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Control of *Listeria monocytogenes* in ready-to-eat meats: A review of technologies

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Executive summary

Listeria monocytogenes is a food borne pathogen of particular concern on ready-to-eat processed meats. Most contamination of products with this organism occurs post-cooking before packaging, and subsequent storage during shelf-life may allow the pathogen to grow to unacceptably high levels. Currently numerous intervention strategies designed to specifically inhibit or eliminate this pathogen exist, but vary in their applicability, safety, effectiveness and cost. A literature review examining the breadth and effectiveness of these technologies was undertaken.

Four broad categories of technologies, namely chemical additives, natural additives, post-packaging thermal technologies and post-packaging non-thermal technologies were identified. In all categories specific technologies which were effective at either eliminating or preventing the growth of *L. monocytogenes* on ready-to-eat meats were described.

Similarly, technologies which were ineffective for this purpose were also reported on. In particular, the use of combinations of organic acids (chemical additives), plant extracts (natural additives), and high pressure and irradiation (postpackaging non-thermal technologies) seem to be very effective at controlling this pathogen.

The practical applicability of the technologies was also examined. Many effective technologies, such as high pressure require specialised equipment and high financial outlays. In comparison other methods, such as organic acids and plant extracts, were cheaper but not as effective in eliminating the pathogen at low levels. At higher levels these additives produced flavour defects. Other techniques still, such as irradiation, have many regulatory and consumer resistance hurdles in the way of their easy application.

It was concluded that a variety of technologies are applicable to the control of *L. monocytogenes* in ready-to-eat meats but these need to be specifically tailored to individual products. Using combinations of effective technologies (chosen based on available financial resources) is feasible to effectively control this pathogen but is not a substitute for stringent hygiene.

1 INTRODUCTION

Listeria monocytogenes is a pathogenic bacterium responsible for high mortality (up to 40%) in infected individuals from at risk groups such as newborns, the elderly and pregnant women (Roberts and Wiedmann, 2003). Clinical manifestations of listeriosis in these cases include septicaemia, meningitis and abortion (Slutsker and Schuchat, 1999). More recently there have been a number of reports, and indirect evidence, linking this pathogen to gastroenteritis in groups of people, such as young adults, outside the 'at risk' groups (Hof, 2001).

The World Health Organisation has concluded that listeriosis is predominantly transmitted by non-zoonotic means, and the primary route of transmission to humans is via foods contaminated during production (Anon, 1988). However, ingestion of *L. monocytogenes* does not necessarily result in listeriosis since this pathogen is commonly found in food products, including coleslaw (Schlech *et al.*, 1983), unpasteurised cheeses (Linnan *et al.*, 1988; Bula *et al.*, 1995), pasteurised milk (Fleming *et al.*, 1985), shellfish (Rocourt *et al.*, 2000) and cooked ready-to-eat meat products (Goulet *et al.*, 1998; de Valk *et al.*, 2001), at frequencies disproportionately high as compared with the number of clinical cases. Furthermore, up to 5% of healthy individuals are thought to be carriers of this bacterium (Bojsen-Moeller and Jessen, 1996).

As customers demand a constant supply of fresher, less processed convenience foods that are ready-to-eat or require minimal preparation, the risk of bacterial contamination and subsequent survival and growth on these foods during storage has increased (Zink, 1997). One of the foods that pose a high risk for susceptible individuals with respect to *L. monocytogenes* are ready-to-eat cooked meat and meat products such as pâté, sausages, hotdogs, bologna, ham, luncheon meats and cooked beef. These products often have high water activities and equable pH's which are favourable to the growth of this pathogen (Farber and Peterkin, 1991).

Furthermore, they are frequently stored under refrigerated conditions which inhibit the growth of many competing spoilage bacteria but allow the growth of *L. monocytogenes*, often to high numbers (Dykes, 2003). Financial losses to processors associated with recalls and outbreaks due to *L. monocytogenes* are potential very large.

