New Zealand Food Safety
Haumaru Kai Aotearoa

Pathogens in dried uncooked ready to eat meats

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Scientific Interpretative Summary

This Scientific Interpretative Summary is prepared by New Zealand Food Safety (NZFS) risk assessors to provide context to the following report for MPI risk managers and external readers.

FW11009 Pathogens in Dried Uncooked Ready-to-Eat Meats

This report was developed by the Institute of Environmental Science and Research (ESR) in 2012. Data beyond those published in June 2012, and results of the 2008/09 New Zealand Adult Nutrition Survey, are not included in this Discussion Document so consequently it is not the most contemporary science available on this topic. However, as a much of the findings reported on will likely remain relevant, NZFS is publishing the discussion document as an information source. The findings of this report will be taken into account in the prioritisation of further work on pathogens in dried ready-to-eat (RTE) meats.

This Discussion Document compiles information available on dried RTE meats (e.g., jerky, biltong, droëwors), and the microbial hazards most associated with them, in New Zealand and internationally. While consumption of dried meat products has very occasionally been reported by notified cases of suspected food poisoning in New Zealand, no outbreaks have been reported, and there is scant evidence for these types of food being a vehicle for infection. Small outbreaks of illness due to consumption of dried meat products have been reported overseas.

Focusing largely on Shiga-toxin producing *Escherichia coli* (STEC), *Salmonella enterica* serovars, *Staphylococcus aureus*, and *Listeria monocytogenes*, available literature was reviewed to summarise the wide variety of processes used to manufacture different types of dried RTE meat products. Consumption in New Zealand was infrequent according to the nutrition surveys in 1997 (adult) and 2002 (children). Subsequent to the completion of this Discussion Document the updated New Zealand Adult Nutrition Survey of 2008/09 reported a decrease in total energy consumption attributed to “Sausages and processed meats” from 3% to 2.3%. However, as this is on a population basis it does not exclude the possibility that for certain communities within New Zealand dried RTE meat consumption may be increasing. As availability of traditional international foods, including dried uncooked RTE meats (particularly of South African and Asian styles) increases, it is important to see if the various processes of preparation and treatment are sufficient to render the products safe.

Controlled targets of multiple factors such as the relative humidity, temperature, pH, salt content, and water activity (a_w) of the meat during production has been shown to be beneficial in eliminating viable pathogens during the drying process. Although a final a_w of 0.85 or lower after drying is recommended in the US, studies have shown that simply reducing a_w to 0.85 does not necessarily achieve desirable reduction in pathogen numbers, although this a_w does prevent growth during future storage. Most dried RTE meat processing involves the addition of agents such as salt, sugar, vinegar, and spices prior to drying. With the exception of salt or acid tolerant organisms, such as *S. aureus*, these additives are likely to at least inhibit microbial growth during the pre-drying stages. The extent to which New Zealanders produce home-made dried RTE meats remains an unknown factor.

Client report FW 11009

DISCUSSION DOCUMENT: PATHOGENS IN DRIED UNCOOKED READY TO EAT MEATS

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DISCUSSION DOCUMENT: PATHOGENS IN DRIED UNCOOKED READY TO EAT MEATS

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Client report no. FW 11009

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June 2012

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The authors wish to acknowledge the Ministry of Health as owner of the copyright and funders of the 1997 National Nutrition Survey and the 2002 National Children's Nutrition Survey and to thank them for access to food consumption information (24-hour dietary recall and qualitative food frequency questionnaire) from these surveys.

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SUMMARY

The purpose of this discussion document is to collate and review information from overseas and New Zealand regarding bacterial pathogens in dried ready-to-eat (RTE) meats.

This report has been written in a similar manner to a Risk Profile, which normally considers a single food/hazard combination. Although the remit of this document is much broader, for consistency the general structure of a Risk Profile has been adopted.

This discussion document addresses microbial hazards, with particular focus on the following bacterial pathogens:

- Shiga-toxin producing *Escherichia coli* (STEC), including serogroup O157
- *Salmonella enterica* serovars
- *Staphylococcus aureus*
- *Listeria monocytogenes*

Dried RTE meats are the result of simple dehydration or drying of lean meat in natural conditions or in an artificially created environment and can include a variety of source meats and processes. Many cultures from across the world have developed unique dried meat products that vary in taste and favours due to the different ingredients and processes used. Some of the notable types of dried RTE meats (and their regional origins) include:

- Biltong (South Africa)
- Droëwors (South Africa)
- Jerky (North America)
- Dried hams eaten raw (e.g. prosciutto, Italy)
- Fenalår (Norway)
- Charqui (South America)
- Carne seca (Mexico)
- Pemmican (USA)
- Tasajo (Cuba)
- Nikku (Canadian Arctic)
- Pastırma (Turkey and Egypt)
- Bak Kwa/Rou Gan (China and South East Asia)
- Dendeng (Indonesia)
- Soudjuk or Sujuk (Armenia and Turkey)
- Lap Chang or dried Chinese sausage (China)

The majority of the published data on dried meat products focus on jerky due to its popularity in North America. Jerky is also widely available in New Zealand. Biltong and droëwors are also increasing in popularity in New Zealand due to the significant South African migration and specialist producers. Jerky processing generally involves a high temperature step during the curing/marination stage to eliminate pathogens before drying, and is dried at higher temperatures than biltong.

Overall, published studies indicate the importance of validating individual processes for making jerky, to evaluate pathogen number reductions. Using carefully controlled conditions in commercial facilities substantial reductions in pathogen numbers (>5 $\log_{10}$ CFU/sample) can

be achieved during jerky production. The reductions achieved in home style dehydrators are generally lower than this, and additional control steps may be necessary. Growth is prevented and further reductions in bacterial numbers occur during storage at room temperature.

A number of studies have demonstrated the effectiveness of additions to the traditional process to enhance pathogen control. In particular, various modifications to the drying stage can be made, including elevation of the relative humidity and/or use of higher temperatures in the early stages of drying before water activity (a_w) reduces to a level where heat resistance of the pathogens increases.

Compared to jerky, fewer studies of biltong production have been found. However, these studies suggest that the control of *S. aureus* in such high salt foods is the key food safety issue.

The information located for this report suggests that dried RTE meat production in New Zealand is principally jerky and biltong, and a number of small scale commercial producers will be supplemented by an unknown quantity of home production. Consumption is infrequent according to the available nutrition surveys, but is likely to have increased in the last decade.

No information is available on the prevalence of pathogens in such products in New Zealand. However, various studies have shown a prevalence of *Campylobacter, Salmonella, Listeria monocytogenes* and *S. aureus* of up to 10% on commercial raw meats. *E. coli* O157:H7 is rarely found. A single survey of *S. aureus* in feral venison suggests the organism may be ubiquitous in such meat.

According to a major producer, the commercial beef jerky products available at retail in New Zealand are manufactured to US guidelines, which include a lethality heat treatment. The marinating and drying processes have also been shown to be bactericidal to pathogens. It could be argued that such products are cooked and therefore outside the scope of this discussion document. However, the vast majority of scientific literature and regulations currently available for dried meats focus on the manufacture of jerky. Biltong and droëwors are first cured then dried at lower temperatures, but if processed correctly, the resulting product will not allow for the growth or survival of pathogens.

There is potential for microbial growth in dried meat products during the period before drying has reduced the a_w sufficiently to prevent growth. There is a wide variety of processes used to manufacture dried meats, but most involve the addition of agents such as salt, sugar, vinegar, and spices prior to drying. With the exception of salt or acid tolerant organisms, such as *S. aureus,* these additives are likely to at least inhibit microbial growth during the pre-drying stages. Storage at chilled temperatures during this period will also inhibit microbial growth. Drying of the meat reduces the numbers of viable microorganisms, as well as preventing subsequent growth. Several studies have shown that treatments such as marination and the addition of curing mixes can enhance pathogen reduction during drying. While growth (or toxin production) prior to drying cannot be entirely ruled out, the information in this report suggests that the amount will be modest.

It is not currently possible to estimate the risk to New Zealanders of exposure to pathogenic microorganisms through consumption of uncooked dried meat products. Available information suggests that these foods are infrequently consumed in New Zealand, although the food consumption information (1997 and 2002 National Nutrition Surveys) is now quite old and information from the soon to be released 2009 National Nutrition Survey may provide fresh

insights. In view of the increasing numbers of South African and Asian immigrants into New Zealand, it is likely that consumption has increased since the 1997 and 2002 surveys were conducted. Consumption amongst populations with South African and Asian ancestry is likely to be higher than amongst the general population.

An unknown factor is the extent of home-made production of both jerky and biltong. If these products have been prepared from meat of low microbiological quality, not dried to a sufficiently low a_w and stored improperly, the probability of exposure to pathogenic bacteria could be quite high.

While consumption of dried meat products has very occasionally been reported by notified cases of suspected food poisoning in New Zealand, no outbreaks have been reported, and there is no confirmed evidence for these types of food being a vehicle for infection. Outbreaks of illness due to consumption of dried meat products have been reported overseas, although numbers of cases have usually been quite low.

1 STATEMENT OF PURPOSE

The purpose of a Risk Profile is to provide information relevant to a food/hazard combination so that risk managers can make decisions and, if necessary, take further action. Risk Profiles are part of the Risk Management Framework (RMF)[1] approach taken by the Ministry for Primary Industries (MPI; formerly Ministry of Agriculture and Forestry) Food Safety. The Framework consists of a four step process, as shown in Figure 1.

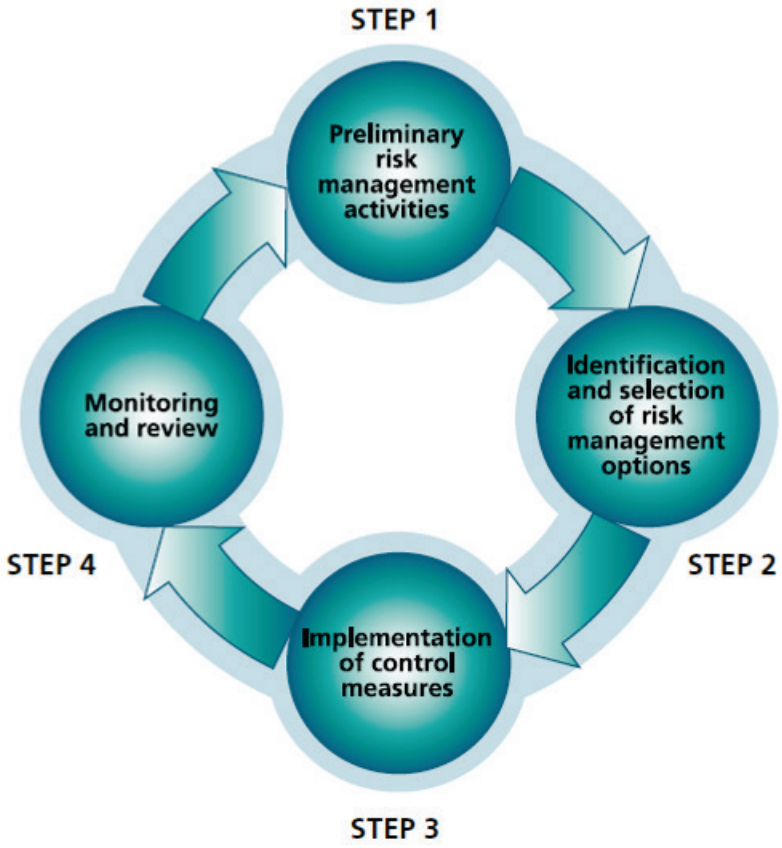

Figure 1: The four steps of the Risk Management Framework

This initial step in the RMF, Preliminary Risk Management Activities, includes a number of tasks:

- Identification of food safety issues
- Risk profiling
- Establishing broad risk management goals
- Deciding on the need for a risk assessment
- If needed, setting risk assessment policy and commissioning of the risk assessment
- Considering the results of the risk assessment
- Ranking and prioritisation of the food safety issue for risk management action.

[1] http://www.foodsafety.govt.nz/elibrary/industry/RMF_full_document_-_11604_NZFSA_Risk_Management_Framework_3.1.pdf

Risk profiling may be used directly by risk managers to guide identification and selection of risk management options, for example where:

- Rapid action is needed;
- There is sufficient scientific information for action;
- Embarking on a risk assessment is impractical.

This report has been written in a similar manner to a Risk Profile, which normally considers a single food/hazard combination. Although the remit of this document is much broader, for consistency, the general structure of a Risk Profile has been adopted.

