of hydrogen peroxide, peroxyacetic acid or peroxyoctanoic acid are anticipated to be present on foods that have been washed in, sprayed with or otherwise treated using peroxyacid solutions derived from acetic or octanoic acid and subsequently cooked. Regardless, the EFSA evaluation included a highly conservative estimate of 1.46 µg/kg bw per day for possible residual peroxyacids and hydrogen peroxide (at the 99th percentile). This estimate was based on a detection limit of 1 mg/l, assuming that peroxide concentrations no higher than 0.25 mg/kg carcass would be present 2 min after treatment.

Acetic and octanoic acids present at equilibrium in the solutions and as by-products from the corresponding peroxyacids would be expected to remain on any treated foods that are not washed or further processed after treatment. JECFA reported that the mean intake of octanoic acid from foods consumed as part of the diet in the USA had been estimated to be approximately 200 mg/day. A highly conservative estimate of exposure to octanoic acid resulting from the use of the antimicrobial solutions of 1.9 mg/day was noted (WHO, 2006c). The intake of acetic acid was not explicitly analysed for JECFA, but its use in and on foods (as vinegar) would result in a greater exposure than that from the use of peroxyacid antimicrobial solutions. There would be no need to further consider exposure to these common food acids. The EFSA evaluation did not consider exposure to the fatty acid by-products.

HEDP is expected to remain on foods that are treated with antimicrobial solutions and that are not further washed, processed or cooked. JECFA reported that, on the international level, the highest estimate of intake of HEDP, prepared using GEMS/Food diets, was that for the European diet: 3.6 µg/kg bw per day, for the upper-bound estimate using a model for vegetables with a high surface area. JECFA also considered national estimates of intake from the Czech Republic, the USA and the United Kingdom. The upper-bound estimate of exposure was 2.2 µg/kg bw per day for the Czech Republic. The mean and 90th-percentile upper-bound estimates of intake for the USA were 2.2 and 4.7 µg/kg bw per day, respectively. The mean and 90th-percentile upper-bound estimates of intake for the United Kingdom were 1.8 and 3.3 µg/kg bw per day, respectively. The EFSA estimate of dietary exposure to HEDP was 1 µg/kg bw per day at the 99th percentile. EFSA noted that its estimates did not consider washing or food preparation and that actual dietary consumption is likely to be lower.

JECFA was aware of non-food uses of HEDP. HEDP is used as an anti-scalant for water treatment and in boilers worldwide (the regulatory limit for this use is 25 µg/l in the USA). HEDP is also used as a drug to treat Paget disease and in some over-the-counter cosmetic and pharmaceutical formulations. The USEPA (1998) estimated that exposure to HEDP from all these uses was not more than 6 µg/kg bw per day, including 0.04 µg/kg bw per day from its use on food. JECFA noted that this estimate of exposure resulting from food uses of HEDP was much less conservative than that used in the present evaluation.

Overall, a conservative estimate of the chronic dietary exposure to HEDP would be 5 µg/kg per day, based on the 90th-percentile national estimate from the USA.

### *Risk characterization*

As JECFA concluded that HEDP does not pose a safety concern at the concentrations of residue that are expected to remain on foods, no health concerns were identified.

#### 4.5.4.2 Aqueous chlorine dioxide in flume water and as a spray/dip

There is less information about the effectiveness of chlorine dioxide compared with hypochlorite as a disinfectant for fresh produce. The effect of chlorine dioxide on pathogenic bacteria on fresh produce is shown in Table 4.10. Zhang & Farber (1996) showed that concentrations of chlorine dioxide in water up to 5 mg/l could inactivate up to 90% of *L. monocytogenes*. Inactivation of *Salmonella* and *E. coli* O157 was similar with chlorine dioxide at 20 mg/l, around 1 log unit over water alone, with a slightly greater effect on apples than on lettuce (Huang et al., 2006). Han et al. (2001) showed that there was little effect of chlorine dioxide at 0.3 mg/l on *L. monocytogenes* on green peppers. Treatment of uninjured green pepper surfaces with chlorine dioxide at 3 mg/l resulted in a 2.3 log reduction of *L. monocytogenes*, whereas no effect was seen on injured green pepper surfaces.

From the limited data available, at the chlorine dioxide concentrations below 3 mg/l that are commonly used in the fresh produce industry, the effect on pathogens is limited to no more than 1 log unit over and above water treatment alone. Data on *Salmonella* and *E. coli* O157 are available only at high experimental concentrations, but even then, inactivation was low. It appears that aqueous chlorine dioxide is no more effective than chlorine at reducing the numbers of pathogens on leafy greens.

#### 4.5.4.3 Peroxyacetic acid in flume water and as a spray/dip

Peroxyacetic acid is used in the fresh produce industry in flume water as an alternative to chlorine. However, data on its effect on pathogen reduction on fresh produce are limited. Table 4.11 shows data quantifying the effects on pathogens. Oh, Dancer & Kang (2005) demonstrated that peroxyacetic acid at 40 mg/l reduced *E. coli* O157 and *L. monocytogenes* by 0.8 and 0.3 log, respectively, with 10 min contact time, but *Salmonella* was more susceptible (2.5 log reduction). To achieve reductions in the other pathogens similar to those in *Salmonella*, it was necessary to increase contact time to 30 min, whereupon similar log reductions of between 2 and 3 log units were achieved for all pathogens studied. Higher reductions of up to 4.5 log units were detected with contact times of 60 min, but this is unrealistic in the industrial setting when peroxyacetic acid is used in flume water. Other studies show similar results. Generally, peroxyacetic acid seems more effective at killing pathogens than chlorine with similar contact times. However, the effect of water alone in these studies was not reported, although other studies on other disinfectants suggest that water may result in up to a 1 log reduction in pathogens alone without disinfectant.

Under commercial conditions, as described in chapter 1, the extent of pathogen reduction by peroxyacetic acid in flume water would depend on the pathogen and would range from 0.3 to 2.5 log units.