Contamination of processed meats by *L. monocytogenes* may occur when the pathogen survives the production chain, but due to its sensitivity to the cooking steps inherent in the process this does not occur frequently (Doyle *et al.*, 2001). Most often products are contaminated post-processing and before packaging or after opening. Post-processing contamination can occur by cross-contamination of foods from resident *L. monocytogenes* within the processing environment, by

the introduction of contaminated raw ingredients to the food after treatment or by mishandling the product before consumption (Farber and Peterkin, 1991).

Traditional and novel methods of preserving food and sanitising processing equipment are used where possible to try and ensure a safe, edible product, free of spoilage and pathogenic micro-organisms including *L. monocytogenes*. However, *L. monocytogenes* is able, in many cases, to survive these measures and persist in food processing environments, and therefore pose a unique threat in ready-to-eat processed food. Intervention strategies designed to specifically inhibit or eliminate, or which are particularly effective against, this pathogen have potential for many high risk products, but vary in their applicability, safety, effectiveness and cost. This review was undertaken to determine the breadth and compare the effectiveness of existing technologies for the control of *L. monocytogenes* on ready-to-eat meats.

2 CHEMICAL ADDITIVES

These types of technologies encompass the addition of generally-recognised-as-safe (GRAS) approved antimicrobial agents to ready-to-eat meat products. This may be done either as part of their formulation or as a post manufacturing application step. Compounds of this type include curing agents such as sodium chloride and sodium nitrite, acidifying agents such as acetic and lactic acids, and antimicrobial agents such as benzoates, propionates and sorbates.

2.1 Scientific studies

2.1.1 Curing agents

Traditionally, the curing agents applied in many ready-to-eat meat products, primarily for their colour development and antioxidant properties, have also been regarded as the mainstay in controlling *L. monocytogenes* in these products (Cammack *et al*., 1999). Sodium nitrite itself has very little antimicrobial activity (Skovgaard, 1992) but its interaction with other factors, such as sodium chloride, is effective in controlling *L. monocytogenes* in many products (Cammack *et al*., 1999; Donnelly, 2001). The presence of sodium nitrite has become entrenched in regulations as is indicated by the fact that many predictive models examining the interaction of this compound with other factors have been developed (Buchanan *et a*l., 1997). Despite this work, *L. monocytogenes* is still able to survive and grow, almost unabated, in many cured meat products (Gill and Holley, 2003). Furthermore, consumer resistance to the use of this compound, due to its potential carcinogenic properties, make it unsuitable for widespread future use (Zink, 1997).

2.1.2 Organic acids

There have been extensive studies into the effects of various GRAS chemical preservatives on the inhibition of *L. monocytogenes*. Most of these studies have been performed on ready-to-eat meats, including frankfurters, luncheon meats, bologna, wieners, and cooked bratwurst. The most commonly used GRAS preservatives in these studies include sodium benzoate, sodium propionate, potassium sorbate, sodium diacetate, potassium lactate, sodium lactate, acetic acid, glucono-β-lactone (GDL), and combinations thereof.

A study which investigated the combined effects of antimicrobials on frankfurters (Samelis *et al.*, 2002), concluded that *L. monocytogenes* post-processing contamination on these cured meats may be controlled by 1.8% sodium lactate (which is lower than the 3% permitted by the USA) in combination with permissible levels (0.25%) of sodium acetate, sodium diacetate, or GDL in the

formulation. Similar work was performed by the same authors (Samelis *et al.*, 2001) where sliced pork bologna was dipped into solutions of varying concentrations of acetic acid, sodium diacetate and potassium benzoate. Their results demonstrated varying levels of listericidal effects, but concluded that post-processing contamination of cured meat products by *L. monocytogenes* may be controlled by exposure to solutions of lactic, acetic, benzoic and sorbic acids or salts after preparation and before packaging. Islam *et al.* (2002) also found that higher concentrations of GRAS chemicals were required