1.1 Food/Hazard Combination and Risk Management Questions

The purpose of this discussion document is to collate and review information from overseas and New Zealand regarding bacterial pathogens in dried ready-to-eat (RTE) meats.

2 HAZARD AND FOOD

2.1 The Hazards

This discussion document focuses on the following bacterial pathogens:

- Shiga-toxin producing *Escherichia coli* (STEC), including serogroup O157
- *Salmonella enterica* serovars
- *Staphylococcus aureus*
- *Listeria monocytogenes*

The literature searches conducted for the document used keywords based on the foods, and where information on additional bacterial pathogens was deemed relevant, it was included. The list of pathogens above is consistent with the focus of other reviews of the microbiological safety of dried uncooked RTE meat products (Burfoot *et al.*, 2010).

Background information concerning the characteristics of the specific pathogens listed above is available in datasheets[2] and Risk Profiles[3] produced by ESR for MPI and has not been repeated here.

2.2 The Food

The foods included in this discussion document are dried uncooked ready-to-eat (RTE) meats (i.e. products that are not required to be cooked or otherwise processed by the consumer). Dried meat products are the result of the simple dehydration or drying of lean meat in natural conditions or in an artificially created environment. The process is based on the fact that dehydrated meat, from which a substantial part of the natural tissue fluid has been evaporated, will not easily spoil (Heinz and Hatuzinger, 2007). Meat drying is not a clearly defined technology. Drying may be done for the sole purpose of dehydrating fresh meat for extension of storage, but may also be one of various processing steps during the manufacture of meat products with desired textures and flavours. Different source meats and processes from around the world have given rise to a wide variety of dried RTE meats. Some notable products (and their regional origins) in this dried meat category include:

- Biltong (South Africa)
- Droëwors (South Africa)
- Jerky (North America)
- Dried hams eaten raw (e.g. prosciutto, Italy)
- Fenalår (Norway)
- Charqui (South America)
- Carne seca (Mexico)
- Pemmican (USA)
- Tasajo (Cuba)
- Nikku (Canadian Arctic)
- Pastırma (Turkey and Egypt)
- Bak Kwa/Rou Gan (China and South East Asia)

[2] http://www.foodsafety.govt.nz/science/other-documents/data-sheets/ accessed 22 June 2012
[3] http://www.foodsafety.govt.nz/science/risk-profiles/ accessed 22 June 2012

- Dendeng (Indonesia)
- Soudjuk or Sujuk (Armenian and Turkey)
- Lap Chang or dried Chinese sausage (China)

Further details of the characteristics of these products are included in Appendix 1. The majority of these products are stored at ambient temperature, and may be sold packaged or unpackaged.

Although dried meat products are preserved primarily by the reduction of a_w, additional controls are normally applied during their commercial production. These contribute to the lethality of the process to inactivate or inhibit bacterial pathogens of concern. Examples of these additional controls are: the use of salt, nitrite, and/or anti-microbial agents (e.g. organic acids), low pH, application of smoke, heating of the meat before drying (Naidoo and Lindsay, 2010b).

Drying using natural conditions and ambient temperatures is still practised in some countries, but faster drying methods using higher temperatures and air flows are more common in commercial production. Due to some of the higher drying temperatures used in these processes, it is difficult to accurately define 'uncooked' dried RTE meats. A report prepared for MPI on Uncooked Comminuted Fermented Meats (UCFM) used a definition of 'uncooked' as a product that had not had its core temperature increased to, and maintained at, 65°C for at least 10 minutes or an equivalent combination of time and higher temperature (Wong *et al.* 2011). Some dried meat products, particularly jerky often involve drying steps involving temperature ranges of 60-80°C during their production which could be considered a 'cooking step' according to the definition above.

The majority of scientific literature available for dried meats focuses on the microbiology of jerky during production. Jerky is widely consumed in the United States (US) and so the United States Department of Agriculture (USDA) has developed regulations and recommendations for both commercial manufacturers and home-producers to produce microbiologically safe jerky (Burfoot *et al.* 2010). Other dried meats such as biltong are incorporated into these recommendations[4] (USDA, 2007). This discussion document includes literature relevant to food safety of jerky production, but processes that involve cooking steps (e.g. cooked hams) or fermentation (e.g. UCFM, such as salamis) are excluded.

2.2.1 The Food Supply in New Zealand: Dried RTE Meats

Of the dried meats identified above, those most likely to be produced and consumed in New Zealand are jerky, biltong and droëwors. This conclusion is based on internet searches, which have located a number of producers of these products, as well as offers for drying equipment to manufacture such products at home.

2.2.1.1 Jerky

Jerky is produced by a variety of processes, some of which may involve a cooking step (ICMSF, 2005). The raw material may be whole or moulded meats, which are cut or extruded into strips. The simplest process involves only drying, but usually spices and/or marinades (using vinegar) are used in combination with drying. The meat may also be smoked. Jerky

[4] http://www.fsis.usda.gov/Factsheets/Jerky_and_Food_Safety/index.asp#1. Accessed 13 June 2012

and biltong are similar, but jerky processing often involves a high temperature step during the curing/marination stage to eliminate pathogens before drying, and jerky is dried at higher temperatures than biltong. Raw meat weight is reduced by a factor of four during jerky production (Nummer *et al.*, 2004). The a_w of jerky is reduced to approximately 0.86, with a final water content of 15-20% (ICMSF, 2005).

Jerky may also be made from chopped or ground meats that are mixed with a dry spice mixture and formed into strips (by extrusion) or stuffed into narrow casings (Nummer *et al.*, 2004). The filled casing may be cooked before being sliced into discs which are dried (and possibly smoked) on trays. Immersion of such products in a curing/marination mixture is not feasible, and so pathogen control relies on the drying process (Borowski *et al.*, 2009b).

The United States Department of Agriculture (USDA) has published a "Compliance Guideline for Meat and Poultry Jerky Produced By Small and Very Small Plants" which identifies lethality treatments (prior to drying) in terms of temperature, time, and humidity parameters (USDA, 2007). This document stresses the importance of humidity control during the jerky making process, which is in addition to the time and temperature combinations specified in Appendix A of the final rule "Performance Standards for the Production of Certain Meat and Poultry Products" (USDA, 1999). For people making jerky at home, where achieving temperatures of 160°F (71°C) or more may be difficult, drying at 130–140°F (54-60°C) is recommended (USDA, 2005).

A final a_w of 0.85 or lower after drying is recommended by the USDA. Water activity is considered a better measure of available water for microbial growth than the previously used measure, moisture to protein ratio (MPR). However, in the US, an MPR of 0.75:1 or less remains part of the standard of identity for jerky. Thus, an MPR of 0.75:1 or less is necessary to call the product "jerky," but it is not sufficient to ensure a safe product (USDA, 2007).

2.2.1.2 Biltong and Droëwors

In the United Kingdom (UK), biltong and droëwors production has accompanied the migration of South African populations, and retailers specialising in these commodities have appeared (Naidoo and Lindsay, 2010a). It is likely that the same has occurred in New Zealand. In 2006, New Zealand had a sub-population of approximately 42,000 South African-born residents (~1% population), up from 21,000 in 2001[5].

Biltong and jerky are similar products, but the difference between them is that biltong is cured and then dried (sometimes at ambient temperature), while beef jerky is cut into thin strips, marinated and heated or smoked before drying. Many meat species, meat cuts and seasonings are used in the manufacture of biltong but larger, high quality cuts of beef or game meat are most common. Biltong processing involves cutting meat into strips approximately 2.5 cm thick, dry salting (2.5-4% salt), storage overnight at 4-5°C for salt equilibration, and low temperature drying in heated air (e.g. approximately 30°C, 30% relative humidity, 3 m/s air flow) (ICMSF, 2005). The final moisture content is less than 24%. Originally biltong was produced by drying at ambient temperatures, but hot air boxes and commercial driers are commonly used so that the conditions can be controlled. Using the specific 30°C, 30% relative humidity, 3 m/s air

[5] http://www.stats.govt.nz/Census/2006CensusHomePage/QuickStats/quickstats-about-a-subject/culture-and-identity/birthplace-and-people-born-overseas.aspx accessed 4 August 2011

flow drying conditions achieves a suitably dry product at 144 h but the microbial load would decrease further with longer drying times (Burfoot *et al.* 2010).

The dry salting step will also include a variety of spices, and usually dipping (or tumbling, in larger scale operations) into an acidic liquid such as vinegar for hours or days. Sometimes the vinegar and spices are mixed in a process usually described as marination. Vinegar and roasted coriander feature in many recipes but chilli and garlic are also used. Additives and preservatives may also be used, including nitrate, nitrite, boric acid, pimaricin (a naturally occurring antifungal agent from *Streptomyces natalensis*) and potassium sorbate (Burfoot *et al.* 2010).

Typical values of biltong after drying would be: moisture content (20 to 30%); salt (3 to 8%); pH (5.6 to 5.9); a_w (0.7 to 0.75) (Burfoot *et al.* 2010). In South Africa there is a trend towards consumers preferring higher moisture products (a_w 0.85-0.93) and some retailers sell products marketed as dry, medium or wet (Burfoot *et al.* 2010, Nortje *et al.*, 2006). It has been suggested that biltong with a moisture content less than 24%, or a_w less than 0.68, is microbiologically stable with rancidity limiting the shelf life in products with such moisture contents (Burfoot *et al.* 2010, Van der Riet, 1976).

Droëwors are thin sausages of meat that have been cured. To make droëwors, small pieces of beef are obtained from trimming and/or grinding, seasoned (high-salt), stuffed into casings and dried in the same way as biltong[6] (Burnham *et al.* 2008). Some processes also flatten the sausages by rolling them across a board so that any pockets of air in the sausage are removed to avoid mould growth. Traditionally droëwors are put over wooden rods and dried at ambient temperature for approximately 2 weeks, but the same hot boxes and driers used for biltong are now used to control the drying step. The drying conditions used to produce biltong are also used for droëwors.

2.2.1.3 Asian dried meats

Popular RTE dried meat products originating from Asian countries are Rou Gan and Bak Kwa. These products are produced by cooking strips or slices of beef, pork or mutton with spices, sugar, salt, and soy sauce until the mixture is almost dry, and the pieces are then dried on racks at 50-60°C to a final a_w of 0.60-0.69 (ICMSF, 2005). A dried 'Chinese sausage' known as Lap Chang is normally smoked, sweetened and seasoned. These sausages are neither fermented nor ripened and involve firstly drying the sausage for two days at approximately 60°C (usually from charcoal based heat), followed by 2-3 days at approximately 50°C. The internal temperatures in the sausages normally do not exceed 50°C. Chinese style sausages and dried meat are never eaten directly but cut into small pieces and cooked with rice or noodles before eating (Heinz and Hautzinger, 2007). While these products do not appear to be widely available commercially in New Zealand, the authors have found locally made pork Bak Kwa available in speciality Asian food markets in Christchurch.

In the 2006 census 3.5% of the New Zealand population reported Chinese ethnicity, and a total of 8.8% people reported Asian ethnicity. This census also found that the population included 76,000 people born in the People's Republic of China.

[6] http://www.biltongusa.com/what-is-biltong-droewors, accessed 30 May 2012

2.2.1.4 New Zealand Production

There are approximately seven commercial manufacturers of biltong and/or droëwors in New Zealand (see website collating South African cooking links)[7], but only one production facility is approved for export of biltong. This company, Loranto Limited[8], also manufactures for the New Zealand market under the Meathogs brand. They report processing 1000 kg of biltong in 2010, with 30% growth expected annually over the next few years (Anthony Wakefield, Loranto Limited, pers. comm., 18 August 2011). Other commercial producers have indicated that the sales of biltong and droëwors in New Zealand are increasing every year due to its availability in supermarkets.

Another manufacturer, Kiwi Biltong in Auckland[9], has a Food Safety Manual that includes instructions that prior to marination (spice and vinegar) meat is kept below 7°C. Marination continues for 6-24 h in the chiller. Drying is performed at approximately 25°C with the aim of achieving a_w of less than 0.8 in approximately 7 days (Hein Erasmus, pers. comm., June 2012).

A major New Zealand manufacturing export facility reported that the jerky it produces and sells in New Zealand is cooked prior to drying (4 h at >82°C, product reaches 72°C for 30-40 minutes) to comply with US standards. Traditional jerky production is not viable commercially because it is slow, not cost effective, and also fails to meet regulators expectations (Martin Beever, Jack Link's New Zealand Ltd, pers. comm., 5 August 2011).

The extent of home-production of these foods and their quality is unknown. Biltong or droëwors are not usually made in a food dehydrator, but in a home-made or purchased drying cabinet, where the product is air-dried with the help of a fan and a heat source, such as a light bulb. Instructions are easily found by internet searches, with a common timeframe of 3-4 days drying time if a dry environment is used.

Food dehydrators sold in New Zealand include in the user manual a section on how to make jerky. However, these instructions do not include a lethality treatment prior to drying and users rely on a pre-set time and temperature.

2.2.1.5 New Zealand Imports and Exports

The Harmonised System (HS), used for categorisation of goods in international trade, does not allow identification of imports or exports meeting the food definition used in the current discussion document. For example, no distinction is possible between brined and dried products or between cooked and uncooked products.

Although a number of the New Zealand websites offering biltong for sale also offer imported South African products, these do not appear to be meat products. The Mediterranean Warehouse[10] has imported prosciutto from Italy and Australia. Some shops also carry jamon serrano from Spain.

[7] http://www.rainbowcooking.co.nz/ accessed 5 August 2011
[8] http://www.loranto.co.nz/ accessed 19 August 2011
[9] http://www.kiwibiltong.com/index.html accessed 25 June 2012
[10] http://www.medifoods.co.nz/ accessed 29 August 2011

2.2.2 Behaviour of pathogens in dried RTE meats

Only a few studies of pathogen behaviour on dried RTE meats other than jerky were found during literature searches.

2.2.2.1 Whole meat jerky

Pathogen control during jerky processing is dependent on the pre-treatment ingredients and conditions, as well as the drying conditions. The drying step may result in enhanced pathogen thermotolerance (greater heat resistance at lower a_w) and evaporative cooling may reduce the ability of the process to eliminate pathogens (Buege *et al.*, 2006). USDA Guidelines for jerky production identify the importance of a lethality heating step before drying for pathogen control (USDA, 1999, 2007). Various time-temperature options are provided and it is stated that the relative humidity (RH) must be maintained at ≥90% in dehydrators or smokehouses. This is critical for assuring sufficient lethality, because conditions of higher moisture and RH typically result in greater lethality towards pathogens (USDA, 2007). A survey of small and very small commercial plants in the US found that many processors heated product to 74°C and subsequently held it for several hours at 71°C. The least severe treatment that was encountered was using air at 52°C for 45 min followed by air at 57°C for 1 h, while the most severe treatment found consisted of heating in air at 93°C for 9.5 h (Lonnecker *at al.* 2010). The thermal treatment recommended by the USDA guidelines (2007) is a post-drying heating step using air at 135°C for 10 minutes. This treatment is advocated to reduce *Salmonella* levels and result in an adequate lethality when the initial heating phase has been insufficient to achieve a 7-log reduction in *Salmonella* (Burfoot *et al.* 2010).

Overall, published studies indicate the importance of validating individual processes for making jerky, to evaluate pathogen number reductions. Using carefully controlled conditions in commercial facilities, substantial reductions in pathogen numbers (>5 $\log_{10}$ CFU/sample) can be achieved during jerky production. The reductions achieved in home style dehydrators are generally lower than this, and additional control steps may be necessary. Growth is prevented and further reductions in bacterial numbers occur during storage at room temperature.

A number of studies have demonstrated the effectiveness of additions to the traditional process to enhance pathogen control. In particular, various modifications to the drying stage can be made, particularly elevation of the relative humidity and/or use of higher temperatures in the early stages of drying before a_w reduces to a level where heat resistance of the pathogens increases.

Commercial Processing

Commercial jerky making processes have been tested to determine their effect on multiple strain cocktails of the pathogens *E. coli* O157:H7, *Salmonella* Typhimurium, and *L. monocytogenes* (Porto-Fett *et al.*, 2008). Commercial processes use shorter drying times at higher temperatures (≥77°C) compared to home-style dehydrators (49-68°C). Beef strips inoculated with one of the three bacterial mixtures (approximately 7.3 $\log_{10}$ CFU/g) were then dried and smoked in a commercial facility. Before drying, half the strips were marinated in a commercial marinade (pH 5.5) for approximately 15 minutes at 4°C and loaded into a commercial smokehouse and cooked and dried for up to 3.5 h at a target smokehouse chamber

temperature of 82.2°C (dry-bulb drying[11]). The results showed that for both marinated and non-marinated strips, cooking and drying for 1.5, 2.5, or 3.5 h at a target smokehouse temperature of 82.2°C (average of 80.7 ± 3.1°C) with exposure to constant hickory smoke with an average initial relative humidity of ca. 63.1% and an average final relative humidity of ca. 20.9%, resulted in a decrease of ≥7.3 log CFU per strip (≥6.9 log CFU/g) for all three pathogens tested. This meant that all tests were below the limit of detection (≤1.2 log CFU per strip or ≤0.4 log CFU/g). However, the bacteria could be detected in some samples using enrichment, particularly *Salmonella* in over 80% of non-marinated strips (recovery with enrichment in marinated samples was generally lower). Although these bacterial reductions could be achieved after 1.5 h of drying, it took 2.5 h for the moisture to protein ratio and a_w of all samples to reach an acceptable level (≤0.75:1 and ≤0.8 respectively).

Similar experiments using turkey meat and the same pathogens indicated that equivalent pathogen reductions and proximate values could be achieved, although in general longer drying times (3.5 h) were required (Porto-Fett *et al.*, 2009).

Experiments to determine lethality parameters for *Salmonella* and *E. coli* O157:H7 in beef jerky have been reported (Buege *et al.*, 2006). Beef strips inoculated with pathogens (8 $\log_{10}$ CFU/strip) were tumbled manually with a liquid spice/salt/sugar mixture and then stored for 24 h at 5°C. They were then dried in a small scale commercial facility, using a variety of drying regimes, some of which included the addition of water vapour to elevate the relative humidity (51.7 or 54.4°C for 60 min, 57.2°C for 30 min, or 60°C for 10 min) followed by drying at 76.7°C (dry-bulb temperature)). Only modest reductions in pathogen numbers (<0.5 $\log_{10}$ CFU) were found after the refrigerated marination step. To promote pathogen destruction, so-called wet bulb spikes (i.e. elevated relative humidity; RH) were included in the drying regime. These spikes used RHs up to 43%, which was much lower than the USDA recommended >90% RH, but still achieved the target reduction in *Salmonella* and *E. coli* numbers (>5.0 $\log_{10}$ CFU). Overall, these experiments showed that reductions in counts of *Salmonella* serovars and *E. coli* O157:H7 of 5.0 $\log_{10}$ CFU can be achieved in the production of whole-muscle beef jerky by ensuring that wet-bulb temperatures (≥82.2°C) and percent RH values are high enough and are reached (initial RH of ≥63% to a final RH ≥20%) and maintained early in the process or that high dry-bulb temperature heating and drying occurs before the beef strip a_w has fallen below 0.86.

Other experiments have investigated the use of modified marinades including food grade chemicals in the pre-drying phase of jerky manufacture. These were conducted to determine the effectiveness of some of these treatments in controlling acid-adapted and non-acid adapted bacteria inoculated onto beef before drying or after drying. The bacteria studied were *E. coli* O157:H7 (Calicioglu *et al.*, 2003b; Calicioglu *et al.*, 2002b), *Salmonella* (Calicioglu *et al.*, 2003c; Calicioglu *et al.*, 2003d) and *Listeria monocytogenes* (Calicioglu *et al.*, 2003a; Calicioglu *et al.*, 2002a). Acid-adapted cultures were created by incubating the bacteria in a broth that contained glucose. Bacteria were inoculated at 6.0-6.5 $\log_{10}$ CFU/cm^2. Treatments included a marinade with added chemicals (1.2% sodium lactate, 9% acetic acid 68% soy sauce, 5% ethanol), or pre-dipping before marination in 5% acetic acid, or 5% acetic acid/1%

[11] For "dry" air, air that is less than saturated (i.e. air with less than 100 percent relative humidity), the wet-bulb temperature is lower than the dry-bulb temperature due to evaporative cooling. The greater the difference between the wet and dry bulb temperatures, the drier the air and lower the relative humidity. Wet-bulb temperature is measured using a thermometer that has its bulb wrapped in cloth—called a *sock*—that is kept wet with water via wicking action (from: http://en.wikipedia.org/wiki/Wet-bulb_temperature).

Tween. After treatment, the beef strips were held at 4°C for 24 h before drying, which was conducted in dehydrators set to 60°C. The dried pieces of jerky were then stored at ambient temperatures (25°C) for up to 60 days.

Although some of the pre-treatments caused modest reductions in numbers (1-2 $\log_{10}$ CFU), the changes were not always statistically significant. The greatest change in bacterial numbers occurred after 4 h of drying; further drying up to 10 h did not cause significant further reductions. Pre-treatment with marinades with added chemicals did result in significantly greater reductions in bacterial numbers compared to the traditional marinade. Storage of the dried jerky caused further reductions in bacterial numbers. Significant differences in the behaviour of acid-adapted and non-acid-adapted cells were not observed. Overall, the use of certain food-grade chemical preservatives as ingredients in pre-drying marination treatments could improve the effectiveness of the drying process in inactivating the bacteria. Depending on conditions, reductions of 5-6 $\log_{10}$ CFU were achieved, after storage.

The effect of storage on bacterial numbers inoculated onto dried jerky (at similar concentrations) was also investigated, to mimic post-processing contamination. For *E. coli* O157:H7 and *Salmonella*, counts reduced by more than 5 $\log_{10}$ CFU/cm^2 over the 60 day period, with the greatest reduction occurring in the first 14 days. The same was found for *L. monocytogenes*, although acid-adapted bacteria declined faster than non-acid adapted bacteria. While the numbers of bacteria declined during storage, reductions on jerky that had received the pre-treatment were greater.

The impact of two pre-drying treatments compared to a control (C; no treatment) on survival of *Salmonella* and *E. coli* O157:H7 in beef jerky has been reported (Yoon *et al.*, 2005; Yoon *et al.*, 2009). The two treatments were marination (M), and dipping in a 5% acetic acid solution (pH 2.5) for 10 minutes followed by marination (AM). C and M had little direct impact on bacterial concentrations, while AM decreased *Salmonella* concentrations by 1.1-2.4 $\log_{10}$ CFU/cm^2 and *E. coli* O157:H7 concentrations by 1.3-1.7 $\log_{10}$ CFU/cm^2. AM treatment also resulted in greater death rates during drying, for both organisms.

Alternative pre-treatments

A study conducted for the USDA examined variations in the production of beef jerky to assist small and very small meat processors in the development of their Hazard Analysis and Critical Control (HACCP) plans to address concerns with *Salmonella*, *E. coli* O157:H7, and *L. monocytogenes* (Harrison *et al.*, 2006). The chemical pre-treatments evaluated were:

- chlorine dioxide (500 and 1200 ppm)
- acidic calcium sulphate (1:2 and 1:3 water:calcium sulphate ratios)
- ozone

These pre-treatments were used as 30 second dips of the inoculated beef strips prior to overnight marination. The beef jerky strips were made using a horizontal-flow dehydrator set at 62°C or a commercial-type smokehouse with a dry-bulb/wet-bulb setting of 63°C/43°C (33% RH).

Pre-treatments with ozone were unsuccessful due to technical difficulties. Populations of *E. coli* O157:H7 were reduced by at least 5 $\log_{10}$ CFU/strip for the other treatments except for jerky pre-treated with the lower concentration of chlorine dioxide and dried in the dehydrator.

For *L. monocytogenes*, 5 $\log_{10}$ CFU reductions were noted for all the treatments regardless of the drying method. *Salmonella* populations were reduced by more than 6.5 $\log_{10}$ CFU on jerky strips that were pre-treated with the higher concentration of calcium sulphate and dried in the dehydrator and jerky pre-treated with the 1200 ppm concentration of chlorine dioxide and dried in the smokehouse. Populations were reduced almost as well on jerky pre-treated with calcium sulphate, both concentrations, and dried in the smokehouse (Harrison *et al.*, 2006).

The authors commented that "Most jerky processors who have contacted us over the years use dehydrators rather than smokehouses to process their product. Ingram *et al.* (Interim Report, Wisconsin Study) showed the percent relative humidity (%RH) control in smokehouses during jerky processing is important. No such data using dehydrators are available. Humidity control in dehydrators presents challenges that cannot be addressed using a smokehouse. For instance, the %RH in dehydrators is influenced by the %RH of the room air, which can widely vary. This is especially true for the initial operating period during the drying process."