if the product was sprayed than if it was immersed in the preservative. Schlyter *et al.* (1993) found that antilisterial activity was enhanced in treatments containing sodium lactate (2.5%) and sodium diacetate (0.1%) compared to similar treatments containing sodium diacetate or sodium lactate alone. A further study (Qvist *et al.*, 1994) concluded that 2% sodium lactate alone was insufficient to suppress growth of *L. monocytogenes* on bologna-type sausages, but when used in combination with GDL, which effectively lowered the pH, the antilisterial effect was more pronounced. In a recent study (Bedie *et al*., 2001) investigated the effects of dipping contaminated frankfurters into various concentrations of sodium lactate and sodium diacetate. The study found that while the currently permitted levels of sodium lactate (3%) and sodium diacetate (0.25%) may be inhibitory for 70 days, higher levels (6% and 0.5% respectively) of these antimicrobials may provide complete control at 4°C of growth over 120 days of *L. monocytogenes*. Wieners and bratwurst were treated in a similar manner by Glass *et al.* (2002), who found that dipping these products in lactatediacetate solutions was not an efficient way to apply these antimicrobial agents, but that the inclusion of combinations of lactate-diacetate in both wiener and bratwurst formulations did inhibit the growth of *L. monocytogenes* at ≤ 7°C.

2.1.3 Proprietary mixes

Two new commercially available antimicrobial formulations that reportedly show strong activity against *L. monocytogenes* are acidic calcium sulphate (ACS; Keeton *et al*., 2002) and acidified sodium chlorite (ASC; Su and Morrissey, 2003). Both these products have been traditionally applied as sanitisers to food processing equipment and to products other than ready-to eat meats, such as beef carcases, with some success (Ransom *et al*., 2003). Although the numbers of studies on the effectiveness of these compounds on ready-to-eat meats is limited (Keeton *et al*., 2002), strong potential for their application may exist.

2.2 Practical considerations

In general GRAS antimicrobial compounds do appear to exhibit listericidal or listeriostatic effects, but work best when used in tandem or in conjunction with each other or with other preservative methods. These compounds also have the added benefit of having a residual effect within the product (if incorporated into the formulation) and therefore potential to combat post-processing contamination. No particular compound or combination of compounds stands out as being obviously better than the others that are available, although the proprietary mixes mentioned above are receiving a lot of industry attention.

2.2.1 Web sites of relevance

Lactate blends – www.purac.com
Acidic calcium sulphate - www.mionix.com
Acidified sodium chlorite – www.alcide.com
Approval for acidified sodium chlorite in Australia - http://www.foodstandards.gov.au/_srcfiles/A476_Chlorite_Final_Assessment_Report.pdf

2.2.2 Advantages

Relatively cheap for generic products, proprietary mixes may be more expensive
Residual activity
Readily available
Can be applied as dip, spray or added during formulation

2.2.3 Disadvantages

Higher levels may change flavour
Development of acid resistance in bacteria
Limited scientific studies on some proprietary mixes

3 NATURAL ADDITIVES

These types of technologies encompass the addition of antimicrobial agents of direct bacterial, plant or animal origin to ready-to-eat meat products. As is the case with chemical additives, this may be done either as part of their formulation or as a post manufacturing application step. Compounds of this type include bacteriocins, extracts of various herbs and spices, and lactoferrin and lactoperoxidase from milk. In addition, bacterial cultures designed to inhibit *L. monocytogenes* and other bacteria through competitive exclusion may be included here.