Storage

A series of studies has examined the survival of pathogens on a range of ready-to-eat meat products purchased from processors, inoculated, and then stored, usually under vacuum. Jerky was one of the products investigated. The objective of this research was to demonstrate the effectiveness of the production processes in suppressing or limiting growth throughout product shelf life, which would help to fulfil requirements placed on manufacturers by the USDA.

Jerky inoculated with a five-strain cocktail of *L. monocytogenes* (3.6 $\log_{10}$ CFU/sample, where each sample was a standard size square cut from the products), was repackaged under vacuum, and then stored at room temperature (21°C) (Ingham *et al.*, 2004). After one week, the numbers of *Listeria* had reduced to 1.2 $\log_{10}$ CFU/sample, while after five weeks they had reduced to 0.9 $\log_{10}$ CFU/sample. *Staphylococcus aureus* inoculated onto jerky at 5.9-6.6 $\log_{10}$ CFU/cm^2 had reduced to 3.3-5.1 $\log_{10}$ CFU/cm^2 after one week, and 1.4-2.8 $\log_{10}$ CFU/cm^2 after four weeks under vacuum (Ingham *et al.*, 2005). A further study examined a higher number of vacuum-packed jerky samples inoculated with either *L. monocytogenes* or *S. aureus* (Ingham *et al.*, 2006). None of the 15 jerky products supported growth of either pathogen. Counts of *S. aureus* fell by 0.2 to 1.8 $\log_{10}$ CFU/sample after 1 week of storage and by 0.6 to 5.3 $\log_{10}$ CFU/sample after 4 weeks of storage. Numbers of *L. monocytogenes* fell by 0.6 to 4.7 $\log_{10}$ CFU/sample and by 2.3 to 5.6 $\log_{10}$ CFU/sample after 1 and 4 weeks of storage, respectively. Although factors other than a_w may have some effect on pathogen survival, these results supported the drying of beef jerky to $a_w \leq 0.87$ to ensure that bacterial pathogens cannot grow on vacuum-packaged product stored at room temperature.

Beef jerky inoculated with *L. monocytogenes* (4.1-4.5 $\log_{10}$ CFU/g) and then either vacuum-packed (control), dipped in water (72°C for 20 seconds) or dipped in 2% sodium lactate has been studied to determine the survival of the bacteria during storage (Boles *et al.*, 2007). Samples were stored for 0, 3, 6, 9 or 12 weeks at 21°C. After 3 weeks, bacterial reductions were similar for control (3.2 $\log_{10}$ CFU/g reduction) and water dip (3.1 $\log_{10}$ CFU/g reduction), but lower for sodium lactate dip (2.7 $\log_{10}$ CFU/g reduction). *L. monocytogenes* was not detectable in any sample after 12 weeks of storage.

Production using food dehydrators

One study has found that marination has little impact on bacterial reduction on beef strips inoculated with *E. coli* O157:H7 (Albright *et al.*, 2002). Samples were inoculated with a four strain cocktail and stored at 4°C for 24 h. Samples were then either marinated (4°C for 24 h in a solution including a variety of ingredients at pH 4.3), dried in a home style dehydrator (10 h at 62.5°C) and stored (90 days at 21°C), or immediately dried and stored under the same conditions (control). Marination itself had a variable impact on bacterial concentrations (-0.4 to +0.6 $\log_{10}$ CFU/cm^2), but had no impact on bacterial reduction during the subsequent drying process. After four hours of drying bacterial reductions were similar for marinated (reduction of 2.1-2.3 $\log_{10}$ CFU/cm^2) and control (reduction of 2.2-2.5 $\log_{10}$ CFU/cm^2). Bacterial reduction was greater in marinated product dried at 68.3°C than that dried at 62.5°C (reduction of 3.5-4.1 compared to 2.1-2.3 $\log_{10}$ CFU/cm^2). The greatest bacterial reductions were achieved during the first four hours of drying and all treatments had surviving bacteria after 10 hours drying. Irrespective of treatment, bacterial counts had reduced to undetectable levels after 30 days of storage.

Partly in response to the results in the study above, a variety of pre-treatments of meat, used before drying of beef jerky, made using a home style dehydrator, have been examined for their effect on *E. coli* O157:H7 (Albright *et al.*, 2003). Sliced beef was inoculated with 5.3-7.6 $\log_{10}$ CFU/cm^2 of the organisms and then subjected to treatments involving marination (same recipe as above) at 4°C for 24 h, with immersion in various heated solutions (water, pickling brine, vinegar) either before or after marination. The beef slices were then dried in commercial dehydrators at 62.5°C for periods up to 10 h. All pre-treatments reduced the numbers of *E. coli*, but the most effective was marination followed by immersion in pickling brine (78°C, 90 seconds). This process achieved a reduction of 3.1-4.1 $\log_{10}$ CFU/cm^2 before drying, and 5.7-5.8 $\log_{10}$ CFU/cm^2 after 10 h of drying. Bacterial populations declined to less than 1.0 $\log_{10}$ CFU/cm^2 after 30 d storage and remained at this level throughout 90 d storage at 21°C.

Pathogen reduction during jerky production has been assessed in a study that also used a consumer panel to determine acceptability of the final product (Harrison *et al.*, 2001). Jerky was prepared after inoculation of beef strips with *L. monocytogenes*, *E. coli* O157:H7 and a cocktail of five *Salmonella* Typhimurium strains at approximately 4-6 $\log_{10}$ CFU/strip. Preparation methods were:

- Marination in a salt-containing marinade overnight at 4°C and then drying in a home style dehydrator at 60°C;
- As above, followed by heating in an oven at 135°C for 10 minutes;
- Marination in a salt-containing marinade overnight at 4°C, bringing strips and marinade to boiling temperature and boiling for 5 minutes, and then drying in a home style dehydrator at 60°C; and,
- Marination in a salt-containing marinade overnight at 4°C, heating strips in an oven at 163°C for 10 minutes, and then drying in a home style dehydrator at 60°C.

Control samples without marination were also prepared.

Marination (same recipe as above) clearly increased the pathogen reduction effect of drying in this study. For the first process, the numbers of all three pathogens were below the detection limit (0.6 $\log_{10}$ CFU/strip) after drying with marination, while without marination *L. monocytogenes* and *Salmonella* were detected even after drying and oven heating. Boiling before drying eliminated all pathogens. Oven heating before drying eliminated pathogens in all samples that were made with marination. In jerky prepared without marination, the oven

heating reduced pathogen numbers by approximately 4 $\log_{10}$ CFU, and drying further reduced them to undetectable levels, apart from residual *Salmonella* (1.1 $\log_{10}$ CFU/strip).

Samples prepared by the same processes (but without inoculation) were used for sensory evaluation studies. Consumer acceptability scores were similar for texture and off flavours for jerky prepared by all four processes, and while colour and saltiness acceptability scores were reduced by the third and fourth processes, no product was unacceptable. Oven heating of jerky after drying was advocated as a useful control step for home producers.

An early study of the behaviour of *E. coli* O157:H7, *L. monocytogenes,* and *Salmonella* Typhimurium during preparation and storage of beef jerky used inoculated (at approximately 7 $\log_{10}$ CFU) beef loin strips that were marinated at 4°C overnight and dried at 60°C for 10 h in a food dehydrator (Harrison and Harrison, 1996). Other inoculated samples were heated in marinade to 71.1°C prior to drying. Microbial populations were determined at intervals during drying up to 10 h and also from samples stored at 25°C for 8 weeks at various moisture levels. After 3 h of drying, populations of the pathogens on the unheated, inoculated samples were reduced by 3.3, 1.8 and 3.1 $\log_{10}$ CFU/strip for each pathogen respectively, and all three were reduced by 5.5 to 6.0 $\log_{10}$ CFU/strip after 10 h. Reduction of the three populations on strips that were cooked prior to drying was 4.5-5.5 $\log_{10}$ CFU immediately after cooking. In general, *L. monocytogenes* was more resistant to the treatments, but all populations decreased to undetectable levels after 10 h of drying. After 8 weeks of storage none of the pathogens were detected, indicating that they were unable to recover under the moisture conditions during storage.

Home-style dehydrators have been investigated for their ability to reduce numbers of *E. coli* O157:H7, *Salmonella*, *L. monocytogenes*, and *S. aureus* on jerky (Dierschke *et al.*, 2010). Whole-muscle beef strips were inoculated with *L. monocytogenes* (five strains), *S. aureus* (five strains), or a mixed inoculum of *E. coli* O157:H7 (five strains) and *Salmonella* (eight strains). After allowing for attachment of cells, strips were marinated for 22 to 24 h and dried in three home-style dehydrators at 57.2 to 68.3°C. Samples were taken post-marination; after 4, 6, and 8 h of drying; and after drying, followed by heating for 10 min in a 135°C oven. Surviving inocula were enumerated. With a criterion of >5.0 log CFU/cm^2 reduction as the standard for adequate process lethality, none of the samples achieved the target lethality for any pathogen after 4 h of drying, even though all samples appeared "done" (a_w of less than 0.85). A post-dehydration oven-heating step (10 minutes at 135°C) increased the proportion of samples meeting the target lethality after 4 h of drying to 71.9, 88.9, 55.6, and 77.8% for *L. monocytogenes*, *S. aureus*, *E. coli* O157:H7, and *Salmonella*-inoculated samples, respectively, and after an 8-h drying to 90.6, 94.4, 83.3, and 91.7% of samples, respectively. These experiments illustrate that home style dehydrators may not achieve sufficient reductions in pathogen numbers, even if operated according to instructions (and home dehydrator temperature settings may not match actual temperatures reached). The authors also commented that although the USDA regard *Salmonella* to be the target organism for jerky making process validation, *E. coli* O157:H7 was more heat resistant in these experiments.

A home-style dehydrator was found to produce a temperature of 52.9 ± 0.8°C when set at 68.3°C and a temperature of 48.2 ± 0.4°C when set at 60°C (Holley, 1985a). Studies were carried out using the indicated temperature, to fully represent the hazard to a consumer preparing jerky at home. Defatted and marinated flank steak was dehydrated for four hours at each of these temperatures. Meat was inoculated with a mixture of *Clostridium perfringens* vegetative cells and *Salmonella* (equal mixture of *Salmonella* Typhimurium and *Salmonella*

Blockley) in one experiment (initial concentration approximately 4.5 $\log_{10}$ CFU/g dry weight), and *S. aureus* and *Bacillus subtilis* in a second experiment (initial concentration *S. aureus* approximately 6 $\log_{10}$ cfu/g dry weight, *B. subtilis* approximately 4.5 $\log_{10}$ CFU/g dry weight), (Holley, 1985b). In this study the a_w decreased to 0.86 and a shelf stable moisture-protein ratio of ≤1.6 was found within 2.5-3 h of drying in all cases. *S. aureus* numbers approximately doubled during the first two hours of drying, before decreasing. However, after 8 h drying bacterial numbers were still at 64% of the initial concentration. *Salmonella* concentrations reduced to 0.3% of the initial concentration after 8 h drying, while *C. perfringens* and *B. subtilis* were undetectable after 4 and 6 h drying, respectively. After being undetectable at 6 h drying, *B. subtilis* was detected after 8 h drying at 5.6% of the initial concentration. Storage of jerky for 28 days at 2.5°C post-drying resulted in further reductions in bacterial concentrations of *Salmonella, S. aureus* and *B. subtilis*, but *C. perfringens* was detected after being undetectable after the drying step. Storage at 20°C for 28 days resulted in the concentrations of all organisms reducing to undetectable levels.

A study reported on the ability of home-style dehydrators to reduce *Salmonella* on raw chicken meat during drying for up to 6 h with temperatures during the drying period rising from 50°C to 60°C (Weber *et al.*, 2011). Although RH was increased by the addition of water it was still only 38%, and the desired reduction in pathogen numbers (5 $\log_{10}$ CFU) as required for jerky was not achieved. This was despite the a_w being reduced to <0.85.

These studies illustrate that simply reducing a_w to <0.85 does not necessarily achieve desirable reduction in pathogen numbers, even though this level of a_w is required to prevent growth during future storage.

2.2.2.2 Ground and reformed jerky

Experiments have also been described using jerky made from chopped or ground meats, followed by extrusion into strips or stuffing into narrow casings (Nummer *et al.*, 2004).