3.1 Scientific studies

3.1.1 Bacteriocins

Nisin is a bacteriocin produced by *Lactococcus lactis* subsp. *lactis* which has approval to be used in foods, applied either as a purified active compound, or through bacteriocin-producing cultures. Nisin is also recognised as a GRAS additive (Anon, 1988). Other examples of bacteriocins with listericidal effects include pediocin (produced by *Pedicoccus acidilactici*), lactocin 705 (*Lactobacillus casei*), sakacin P (*Lactobacillus sake*), enterocin (*Enterococcus faecium*), and ALTA 2341 (a commercial fermentation by-product of a lactic acid bacterium containing pediocin). At present, bacteriocins are used mainly in the dairy industry, although investigations on the effect of various bacteriocins on *L. monocytogenes* in many different food substrates including ready-to-eat meats such as dry sausages (Tantillo *et al.*, 2002), and ham and bologna (Gill and Holley, 2000), have been performed.

Experiments on the efficacy of bacteriocins on inhibiting growth and survival of *L monocytogenes* on food have shown that growth is often reduced but not inhibited (Szabo and Cahill, 1999; Katla *et al.*, 2001). Furthermore, the initial reduction in viable numbers is often followed by re-growth of the culture, probably due to the presence of a sub-population of bacteriocin-resistant cells (Schlyter *et al.*, 1993; Dykes and Moorhead, 2002; Gravesen *et al.*, 2002). However, a study by Dykes and Hastings (1998) investigated the likelihood of this resistance being retained in the absence of bacteriocin, and found that in at least one strain examined, this was not a stable mutation and was lost after successive generations.

The efficacy of bacteriocins against *L. monocytogenes* is enhanced when used in conjunction with other preservative techniques, such as GRAS chemical preservatives (Schlyter *et al.*, 1993; Buncic *et al.*, 1995), modified atmosphere

packaging (Szabo and Cahill, 1999; Nilsson *et al.*, 2000), the lactoperoxidase system (Zapico *et al.*, 1998), heat (Modi *et al.*, 2000), acidic conditions and reduced water activity (Bouttefroy *et al.*, 2000) and ethanol (Brewer *et al.*, 2002).

3.1.2 Plant extracts

Herbs, spices and associated extracts have been widely applied for their antioxidant and antimicrobial activity in ready-to-eat meats and other foods (Hao *et al*., 1998). Many of these compounds show strong listeriacidal activity (Larson *et al*., 1996; Kouassi and Shelef, 1998). Although a vast array of plant extracts have potential with respect to controlling *L. monocytogenes*, two common herbs in particular, namely rosemary and oregano appear very effective. A commercial rosemary extract, which is often used primarily as an antioxidant, has been applied at a concentration of 0.5% and shown to inactivate *L. monocytogenes* in various foods (Del Campo *et al*., 2000). Activity of rosemary essential oils has also been shown to be effective against this pathogen (Friedman *et al*., 2002; Fabio *et al*., 2003). Oregano extracts and oil appear to be effective against *L. monocytogenes*, both on fresh and ready-to-eat meats (Tsigarida *et al*., 2000). Addition of higher levels of herbs and spices may result in undesirable flavour effects in products. Plant extracts are often applied and may be more effective in association with other control measures, which allow their use at lower levels (Tsigarida *et al*., 2000; Lambert *et al*., 2001).

3.1.3 Lactoferrin/lactoperoxidase

Lactoferrin and lactoperoxidase are compounds which occur naturally in mammalian tissues and fluids, such as milk. They act as natural antimicrobials and are part of the innate immunity of the host (Farnaud and Evans, 2003). The lactoperoxidase system has been demonstrated to have antimicrobial activity in fresh meat (Kennedy *et al*., 2000) and enhances the activity of physical food preservation systems such as high pressure treatment (McLay *et al*., 2002). Studies on this system are, however, very limited and most studies are confined to its use in milk. Lactoferrin, on the other hand, is widely used as additives in products such as infant formula as it reportedly enhances iron uptake in infants (Jovani *et al*., 2003). It also inhibits the growth and attachment of bacteria, including *L. monocytogenes* (Farnaud and Evans, 2003). For this reason it has been suggested and tested as a beef carcass wash and was shown to be effective (Naidu, 2002). It has not been widely applied in ready-to-eat meats but does have strong potential for this purpose.