Ground beef inoculated with *Listeria monocytogenes* and a mixture of five *Salmonella enterica* serovars at approximately 6 $\log_{10}$ CFU/g and mixed with a commercial spice mixture, with or without cure ingredients (salt and sodium nitrite) has been studied (Harrison *et al.*, 1997). Jerky strips were laid out, and dried in a food dehydrator at 60°C for up to 8 h. Some strips were heated in an oven until the internal temperature reached 71.1°C, before drying for up to 6 h. In strips prepared without cure mix, the reduction in *Listeria* and *Salmonella* numbers after 8 h of drying was modest (2.5 and 3.2 $\log_{10}$ CFU/g respectively). In strips treated with spice and cure mix, after 8 h the corresponding reductions were 4.0 and 4.2 $\log_{10}$ CFU/g respectively. The effect of the cure mix was less dramatic in samples pre-heated in an oven. In such samples, the pre-heating caused substantial reductions in pathogen numbers, with smaller further reductions during drying. Similar experiments using *E. coli* O157:H7 also found an enhanced reduction in pathogen numbers with the addition of cure mix (4.3 $\log_{10}$ CFU without cure mix, 5.2 $\log_{10}$ CFU reduction with cure mix, after 8 h of drying) (Harrison *et al.*, 1998). Pre-heating in an oven before drying meant that a reduction in numbers of 5.2 $\log_{10}$ CFU was achieved after only 6 h of drying.

Reductions in *Salmonella* and *Listeria* numbers did not reach the 5 $\log_{10}$ CFU usually cited as a target, whatever the process used. However, reductions in *E. coli* O157:H7 numbers greater than 5 $\log_{10}$ CFU could be achieved. The reductions in bacterial numbers in jerky made from

ground beef were lower than those found in similar experiments with whole meat strips (Harrison and Harrison, 1996).

The viability of *E. coli* O157:H7 in ground and formed beef jerky prepared at levels of 5 and 20% fat and dried at 52, 57, 63, or 68°C in a home-style dehydrator has been reported (Faith *et al.*, 1998). This study inoculated a ground beef batter with 8 $\log_{10}$ CFU/g *E. coli* O157:H7 and this was formed into strips for drying. Reductions in pathogen numbers increased with temperature. For the 5% fat product a reduction of approximately 5 $\log_{10}$ CFU was achieved after 10 h at 52°C, 8 h at 57°C, 6 h at 63°C, and 4 h at 68°C. In the 20% fat mixture, pathogen reduction was slower, requiring approximately twice as long at 52°C and 57°C to reduce numbers by 5 $\log_{10}$ CFU. It was notable that the settings on the dehydrator controls were lower than the actual temperatures inside the unit, by up to 10°C. Visual judgements were made to assess when the jerky was "done" and ready for eating, which occurred at shorter times than that required for the 5 $\log_{10}$ CFU reduction. Overall, it was recommended that ground beef jerky be made from leaner cuts of meat and dried at temperatures ≥63°C for at least 8 h.

Reduction of *E. coli* O157:H7 and *Salmonella* serovars during thermal processing of chopped and formed beef jerky has been evaluated under two processing schedules representative of those used by large-scale (LS) and small-scale (SS) jerky production facilities (Harper *et al.*, 2009). Fresh chopped and formed all-beef jerky batter was inoculated with 5.8-7.3 log CFU/g of *E. coli* O157:H7 or *Salmonella*, extruded into strips, and thermally processed by LS or SS schedules (using a commercial smokehouse). For the LS process, a ≥5.0 log CFU/g reduction of both pathogens occurred with <10% relative humidity and a cumulative process of 44 min at 55.6°C followed by 46 min at 77.8°C. Additional drying at 77.8°C for 3.5 h was needed to achieve a_w of 0.67 and an MPR of 0.77. For the SS process, a ≥5.0 log CFU/g reduction of both pathogens occurred with 15 to 20% relative humidity and a cumulative process of 45 min at 52°C, 60 min at 57°C, 45 min at 60°C, 45 min at 63°C, 90 min at 68°C, and finishing with 30 min at 77°C. After processing for an additional 90 min at 77°C, a_w was 0.60 while the MPR was 0.82. The LS and SS processes for producing chopped and formed jerky provided ≥5.0 log lethality to control *E. coli* O157:H7 and *Salmonella*. However, both processes would require additional drying to achieve an MPR of 0.75 to allow product to be correctly labelled as jerky.

These results indicate that high humidity, such as the ≥90% RH stated in the US Food Safety and Inspection Service (FSIS) jerky compliance guideline, may not be necessary to achieve a ≥5.0-log reduction for *Salmonella* and *E. coli* O157:H7 depending on the thermal processing parameters used. This is important because many small and very small processors do not have equipment capable of achieving the specified high-humidity levels. The apparent difference between these results and those by Faith *et al.* (1998) above, may be due to the presence of an air blower and exhaust fan on the smokehouse unit used by Harper *et al.* (2009).

Lactic acid bacteria have been investigated as surrogates to validate beef jerky making processes, on the basis that they are at least as heat resistant as pathogens (*Salmonella* and *E. coli* O157:H7) (Borowski *et al.*, 2009b). These experiments concerned jerky made from ground and formed beef, instead of meat strips where bacteria will occur on the surface of the meat. The USDA mandated 5.0 $\log_{10}$ reduction in pathogen numbers was the target for *Salmonella*. The USDA has not set a target for *E. coli* O157:H7 reduction in jerky, but the US meat industry has chosen a 5.0 $\log_{10}$ reduction target. Commercial processes were used to derive experimental conditions.

The lactic acid bacteria (LAB) experiments showed that humidity control was an important aspect of effective drying for pathogen control i.e. achieving a high wet-bulb temperature (e.g. 50°C or greater), not just a high dry-bulb temperature (greater than 75°C). Pathogen reductions greater than 5.0 $\log_{10}$ required both high humidity and high dry bulb temperature (greater heat resistance of *Salmonella* and *E. coli* O157:H7 at a_w 0.90 compared to a_w 0.99 has been documented). However, achieving high relative humidities (>90%) in small scale production equipment can be difficult. These experiments also showed that two commercially available strains of lactic acid bacteria could act as reliable surrogates for *Salmonella* and *E. coli* O157:H7, to validate processes where the use of pathogens would be unsuitable. This is useful, as although these experiments investigated several jerky making processes, there is a much greater variety of processes in actual use, and USDA recommended time, temperature and processes can result in an unacceptable product (Borowski *et al.*, 2009b).

A further set of experiments on ground beef jerky investigated the effectiveness of home-style dehydrators and one small commercial unit in reducing the numbers of pathogens (Borowski *et al.*, 2009a). Such units do not usually offer humidity control, and temperature control may be less than ideal. Using the manufacturer's instructions to operate the units, a majority (80%) of samples reached the required 5 $\log_{10}$ CFU reduction in *E. coli* O157:H7 numbers after 12 h drying time, but only 27% of samples achieved the same reduction in *Salmonella* numbers. All samples experienced at least 4 h at a_w <0.85, and final a_w values were all <0.65. Overall the authors recommended that drying at 68.3°C for 12 h was required, with preferably an additional post-drying oven heating step of 135°C for 10 minutes. However, they recognised that such times and temperatures may result in an organoleptically unacceptable product.

Under these experimental conditions, LAB strains were inconsistent in acting as surrogates for pathogens to validate process control. When acting as an indicator for reductions in *E. coli* O157:H7 numbers, the LAB correctly indicated achievement of target (5.0 $\log_{10}$ CFU reduction) for all samples. Predictions of adequate process lethality against *Salmonella* serovars were unsuccessful in 4% of samples, indicating LAB as a pathogen surrogate may yield a falsely safe result in beef jerky.

Inclusion of raisins (extract or purée) in ground beef jerky was shown to have antimicrobial properties decreasing both the pH and a_w of the jerky (Bower *et al.*, 2003). Jerky containing 25% or 50% raisins was challenged with *S. aureus, L. monocytogenes* or *E. coli* O157:H7 (initial inoculum 4 $\log_{10}$ CFU/g). Inclusion of raisins resulted in decreased survival of all three pathogens after 48 h. The antimicrobial effect was stated to be directly related to the decrease in a_w.

2.2.2.3 Biltong

In comparison to jerky, fewer studies of biltong production have been found. However, these studies suggest that the control of *S. aureus* in such high salt foods is the key food safety issue. Traditional South African drying of biltong was achieved by hanging the strips of meat on hooks and leaving them to dry at ambient temperature. Nowadays, home-made biltong is made using a biltong-drying unit (Naidoo and Lindsay, 2010c) while larger scale operations use commercial driers. A warm dry environment is required for making biltong and an air temperature of 35°C will enable a microbiological stable product to be produced in approximately 6 days (Taylor, 1976, Burfoot *et al.* 2010). Ambient conditions in New Zealand will be generally colder and higher moisture than in South Africa, and would not often be

suitable for making biltong. A longer drying time may increase the potential for microbiological growth before sufficient a_w reduction.

Several pathogen isolates found in a survey of retail biltong samples have been tested for growth at 37°C under various conditions relevant to biltong production (Naidoo and Lindsay, 2010c). The strains tested were: *L. monocytogenes* (2 strains), *S. aureus* (3), and *Staphylococcus pasteuri*[12] (3). Seven of these eight grew on agar plates supplemented with 15% NaCl, although at higher salt concentrations only the *Staphylococcus* strains were able to grow. The *L. monocytogenes* strains were able to grow in broth and on plates at 4°C, the usual temperature for the overnight marinade of biltong before drying. Dilute acetic acid inhibited the growth of all strains, but the apple cider and brown spirit vinegars that might be used in marinades only inhabited some strains. The presence or absence of biltong spice mixtures made no difference to growth. The authors commented that these *in vitro* results may not mimic actual production conditions.

The survival of three bacterial pathogens (*L. monocytogenes*, *S. aureus* and *S. pasteuri*) throughout the manufacturing process of biltong has been reported (Naidoo and Lindsay, 2010b). Beef portions were surface inoculated with selected isolates (approximately 7 $\log_{10}$ CFU/g) and prepared using either a traditional, home-style or modern, manufacturing method prior to drying at 25°C for 96 h. These two methods differed in their marination process (traditional: meat dipped in apple cider vinegar and drained, biltong spice flavour spread over each side, followed by 18-20 h at 4°C before drying; modern: the same except biltong spice pre-mixed with apple cider was spread onto meat surfaces).

An initial reduction in pathogen numbers of approximately 2 $\log_{10}$ CFU/g was observed after marination and overnight refrigerated storage, before drying. Biltong produced using the modern method was associated with lower counts compared to product produced using the traditional technique. Fewer than 1 $\log_{10}$ CFU/g *L. monocytogenes* cells were detected in final product and cell counts decreased rapidly throughout both processes. In contrast, 2–4 $\log_{10}$ CFU/g cells of both *Staphylococcus* strains survived in the final product. The latter finding may hold future foodborne illness implications, as these strains of *Staphylococcus* were enterotoxin-producers.

Biltong inoculated with *Salmonella enterica* serovars, *E. coli* O157:H7, *S. aureus* and *L. monocytogenes* (6.4-7.1 $\log_{10}$ CFU/sample immediately before drying) were used to assess the effect of drying (Burnham *et al.*, 2008). The biltong was hung on racks in an environmental chamber set at 22.2°C (actual range 20-22°C) with a target of 50% RH (actual range (38-64%) for 17-26 days. Samples were retested when they had reached water activities of approximately 0.85 and 0.60, then again after vacuum-packaged storage at 22.2°C for 7 days. Total log reductions after 7-days storage were 3.1-4.2, 2.8-4.4, 1.7-2.6 and 2.0-4.0 $\log_{10}$ CFU/sample for the four pathogens listed above, respectively.

The hygiene of the surfaces that came into contact with biltong product at three different retailers in Johannesburg has been studied (Naidoo and Lindsay, 2010a). The microbial tests employed did not include pathogen specific tests, but did show that *Bacillus* and *Staphylococcus* spp. were the dominant populations, from both the biltong and contact surfaces. Cross contamination between the biltong and surfaces was demonstrated.

[12] The role of *S. pasteuri* in causing human disease has not been completely established.

Gamma (γ)-irradiation (1–10 kGy) has been found to be effective in eliminating *S. aureus* from raw and cooked beef, and so its ability to control the same organism in biltong has been investigated (Nortje *et al.*, 2006). Biltong strips were inoculated with *S. aureus* (6-7 $\log_{10}$ CFU/g) and some were also coated with an edible coating made from dairy proteins. A gamma irradiation dose of 4 kGy for 1 hour was applied. The counts of *S. aureus* were reduced to less than 1 $\log_{10}$ CFU/g, but the presence/absence of the edible coating made no difference. The effect on yeasts and moulds was lower, and would not be sufficient to extend shelf life.