3.1.4 Competitive cultures

Bacteria, such as lactic acid bacteria, which are involved in the spoilage of some vacuum-packaged processed meats and the fermentation of others, also inhibit the growth of pathogenic bacteria such as *L. monocytogenes* (Holzapfel *et al*., 1995). The 10 potential exists to apply cultures that are particularly effective at inhibiting this pathogen, but that are poor spoilers, as an additive to assure food

safety (De Martinis and Franco, 1998). Cultures of this type have been used successfully in a number of ready-to-eat meat products such as cooked sliced meats (Budde *et al*., 2003), ham (Kotzekidou and Bloukas, 1996), bologna (Andersen, 1995) and servelat sausage (Bredholt *et al*., 1999). Species of bacteria used include *Leuconostoc gelidum* (Leisner *et al*., 1996), *Leuconostoc carnosum* (Jacobsen *et al*., 2003), *Lactobacillus sake* (Hugas, 1998) and many others. The effect of the cultures varies depending on the product and storage conditions, but commercial cultures are available for most requirements (Jacobsen *et al*., 2003). In all cases it is important that spoilage effects and a shortened shelf-life are not apparent with addition of the culture.

3.2 Practical considerations

All the technologies described in this section are “natural” and in most cases there is little or no need to obtain regulatory approval. Furthermore, labelling requirements are less stringent and consumer acceptance greater. Due to the fact that these products are natural, mechanism of resistance in *L. monocytogenes* and other bacteria exists and so combinations of these types of technologies are often required. Effects on aspects of ready-to-eat meat quality such as flavour and shelf-life may be caused at the higher levels of application of some of these control methods. Many of the products are propriety and may have additional costs associated with them. In all cases the technologies should be tailor-made for specific products.

3.2.1 Web sites of relevance

Nisin – http://www.danisco.com
ALTA 2341 - http://www.questintl.com
Oregano – http://www.amif.org/News2003/AMIF-NEWSREL021403.htm
Lactoferrin - http://www.meatnews.com/mp/northamerican/dsp_particle_mp.cfm?artNum=589
Competitive cultures - www.dsm.com

3.2.2 Advantages

Consumer acceptance
Readily available
No regulatory problems
Most can be applied as dip, spray or added during formulation

3.2.3 Disadvantages

Development of resistance in bacteria
Quality effects
Relatively expensive (particularly bacteriocins)
Limited studies on some technologies

4 POST-PACKAGING THERMAL TECHNOLOGIES

This type of technology encompasses heating of products post-cooking and postpackaging to reduce any *L. monocytogenes* contamination. Generally, this will entail an immersion in water or radiant heating for an appropriate time-temperature combination.

4.1 Scientific studies

4.1.1 Heat sensitivity

The heat resistance of *L. monocytogenes* has been reviewed by a number of authors, notably Farber (1989), Mackey and Bratchell, (1989), and Doyle *et al.* (2001). These reviews state that pasteurisation temperatures (72°C, 15 s) may not be sufficient to kill all *L. monocytogenes* cells if sufficient numbers are present (>10^4 cfu /ml). The studies concluded that variables such as particular environmental conditions e.g. previous exposure to heat shock, acid and other stresses, the composition of the food substrate, strain variation and previous growth conditions influence the heat resistance of *L. monocytogenes*.

The thermal resistance of *L. monocytogenes* in red meat and poultry products was shown to be sufficient to withstand temperatures of 78-85°C for holding periods of up to 15 min, if inoculated at levels of >10^3 cfu/g. Decimal reduction times (*D*-values) have been determined for *Listeria* in a number of meat products (Doyle *et al*., 2001).These results imply that meats cooked rare, and some cooked fermented meats may not be heated adequately to inactivate *Listeria* even if present in low numbers. They also indicate that many factors need to be considered when determining the *D*-value of a particular product. An additional study investigating the heat resistances of 27 strains of *L. monocytogenes* on fresh and cured beef and chicken, reported a range of D_{57}-values from 6.5 to 26 min (Mackay *et al.*, 1990). This same study looked at the effect of curing on one of the more heat resistant strains, the principle effect of which was to extend the *D*-value by two-fold. This protective effect appeared to be due to the added salt.

4.1.2 Post-packaging pasteurization

Post-packaging pasteurization has been applied to many ready-to-eat meat products in an attempt to control *L. monocytogenes*. This technology has met with mixed success depending on the method, time-temperature combination and the product under investigation. Pasteurization of large-sized ready-to-eat deli meats (including roast beef and smoked ham) by hot water submersion under a range of conditions indicated that a time-temperature combination of 2 minutes at 90$_o$C could result in a 2 log reduction in numbers of this pathogen (Muriana *et al*., 2002). Problems were encountered with heat distribution, and variation in the

decline of numbers between individual packs was high. Smaller sized summer sausage chubs have been pasteurized in a similar way and a 3 log reduction in *L. monocytogenes* observed at 95$_o$C (Roering *et al*. 1998). Ideally high temperature and short time combinations are the best. More recently radiant heat has been used to pasteurize ready-to-eat meats pre-packaging in combination with a post-packaging step and has met with some success, reducing the time required to achieve an acceptable log reduction in numbers of *L. monocytogenes* (Gande and Muriana, 2003). The extended heating times required for bulky items often result in flavour defect in this kind of technology and limits its use to specific products.

4.2 Practical considerations

Anecdotal evidence suggests that the application of post-packaging pasteurization is currently limited in the industry. While an appealing technique, the practicality and cost of installing suitable time-temperature setups for multi-product lines can be prohibitive. Furthermore, the net result of pasteurization is at best a reduction in number of L*. monocytogenes*, rather than their inhibition or elimination from the product. While its use for single layer sliced products, in combination with other control mechanisms may be feasible, other more practical methods are frequently preferred.

4.2.1 Web sites of relevance

Pasteurization - http://www.unithermfoodsystems.com
High temperature short time - http://www.organicconsumers.org/irrad/listerialunch.cfm

4.2.2 Advantages

Non-additive technology
Consumer acceptance
Can be part of existing processing lines

4.2.3 Disadvantages

Time-temperature combinations highly product specific
Results in reductions but not elimination or prevention of growth
May result in quality defects
Expensive to implement

5 POST-PACKAGING NON-THERMAL TECHNOLOGIES

These types of technology encompass any method (usually physical) designed to damage cells of *L. monocytogenes* (and other bacteria) on ready-to-eat meats in the pack without heating. Most of these techniques require the presence of specialised equipment and processing line generally cannot be easily adapted from existing setups. These methods have no residual effects and so require very little in the way of regulatory approval with some exceptions, such as radiation, which are of concern due to consumer perception. Methods included under this broad banner are techniques such as ionizing radiation, ultra-high pressure, ozone treatment, pulsed light and electricity, ultrasound and active packaging.

5.1 Scientific studies

5.1.1 Ionizing radiation

Ionizing radiation, also known simply as 'irradiation', can be used to kill or damage micro-organisms that contaminate food or cause food spoilage and deterioration. Approval has been given in the United States by the Food and Drug Administration (FDA) for irradiation of wheat, potatoes, flour, spices, tea, fruits and vegetables, pork, chicken, turkey, and other fresh and frozen uncooked poultry and most recently in fresh and frozen red meats such as beef, lamb, and pork (Anon, 1997).

In 1999, Food Standards Australia New Zealand (FSANZ) lifted a ten year moratorium on food irradiation, allowing it on a case-by-case basis. To date, in Australia, only herbs and spices have been approved to be irradiated, although the organisation is currently assessing a new application seeking permissions to irradiate a range of tropical fruits (breadfruit, carambola, custard apple, litchi, longan, mango, mangosteen, papaya and rambutan) as a phytosanitary measure.