2.2.2.4 Droëwors

Very few studies have investigated the potential of pathogen growth during droëwors processing. The study of Burnham *et al.* (2008) outlined above for biltong was also performed for droëwors, whereby ground meat was inoculated with *Salmonella enterica* serovars *E. coli* O157:H7, *S. aureus* and *L. monocytogenes* (6.0-7.3 $\log_{10}$ CFU/sample) and stuffed into natural casings and dried using the same conditions outlined for biltong, but for 12-21 days. The droëwors samples were also tested as outlined for biltong and results showed a steady population decrease during drying. Total log reductions after 7 days storage were 2.3-3.4, 2.4-3.1, 1.6-1.9 and 1.5-2.7 $\log_{10}$ CFU/sample for the four pathogens listed above, respectively. This study found the pathogen decreases associated with the manufacture of biltong were greater than those occurring during the manufacture of droëwors. In addition, the lethality achieved in making biltong and droëwors is not sufficient to meet USDA regulatory standards of either ≥6.5 log or ≥5-log reductions for beef products as stated in the guidance for cooked products or fermented shelf-stable products, respectively (USDA, 1999 and 2005). It was recommended that processors of these products incorporate additional treatments such as spraying peracetic acid on the meat cuts, or undertaking raw material pathogen testing to meet the alternative lethality standard of ≥2-log reduction in *E. coli* O157:H7 provided that the starting material tested is negative for this pathogen.

2.2.2.5 Charqui

Survival of *Clostridium botulinum* and *S. aureus* was examined during charqui processing (Lara *et al.*, 2003). Beef was brined, dry salted, re-salted, restacked, sun-dried and stored. *S. aureus* was inoculated onto the raw beef (5 $\log_{10}$ CFU/g). There was little decline in bacterial concentration through the brining and salting steps, but a minimum of approximately 2 $\log_{10}$ CFU/g reduction occurred during sun-drying (concentration reported as <3 $\log_{10}$ CFU/g). For *C. botulinum,* the inoculum spore concentration (100 viable cells/g) remained constant throughout processing. There was no evidence of spore germination or toxin production.

2.3 Viruses and Parasites

A recent review of preservation methods to inactivate foodborne viruses reported that viruses survive well under dried conditions, although numbers are reduced (Baert *et al.*, 2009). However, no studies of virus survival on dried meat have been conducted; existing studies have mostly used inanimate surfaces, and virus survival rates at different relative humidities are quite variable.

Dried meat may be a contributing factor to *Toxoplasma gondii* infection, which is of particular importance for pregnant women. Cysts are inactivated by freezing (≤-12°C, 3 d or ≤-20°C, 28 h) and heat treatment (55°C for 20 min, 61°C, for 3.6 min, or 67°C for 7 s). The interaction of salt and maturation time can reduce the number of viable cysts, depending on

concentration/temperature and time (for example, 10, 15 and 20°C for 3-35 d in 6% salt reduces numbers) (Mie *et al.* 2008). A quantitative risk assessment for meatborne *T. gondii* infection in the Netherlands ranked smoke-dried beef and dry sujuk Turkish sausage as having amongst the lowest probability of infection per serving of all the meat products examined, based on salt content (2.5-3.9%), temperature (20°C) and treatment time (21 days) (Opsteegh *et al.*, 2011).

2.4 Exposure Assessment

2.4.1 Food consumption

Dried meat products appear to be rarely consumed in New Zealand. The New Zealand National Nutrition Survey (NNS) conducted in 1997 (Russell *et al.*, 1999) and the 2002 Children's National Nutrition Survey (CNS) (Ministry of Health, 2003) were searched for references to biltong, jerky, charqui, rou gan, dried meat (meat, dried) or meat sticks. The NNS (n = 4,636 respondents) contained one instance of beef jerky (54 g) and one of meat sticks (36 g). The CNS (n = 3275 respondents) contained one instance of beef jerky (50 g) and two of meat sticks (75 g, 120 g). It is uncertain whether 'meat sticks' refers to a dried meat product.

The nutrition surveys quoted were conducted in 1997 and 2002; in view of the increasing populations of South African and Asian immigrants (see Section 2.2.1) it is likely that consumption has increased since the surveys were conducted. Consumption amongst populations with South African and Asian ancestry is likely to be higher than amongst the general population.

2.4.2 Evaluation of exposure

2.4.2.1 Number servings and serving sizes

There are no data available on consumption of dried uncooked RTE meat products in New Zealand (see Section 2.4.2 Food consumption).

Supermarkets, small retailers such as service stations and local dairies, as well as speciality stores such as Asian markets sell RTE meat products made locally as well as product imported from Australia. Products available at retail outlets are predominantly sold in 25–50 g serving sizes. On-line stores offering biltong sell product in larger (kg) quantities.

2.4.2.2 Frequency of contamination

There is little information available on contamination of dried uncooked RTE meat products performed in New Zealand. Surveys of contamination of retail minced red meats in New Zealand in 2003 – 2004 found a low prevalence (≤10%) and counts of *Campylobacter* (Wong *et al.*, 2007a), and a low prevalence of *Salmonella* (1.1% overall) (Wong *et al.*, 2007b). The results for *Campylobacter* are consistent with more recent data from the Manawatu for 2005-2008[13]. Testing for *E. coli* O157:H7 in export meat as recorded by the National Microbiological Database indicates that positive samples are rare.

[13] http://www.foodsafety.govt.nz/elibrary/industry/enhancing-surveillance-potentially-research-projects-2/Campy_Attribution_Manawatu.pdf accessed 5 August 2011.

A Risk Profile of *Listeria monocytogenes* in processed ready-to-eat meats summarised studies that found a prevalence of up to 4% in ham, pâté and other products in New Zealand[14].

Information on *S. aureus* on New Zealand meats is very limited. A study of feral venison found that *S. aureus* was present on all samples, with counts mostly 3-5 $\log_{10}$ CFU/g (Sumner *et al.*, 1977). A study of imported beef trim from several countries into the US used presence of *S. aureus* as one of its parameters for hygienic status (Bosilevac *et al.*, 2007). Frozen beef trim from New Zealand had a prevalence of 8.2% with a mean count of 1.3 $\log_{10}$ CFU/g.

2.4.2.3 Growth rate during storage and most likely storage time

Inoculation and storage studies (outlined in Section 2.2.2) indicate that properly produced beef jerky and biltong do not provide a suitable growth medium for the pathogenic bacteria considered here. Storage at room temperature for 12 months or more is generally acceptable for commercially made product, during which time, bacterial numbers and concentrations are known to be reduced even further. Products manufactured at large scale are packed with nitrogen flushing or vacuum-packed to maintain the shelf life. There is no definitive shelf life identified in the literature for biltong or droëwors. Commercial products available in New Zealand supermarkets recommend storage of biltong and droëwors in a cool dry place or frozen for longer storage and unless frozen should be consumed within 10 days of opening. The RTE nature of these products means that a heat treatment by the consumer is not necessary.

Home-made jerky and biltong/droëwors makers have no official guidelines for storage, however the manual of a leading manufacturer's dehydrator suggests storing the dried meat products in an airtight container in the refrigerator for up to 3-4 weeks, or freeze for longer storage.

For microbiological safety, a lethality step is recommended by the FSIS in Appendix A of the final rule "Performance Standards for the Production of Certain Meat and Poultry Products" (USDA, 1999). This Appendix gives validated time and temperature combinations.

There are no official guidelines in New Zealand for heat treating home-made jerky-type products prior to drying.

2.4.2.4 Exposure summary

New Zealanders do not appear to be high volume consumers of dried uncooked RTE meat products, although consumption has probably increased since the available nutrition surveys which were conducted over ten years ago. No information is available on the prevalence of pathogens in such products in New Zealand. However, various studies have shown a prevalence of *Campylobacter, Salmonella, L. monocytogenes* and *S. aureus* of up to 10% on commercial meats. *S. aureus* in feral meat appears to be ubiquitous. *E. coli* O157:H7 is rarely found.

The beef jerky products available at retail in New Zealand are manufactured to US guidelines, which includes a lethal heat treatment, and the marinating and drying processes are also shown to be bactericidal to pathogens. As outlined earlier it may be argued that such products are

[14] http://www.foodsafety.govt.nz/elibrary/industry/Risk_Profile_Listeria_Monocytogenes_Processed-Science_Research.pdf accessed 5 August 2011

cooked and therefore outside the scope of this discussion document. Biltong is first cured then dried; when performed correctly, the published studies indicate that the process does not allow for the growth of pathogens. However, pathogen reductions during biltong production are modest (<5 $\log_{10}$ CFU/sample), so the quality of the raw meat should be controlled. Care must also be taken to avoid cross-contaminating the product following its production.

2.5 Overseas Context

The limited number of surveys of these products from overseas summarised below suggest a low prevalence of pathogens in jerky, and potential problems with *S. aureus* in biltong.

2.5.1 Jerky

Surveys by the USDA–FSIS of ready-to-eat meat and poultry products between 1990 and 1999 included testing of jerky for *L. monocytogenes* and *Salmonella* (but not *E. coli* O157:H7) (Levine *et al.*, 2001). *Salmonella* was detected in 2/648 samples (0.31%, 95% CI 0.04 – 1.11%), and *L. monocytogenes* in 4/770 samples (0.52%, 95% CI 0.14 – 1.32%).

Analysis of 42 commercial beef jerky samples from Oklahoma failed to detect *S. aureus, Salmonella* and *E. coli* O157:H7 in any sample (Velasco Ramos, 1991).

2.5.2 Biltong

A microbiological survey of 121 samples of retail biltong available in Johannesburg in 1963 recovered *E. coli* from 34 samples (*E. coli* Type 1 apparently suggesting faecal contamination), and a pathogen (*Salmonella* Poona) from one (Bokkenheuser, 1963). A survey of 45 retail samples of biltong in Pretoria in 1973–1974 found *Salmonella enterica* serovars in seven (16%) (*S.* Typhimurium (2 samples), *S.* Thompson (1), *S.* Johannesburg (3), *S.* London (1)) (Prior and Badenhorst, 1974).

A more recent microbiological survey of 150 samples of biltong was conducted in South Africa in July–September 2008 (Naidoo and Lindsay, 2010c). Suppliers included slaughterhouses, biltong bars, convenience stores, biltong shacks, home based industries and sweet shops. The aerobic plate count (APC) was highest (approximately 7 $\log_{10}$ CFU/g) in samples from biltong bars selling unpackaged product, while the APC from packaged products was lowest (approximately 6 $\log_{10}$ CFU/g). Coagulase positive *Staphylocccus* counts were also highest in unpackaged samples, at up to 3 $\log_{10}$ CFU/g.

Fifteen presumptive *Staphylococcus* isolates were further analysed and found to consist of a variety of *Staphylococcus* species, and isolates from three samples (2.0%) were toxin producers. It was considered that the presence of enterotoxin producing strains may have been promoted by the high concentration of salts, acidic pH, and higher a_w of 0.85 than traditional biltong, which will allow growth of strains of *S. aureus*. Two samples (1.33%) tested positive for *L. monocytogenes*. *Salmonella* were not detected in any samples.

In a pilot survey for the above study, 26 biltong samples including traditional, spiced, chicken and venison varieties, were tested for APC, yeast, and presumptive *Staphylococcus* counts (Mhlambi *et al.*, 2010). All of these were above 5 $\log_{10}$ CFU/g. Eleven presumptive *S. aureus* isolates were 16S rDNA sequenced and confirmed. Two of these isolates were found to produce enterotoxin.

A survey of various foods, including biltong, for *L. monocytogenes* has been conducted in Botswana (Morobe *et al.*, 2009). Between 250 and 300 samples were taken, and none were positive for *L. monocytogenes*. The authors commented that biltong is exported from Botswana to European markets and the absence of the organism may be due to the zero tolerance limits in the processing of the meat.

A survey of retail meat and meat products in the Eastern Cape Province of South Africa detected *E. coli* O157:H7 in 1/45 (2.2%, 95% CI 0.1-11.8%) biltong samples (Abong'o and Momba, 2009)

A survey of the microbiological quality of specialty meats sampled from retail in the UK included 93 samples of biltong, 11 of jerky, 37 of 'other' dried meat (Gormley *et al.*, 2010). Of the 141 dried meats, 137 were of satisfactory microbiological quality (*Salmonella* not detected in 25 g, *E. coli, S. aureus, Listeria* spp. <20 CFU/g), with the remaining four of acceptable microbiological quality (*E. coli, S. aureus, Listeria* spp. 20-<100 CFU/g).