Benefits of irradiation are that products can be processed after packaging. The amount of radiation necessary to reduce the bacterial population by 90% is called the D_{10} value. A D_{10} reduction of *L. monocytogenes* can be achieved with irradiation doses of <0.7 kGy on meat and cheese substrates, but higher doses are required for vegetables. Microorganisms that survive low and medium dose radiation treatment are more sensitive to environmental stresses or subsequent food processing treatments than the microflora of non-irradiated products (Szczawinski, 1983; Szczawinski *et al.*, 1984; Szczawinski *et al.*, 1985), therefore potential exists for investigating combined effects with other preservation techniques. While food irradiation is adequate to eliminate *L.monocytogenes*

contamination, this treatment has no persistent effect, therefore post irradiation contamination must be prevented.

The number of studies on the control of this pathogen in processed meats is limited. Levels of *Listeria* on a number of ready-to-eat meats is effectively reduced by up to 5 log units by ionizing radiation of >2.5 kGy (Sommers *et al*., 2002; Sommers and Fan, 2003). Flavour of products, however, may be affected at higher doses due to oxidation of fats (Sommers and Fan, 2002). Furthermore, resistance of *L. monocytogenes* to radiation, and re-growth of the pathogen, may occur (Sommers *et al*., 2003). A petition to allow the use of radiation on ready-to-meats is currently under consideration by the US Food and Drug Administration.

5.1.2 Ozone

Fisher *et al.* (2000) demonstrated that 5 min exposure of 1 ppm of ozone effectively inactivated *L. monocytogenes*. This study also investigated the phase of growth with regards to ozone resistance, and found that early stationary phase cells were less sensitive to ozone than mid-exponential and late stationary phase cells. They concluded that both catalase and superoxide dismutase were protective against ozone attack. The antimicrobial effect of ozonated water was evaluated against *L. monocytogenes* by Restaino *et al.* (1995). *L. monocytogenes* was more susceptible than other Gram-positive bacteria (*S. aureus, Bacillus cereus* and *Enterococcus faecalis*), but the efficacy of ozone was profoundly affected by the presence of organic substances. Little work has been done using ozone on processed meats, however, because it is such a powerful oxidant the likelihood of organoleptic effects is high and its use for this application probably not ideal.

5.1.3 High Pressure

High hydrostatic pressure (HHP) treatment of foods is of substantial current interest to the food industry for its potential application in enhancing food safety. Pressure treatments between 600 and 700 MPa for 15 min, or 350 MPa for 40 min are able to inactivate vegetative cells of fungi and bacteria, including most food-borne pathogens (Smelt and Hellemons, 1998; Palou *et al.*, 1999). High pressures manifest their effects on cellular processes in many different ways, including disruption of protein and DNA synthesis, membrane associated processes and macro-molecular quarternary structures (e.g. protein denaturation) (Somero, 1992; Cheftel, 1995; Yayanos, 1995;
Palou *et al.*,1999).

In general, Gram-positive bacteria are more HHP tolerant (piezotolerant) than Gramnegative bacteria (Smelt and Hellemons, 1998; Palou *et al.*, 1999), and different strains of a species can differ widely in their resistance to HHP (Alpas *et al.*, 1999). Data concur that high pressure processing has considerable listericidal ability, being able to induce a 5 log reduction in *L. monocytogenes* Scott A

(serotype 4b) in one study (Lucore *et al.*, 2000), and obtaining a *D* value of between 1.89 and 4.17 min depending on the strain being examined (of unspecified serotypes) in another (Murano *et al.*, 1999). There are few published studies on the application of HHP to *L. monocytogenes* on ready-to-eat meats; however, it is likely that this technique will prove effective in these products. Problems associated with this type of technology include high initial outlay costs of the equipment and the fact that at present only batch-type systems exist, limiting its use in production lines.