2.5.3 Other uncooked dried meat products

A survey of *Listeria* on raw dried Bulgarian sausage (n = 141) detected *L. monocytogenes* on 16 samples (11.3%, 95% CI 6.6-17.8%), *L. ivanovii* on 2 samples (1.4%, 95% CI 0.2-5.0%), *L. innocua* on 7 samples (5.0%, 95% CI 2.0-10.0%) and *L. welshimeri* on 2 samples (1.4%, 95% CI 0.2-5.0%) (Karakolev, 2009).

A survey of the microbiological quality of meat products was carried out in Sydney, Australia (NSW Food Authority, 2009). While many of the products were outside the definition used in the current discussion document, 38 samples were described as 'prosciutto' or 'Bresaola', varieties of dry-cured raw ham. *E. coli* and *Salmonella* were not detected in any sample. A *Listeria* species was detected in one sample (2.6%, 95% CI 0.1-13.8%), but it was not *L. monocytogenes*. A proportion of samples (3, 8%) were analysed for STEC, with no detections.

A survey of 637 dry-cured uncooked Italian hams (Parma and San Daniele) detected *Listeria monocytogenes* in 20 samples (3.1%, 95% CI 1.9-4.8%) (Giovannini *et al.*, 2007). *L. monocytogenes* was only detected in de-boned ham samples and was not detected in bone-in ham or sliced, vacuum-packed ham. The maximum concentration of *L. monocytogenes* in any sample was 1.5 $\log_{10}$ MPN/g.

3 EVALUATION OF ADVERSE HEALTH EFFECTS

3.1 Disease characteristics

This discussion document addresses bacterial pathogens as hazards. In particular:

- Shiga-toxin producing *Escherichia coli* (STEC), including serogroup O157
- *Salmonella enterica* serovars
- *Staphylococcus aureus*
- *Listeria monocytogenes*

Disease characteristics of these and other food-borne pathogens can be found on the MPI website[15].

3.2 Dose-Response

The dose response for each pathogen of interest has been discussed at length in previous Risk Profiles. These are available on the MPI website[16].

3.3 New Zealand Human Health Surveillance and Outbreak Information

A search of the EpiSurv database was conducted in January 2011 to look for notification or outbreak records that mentioned dried meats (for the period 1 January 1997 to 1 January 2011). No relevant outbreaks were located. There have been four cases reported in New Zealand where beef jerky or dried meat was consumed prior to illness, although these foods were not confirmed as the responsible vehicles.

Two of these cases were reported in 1999. A case of gastroenteritis reported consumption of beef jerky that was served using tongs that were kept in water. A case of salmonellosis reported consuming a meal that included dried meat.

In 2000, a single case of gastroenteritis reported to the Canterbury Public Health Unit was investigated including submission of a sample of beef jerky to the Public Health Laboratory as a suspected food. No pathogens were found in the sample.

A case of gastroenteritis in 2004 reported venison jerky as the suspected vehicle, however testing of the product did not detect any pathogens.

3.4 Adverse Health Effects in Other Countries

3.4.1 Outbreaks

Table 1 gives a list of outbreaks linked to RTE dried meats overseas, with further discussion of some of these below.

[15] http://www.foodsafety.govt.nz/science-risk/hazard-data-sheets/pathogen-data-sheets.htm accessed 22 June 2012

[16] http://www.foodsafety.govt.nz/science-risk/risk-assessment/risk-profiles/ accessed 22 June 2012.

Table 1: International outbreaks linked to RTE dried meats

Date	Location	Food source	Organism	Food preparation	No. ill/ fatal	Reference
1954	South Africa	Biltong	*Salmonella* Newport	Household	21/1	(Neser *et al.*, 1957)
1966	California, USA	Venison jerky	*Clostridium botulinum* type F	Household	5/0	(Midura *et al.*, 1972)
1966-67	New Mexico, USA	Beef jerky	*Salmonella* Thompson	Commercial	39/0	(CDC, 1967)
1982	New Mexico, USA	Beef jerky	*S. aureus*	Commercial	15/0	(Eidson, 2000)
1985	New Mexico, USA	Carne seca	*Salmonella* Cerro	Commercial	44/0	(CDC, 1985)
1986	New Mexico, USA	Beef jerky	*Salmonella* Montevideo	Commercial	5/0	(Eidson, 2000)
1987	New Mexico, USA	Beef jerky	*Salmonella* Newport	Commercial	4/0	(Eidson, 2000)
1988	New Mexico, USA	Beef jerky	*Salmonella* Newport	Commercial	45/0	(Eidson, 2000)
1995	New Mexico, USA	Carne seca	*Salmonella*, multiple serovars	Commercial	93/0	(CDC, 1995)
1995	New Mexico, USA	Antelope jerky	*S. aureus*	Household	5/0	(Eidson, 2000)
1995	Idaho, USA	Cougar jerky	*Trichinella*	Household	10/0	(CDC, 1996)
1995	Oregon, USA	Deer jerky	*E. coli* O157:H7	Household	11/0	(Keene *et al.*, 1997)
2003	New Mexico, USA	Beef jerky	*Salmonella* Kiambu	Commercial	26/0	(Smelser, 2004)
2008	London, UK	Beef biltong	*Salmonella* Typhimurium DT104	Commercial	16/0	(HPR, 2009)
				Total ill / fatal	**339/1**	

Three outbreaks of illness associated with biltong have been noted in South Africa (Naidoo and Lindsay, 2010a). In 1954 biltong, made from a cow found dead, caused an outbreak of 21 individuals, one of whom died (Neser *et al.*, 1957). Bacteriology from biltong samples recovered *Salmonella* Newport, and the organism could still be recovered from samples stored at room temperature after two years, despite the biltong having a salt concentration of 10-12%. It was suspected that the cow had died from *Salmonella* septicaemia. The biltong appears to have been air dried although few details of preparation are reported.

In 1960 *Salmonella* Anatum was isolated from a piece of biltong that was considered to be responsible for a short, but severe attack of gastroenteritis but no details are available (Bokkenheuser, 1963). A further outbreak, in Botswana in 2001, involved 17 cases of illness but no pathogen was reported (Tshekiso, 2006).

In 1966, an outbreak of botulism involving *Clostridium botulinum* type F occurred in California from home-prepared venison jerky. Among the 20 people who ate the jerky, three developed botulism, two developed mild gastroenteritis and 15 remained asymptomatic (Midura *et al.*,

1972). Neither the organism nor the toxin could be isolated from the ingredients used to make the jerky, so it was concluded that the contamination had arisen from soil contamination of the venison meat.

At least eight gastroenteritis outbreaks occurred in New Mexico between 1966 and 1995 from ingestion of meat jerky. Two outbreaks were due to contamination with *Staphylococcus aureus* and six were due to contamination with *Salmonella*. Over 250 illnesses were reported. Most cases were linked to local commercially produced jerky made by soaking beef strips in a spicy marinade prior to dehydrating them. In all of the investigations, processing times and temperatures never reached a level to destroy the pathogens. Based on this series of outbreaks and investigations, the New Mexico Environment Department developed regulations for the production of jerky in 1989. Included were regulations to cook and dry jerky within 3 h to an internal temperature of 63°C for beef, lamb, and fish, and 74°C for poultry. The finished jerky should have an $a_w < 0.85$ (Eidson, 2000).

In 1995, an outbreak of *E. coli* O157:H7 occurred in Oregon involving home-made venison jerky (Keene *et al.*, 1997). As many as 11 persons were infected. The home processor dried the venison in a home-style dehydrator set between 51.7 and 57.2°C for 12 to 14 h. *E. coli* O157:H7 was recovered from the deer jerky, deer meat, and the deer carcass. Deer faecal pellets taken from the area where the deer was harvested also tested positive for *E. coli* O157:H7. This report indicated that deer can be a reservoir for *E. coli* O157:H7. They concluded that some traditional home-drying processes for jerky were insufficient for killing *E. coli* O157:H7 and recommended precooking deer meat to 74°C before drying.

3.4.2 Recalls

A search of the USDA food recall website, the UK Food Standards Agency, MPI and Food Standards Australia New Zealand (FSANZ) websites show that there have been no recorded recalls of RTE dried meats in the UK, Australia or New Zealand. However, there have been product recalls in the US and Canada, although these recalls were not associated with outbreaks of illness.

As shown in Table 2, between 1996 and 2010 five recalls of beef jerky for microbiological contamination have been initiated by the USDA FSIS[17], and one recorded in a regional newspaper.

[17] http://origin-www.fsis.usda.gov/Fsis_Recalls/index.asp Accessed 3 February 2011

Table 2: International RTE dried meat recalls[17]

Date of recall	Location	Product	Suspect organism	Recall information source
1996	Richmond, BC, Canada	Beef jerky	*Listeria* spp	FSIS-RC-015-96
2000	Connecticut, USA	Beef jerky	*L. monocytogenes*	FSIS-RC-046-2000
2002	Los Angeles, USA	Beef jerky	*Salmonella* spp.	FSIS-RC-033-2002
2004	Pennsylvania, USA	Beef jerky	*L. monocytogenes*	FSIS-RC-022-2004
2008	Texas, USA	Beef jerky	*L. monocytogenes*	Houston Chronicle
2010	Virginia, USA	Imported prosciutto	*L. monocytogenes*	FSIS-RC-029-2010

3.5 Health Burden of Infection with Pathogen

The health burden for disease caused by the pathogens of interest in this discussion document has been estimated (Lake *et al.*, 2010). However, no estimate of the fraction of this burden attributed to infections with RTE dried meats as a vehicle has been made.

3.6 Adverse Health Effects Summary

While there have been a number of outbreaks of gastroenteritis from consumption of dried uncooked RTE meat products overseas, there is no evidence for these foods causing illness in New Zealand.

4 EVALUATION OF RISK

4.1 Existing Risk Assessments

Earlier USDA guidelines for beef products have specified a 6.5-log reduction in *Salmonella*. The newer 5-log reduction standard resulted from a USDA draft risk assessment of the impact on the incidence of salmonellosis of different lethality standards for ready-to-eat meat and poultry products (Decisionalysis and USDA, 2005). In this risk assessment, researchers determined that a decrease in the pathogen standard from a 6.5-log reduction to a 5-log reduction for products such as jerky, which does not usually support the growth of salmonellae, would have little effect on the incidence of salmonellosis (Buege *et al.*, 2006).

A quantitative assessment of the risks from illegally imported meat contaminated with foot and mouth disease virus to Great Britain attributed a high proportion of the risk (68%) to bone-in and dried de-boned products (which include biltong and jerky) (Hartnett *et al.*, 2007). The survival of the virus in dried deboned meat was estimated as 112 days.

A quantitative microbial risk assessment was carried out for listeriosis in consumers of dry-cured raw Italian ham (Parma and San Daniele) (Giovannini *et al.*, 2007). The estimated incidence of illness was 4.7×10^{-10} cases per serving for healthy adult consumers and 6.1×10^{-7} cases per serving for organ transplant patients, the most susceptible sub-population.

4.2 Estimate of Risk for New Zealand

The information located for this report suggests that dried RTE meat production in New Zealand is principally jerky and biltong, and a number of small scale commercial producers will be supplemented by an unknown quantity of home production. Consumption is infrequent according to the nutrition surveys in 1997 and 2002, but is likely to have increased over time.

No information is available on the prevalence of pathogens in such products in New Zealand. However, various studies have shown a prevalence of *Campylobacter, Salmonella, Listeria monocytogenes* and *S. aureus* of up to 10% on commercial raw meats. *S. aureus* in feral meat appears to be ubiquitous. *E. coli* O157:H7 is rarely found.

According to a major producer, the commercial beef jerky products available at retail in New Zealand are manufactured to US guidelines, which include a lethality heat treatment. The marinating and drying processes have also been shown to be bactericidal to pathogens. It could be argued that such products are cooked and therefore outside the scope of this discussion document. However, the vast majority of scientific literature and regulations currently available for dried meats focus on the manufacture of jerky. Biltong and droëwors are first cured then dried at lower temperatures, but if processed correctly, the resulting product does not allow for the growth or survival of pathogens.

There is potential for microbial growth in dried meat products during the period before drying has reduced the a_w sufficiently to prevent growth. There is a wide variety of processes used to manufacture dried meats, but most involve the addition of agents such as salt, sugar, vinegar, and spices prior to drying. With the exception of salt or acid tolerant organisms, such as *S. aureus*, these additives are likely to at least inhibit microbial growth during the pre-drying stages. Storage at chilled temperatures during this period will also inhibit microbial growth. Drying of the meat reduces the numbers of microorganisms, as well as preventing subsequent

growth. Several studies have shown that treatments such as marination and the addition of curing mixes can enhance pathogen reduction during drying. While growth (or toxin production) prior to drying cannot be entirely ruled out, the information in this report suggests that the amount will be modest.