5.1.4 Other technologies

The majority of other methods described here have no easily accessible published studies on their ability to control of *L. monocytogenes* in ready-to eat meats. However, some potential for their use does exist as they are active against this pathogen.

Pulsed-light was shown in a study by Rowan *et al.* (1999) to give a 4 log reduction of *L. monocytogenes* numbers. Light inactivation using a pulsed power source was also effective in reducing a *L. monocytogenes* population by 99% (MacGregor *et al.*, 1998). Problems exist in applying this technology to packaged foods as exposure of all surfaces to the light is difficult.

Pulsed electric fields have been shown to be effective against *L. monocytogenes* in liquid foods, such as orange juice (Ayhan *et al*., 2002). The parameters required to assure the effectiveness of this technique need to be carefully controlled however (Alvarez *et al*., 2003). Substantial technical difficulties exist in applying this technique to solid foods but some potential may exist.

Ultrasound is effective in reducing numbers of *L. monocytogenes* which, like many other bacteria, is sensitive to destruction by this process (Pagan *et al*., 1999a). This method is largely applied in liquids, with the potential for resistance to this treatment reported in *L. monocytogenes (*Pagan *et al*., 1999b). Like pulsed electric fields, substantial technical difficulties exist in applying this technique to solid foods but some potential may exist.

In a recent review (Vermeiren *et al*., 2002) the advantages of some active antimicrobial packaging concepts were summarised. The review indicated that 17 inclusions of compounds, such as bacteriocins, silver and triclosan, into packaging material may be effective against *L. monocytogenes* on ready-to-eat processed meats. The need for direct contact between the packaging and the organism, and the high costs of the packaging, limit this technology for wider use at this time. There is however potential for the application of active antimicrobial packaging in the future.

5.2 Practical considerations

Many of the technologies described in this section are considered to be the state-of the art methods for the control of pathogens in foods. Being non-additive, influences on the product quality are often limited provided levels of treatment are kept within reasonable limits. The application of any one of these methods to ready-to-eat meat products is currently limited by such considerations as applicability, cost and practicality. Some of these methods will, no doubt, become more widely used in the small-goods industry as the technologies improve.

5.2.1 Web sites of relevance

Irradiation – http://www.amif.org/Listeria%20Irradiation.pdf
Ozone – http://www.ozoneapplications.com/research/ozone%20and%20ham%20research.pdf
HHP - http://www.amif.org/Listeria%20Pressure.pdf and http://www.avure.com

5.2.2 Advantages

Non-additive technology
Consumer acceptance (with the exception of radiation)
Often highly effective

5.2.3 Disadvantages

Relatively high initial cost
Development of resistance
Practicality for application in existing processing lines

6 CONCLUSIONS

This review indicates that a wide variety of technologies are available for the control of *L. monocytogenes* in ready-to-eat meats. The potential for the practical use of these technologies is highly dependent on the product for which they are being considered, the desired outcome of the intervention and the financial outlay that is available. For example, many technologies such as the use of organic acids and plant extracts are well researched, relatively cheap and applicable across a wide range of products. They suffer, however, from the disadvantage of not achieving a significant kill rate and acting largely to prevent growth.

On the other hand, technologies such as high hydrostatic pressure appear to have significant potential in killing a substantial number of *L. monocytogenes*, but require a high financial outlay and substantial research to be effective. In deciding which technologies are most appropriate in a particular situation the opposing factors of additive versus non-additive technologies and high initial versus low long term costs need to be weighed.

Importantly, it should be remembered that no one technique represents a panacea for the control of *L. monocytogenes* in ready-to-eat meats. Application of a combination of techniques remains the ideal situation. Furthermore, no intervention strategy should be regarded as a substitution for in-plant hygiene.

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