Published studies have shown that simply reducing a_w to <0.85 does not necessarily achieve desirable reductions in pathogen numbers, although this level of a_w is required to prevent growth during future storage. Times, temperatures, and relative humidity of drying must also be considered. D values for foodborne pathogens in meat have been reviewed by ESR for MPI (McIntyre *et al.*, 2011).

It is not currently possible to estimate the risk to New Zealanders of exposure to pathogenic microorganisms through consumption of uncooked dried meat products. Available information suggests that these foods are infrequently consumed in New Zealand, although the food consumption information (1997 and 2002 National Nutrition Surveys) is now quite old and information from the soon to be released 2009 National Nutrition Survey may provide fresh insights.

An unknown factor is the extent of home-made production of both jerky and biltong. If these products have been prepared from meat of low microbiological quality, not dried to a sufficiently low a_w and stored improperly, the probability of exposure to pathogenic bacteria could be quite high.

While consumption of dried meat products has very occasionally been reported by notified cases of suspected food poisoning in New Zealand, no outbreaks have been reported, and there is no confirmed evidence for these types of food being a vehicle for infection. Outbreaks of illness due to consumption of dried meat products have been reported overseas, although numbers of cases have usually been quite low (Table 1).

5 AVAILABILITY OF CONTROL MEASURES

5.1 Risk Management Strategy

MPI has published Risk Management Strategies for *Salmonella*[18] and *Listeria*[19]. The *Salmonella* Strategy aims to achieve a 30% reduction in the reported annual incidence of foodborne salmonellosis after five years, while the *Listeria monocytogenes* Strategy aims to achieve no increase in the reported annual incidence of foodborne listeriosis after five years (2008-2012).

5.2 Current Risk Management Measures

5.2.1 Legislation

Businesses involved in the production of processed meat products, including uncooked dried meat products, must operate under one of the following regimes:

- An approved Food Safety Programme (FSP) under Section 8G of the Food Act 1981
- A registered Risk Management Programme (RMP) under the Animal Products Act 1999; or
- The Food Hygiene Regulations 1974 and local authority (Council) registration.

Processors may choose to operate under the Food Hygiene Regulations, or obtain an exemption from the regulation by operating an FSP approved by MPI. However, those that require an official assurance from MPI in order to export any processed meat product must operate under the Animal Products Act and have a registered RMP.

5.2.1.1 Food Act and Food Hygiene Regulations

Historically, food premises have been inspected against the Food Hygiene Regulations 1974. Since 1996, there has been an option to develop a Food Safety Programme (FSP)–based on HACCP principles-which exempts the food business from the 1974 Regulations. A FSP is registered under the Food Act 1981. The process is applicable to any size or type of food business in New Zealand.

A long term review of the domestic food regulatory regime in New Zealand is underway. Termed the Domestic Food Review (DFR), one of the proposals is the introduction of Food Control Plans (FCPs) to supersede the Food Safety Programme regime. Alternative arrangements would account for those businesses already with HACCP based systems in place such as Risk Management Plans (RMP).

Manufacturers of ready-to-eat meat products have been identified as a food sector for which custom made registered FCPs will be required.

5.2.1.2 The Animal Products Act and risk management programmes (RMPs)

The *Animal Products Act 1999* regulates the processing of animal material into products for use, trade, and export through managing associated risks and facilitating overseas market

[18] http://www.foodsafety.govt.nz/elibrary/industry/salmonella-strategy_2010-13.pdf accessed 22 June 2012
[19] http://www.foodsafety.govt.nz/elibrary/industry/Listeria_Risk-Aims_Help.pdf accessed 22 June 2012

access.[20] The Act requires all animal products traded and used to be "fit for intended purpose". The main means for ensuring that animal products are fit for their intended purpose is by requiring that the production and processing of animal materials and products occurs under a registered risk management programme. Enquiries have revealed that some dried meat manufacturers are currently operating under a risk management programme, and Part 2 of the Act provides for the registration and verification of these risk management programmes.

Part 4 of the Act provides for the setting of standards that must be met before an animal product can be considered fit for intended purpose, and for the setting of any specifications necessary to ensure the standards are met. The New Zealand animal product standards are contained in the Animal Products Regulations 2000 (Section 5.2.1.2) and the Australia New Zealand Food Standards Code (Section 5.2.1.3).

The *Animal Products Act 1999* defines a risk management programme (RMP) as a programme designed to identify and control, manage, and eliminate or minimise hazards and other risk factors in relation to the production and processing of animal material and animal products in order to ensure that the resulting animal product is fit for intended purpose. RMPs must manage risks from hazards to human health, animal health, false or misleading labelling and risks to the wholesomeness of animal material or product.

A RMP is based on the principles of HACCP: Identifying the hazards, the systems of control, and demonstrating that the controls are effective. The Act requires that RMPs are tailored for each animal product business according to the animal materials used, the processes performed and the product range produced. Operators must build any relevant regulatory limits (e.g. microbiological limits) into their RMP, but can also set their own measurable limits to ensure the food is safe and fit for purpose.

5.2.1.3 **Australia New Zealand Food Standards Code**

The Australia New Zealand Food Standards Code, Standard 1.6.1 contains microbiological limits for cooked processed meats and uncooked comminuted fermented meats, but not for uncooked dried meats.

5.2.2 Guidelines and codes of practice

5.2.2.1 **Ministry of Health criteria (1995)**

The New Zealand Ministry of Health has published microbiological criteria for foods intended as a guide for food producers where no mandatory standard exists (Ministry of Health, 1995). There are microbiological criteria for 'manufactured, cured or fermented meat – ready-to-eat'. This appears to be the best match to the foods addressed in the current discussion document. The criteria for this food category are listed in Table 3.

[20] The Act may be viewed at http://www.legislation.govt.nz (accessed 9 March 2011).

Table 3: Ministry of Health microbiological reference criteria applicable to manufactured, cured or fermented meat – ready-to-eat

Organism	Organisms per:	Criteria*			
		n	c	m	M
Bacillus cereus	g	5	2	10^3	10^4
Campylobacter	10 g	5	0	0	
Clostridium perfringens	g	5	2	10^2	10^3
Coagulase producing staphylococcus	g	5	2	10^2	10^3
Faecal coliform	g	5	2	20	2×10^2
Listeria monocytogenes	25 g	5	0	0	
Salmonella	25 g	5	0	0	

* n = the minimum number of sample units that must be examined from a lot of food; c = the maximum allowable number of defective sample units; m = the acceptable microbiological level in a sample unit (values above it are marginally acceptable or unacceptable); M = a microbiological criterion which separates marginally acceptable quality from defective quality. Values above M are unacceptable in the terms of the sampling plan and detection of one or more samples exceeding this level would be cause for rejection of the lot.

5.2.2.2 FSANZ guidelines (2001)

FSANZ has produced generic guidelines for the microbiological examination of ready-to-eat foods that apply to foods sampled at the point of sale or distribution to consumers (FSANZ, 2001).

5.2.2.3 Processed meats code of practice

This Code of Practice (COP) has been developed by MPI and the Pork Processors Association[21]. It has been developed to assist meat processors comply with the requirements of the Food Act 1981 and the Animal Products Act 1999 (APA), and produce processed meats from mammals, ostriches and emus that are safe and suitable for their intended purpose. It provides guidance on Good Manufacturing Practice (GMP), process control, and the application of HACCP principles for the production of processed meats, including smallgoods. The COP specifically mentions dried meat products as examples of processed meat products covered by the COP.

As well as specification of hygienic measures, the COP includes provisions for ingredient and product testing to "demonstrate achievement of relevant regulatory limits or operator-defined limits documented in the FSP or RMP". A section on environmental testing is currently pending.

Section 4 (HACCP Application) of the COP contains a section on 'HACCP Application for Manufacture of Beef Jerky'. This section references the 'RMP Model for Beef Jerky', which is currently pending.

The drying procedure for commercial jerky is subject to compliance with a Risk Management Plan if operating under the Animal Products Act 1999, or if operating under the Food Act 1981

[21] http://www.foodsafety.govt.nz/elibrary/industry/processed-meats-code-part-4/ accessed 22 June 2012

compliance with Food Hygiene Regulations (FHR) 1974 or the manufacturer's own Food Safety Programme is required. The New Zealand Food Safety Authority (NZFSA) Processed Meats Code of Practice[22] provides guidance on GMP, process control and the application of HACCP principles for the production of processed meats which include dried meat products such as jerky and biltong as well as dry-cured meat products (e.g. prosciutto). Standard 1.6.2 of the Food Standards Code (which is mandatory only for Australia) requires dried meat (excluding slow dried cured meat) to be dried to $a_w \leq 0.85$ so that the growth of all bacterial pathogens of concern is controlled but does not include slow dried cured meat. According to the Code of Practice most commercially produced jerky in New Zealand has a_w of 0.75-0.80.

Biltong is produced by a slow air-drying of the salted and/or marinated raw meat, therefore there is no heat treatment or pathogen lethality step, although production must still comply with Standard 1.6.2 of the Food Standards Code. Van der Riet (1976) found that no microbial growth or spore germination was detected on biltong samples with a_w of ≤0.7. Allowing for an arbitrary safety margin, a_w of 0.68 was regarded as the critical moisture content at, or below which, biltong could be kept for long periods. Using values published by Van der Riet *et al.* (1976), Burfoot *et al.* (2010) demonstrated the relationship between critical moisture content of biltong, added salt water and salt content of the final product. For example, biltong created from meat with 1% added salt and then dried to 20% moisture content would have a salt content of 3.3% and could be microbiologically stable. Meat with 4% added salt and dried to 28% moisture content would have a salt content of 11.1% and would also be microbiological stable. Biltong containing 6% salt and 24% moisture was noted to be acceptable and would be typical of the products available at that time (Burfoot *et al.* 2010).

5.3 Risk Communication

Education is currently an actively used form of risk management, especially for pregnant women and other groups with lowered immunity. Direct education campaigns by MPI about food safety for pregnant women[23] and people with low immunity[24] are already in place and specifically identify processed meat products as high risk foods. For pregnant women, much of the focus of the document is on reducing risks of listeriosis, although for dried meats toxoplasmosis might be an additional consideration. Data on the presence of *Toxoplasma* cysts in red meat and meat products to estimate the exposure of the New Zealand population has been previously found to be lacking (Lake *et al.,* 2002).

[22] http://www.foodsafety.govt.nz/elibrary/industry/processed-meats-code-part-4/processed-meats-cop-part-1.pdf Accessed 21 May 2012.
[23] http://www.foodsmart.govt.nz/elibrary/Pregnancy_booklet_revised_Aug08.pdf accessed 22 June 2012
[24] http://www.foodsmart.govt.nz/elibrary/lowimmunity.pdf accessed 22 June 2012

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7 APPENDIX 1: HAZARD AND FOOD

7.1 Types of Dried Uncooked RTE Meats

Much of the material in the following sections is summarised from Burfoot *et al.* (2010).

Biltong

Biltong is an uncooked, air-dried meat product widely consumed in South Africa. Biltong is a ready-to-eat (RTE) product consumed mainly as a snack. It is not re-hydrated or cooked prior to consumption, unlike some other dried meats. Many meat species, meat cuts, and seasonings are used in the manufacture of biltong. Biltong is most often made from beef or game meat (antelope, ostrich, other exotics including elephant and giraffe) (Van der Riet, 1982). Most muscles in the carcass may be used but the large ones are most suitable. Young animals are suggested for use to avoid toughness. Lean meat is recommended as fat can affect salt uptake and cause the development of off-flavours due to oxidation. However some consumers like this taste.

Salt is the main curing ingredient, but spices are usually incorporated in the marinating mixture. In its very simplest form, biltong has been spiced only with salt, black pepper and brown sugar. Vinegar and roasted coriander feature in many recipes as key ingredients whilst a vast range of other seasonings have been mentioned, including those which help differentiate product flavour, such as chilli, garlic, or Worcester sauce, to give the consumer a variety of choice. Additives and preservatives featured throughout the literature include nitrate, nitrite, boric acid, pimaricin and potassium sorbate.

Salt content of commercial biltong has been reported to be in the range 3 to 13%.

Studies suggest that microorganisms are not involved in flavour development and that microbial inhibitors may be added as a preservative without affecting biltong flavour, taste and aroma (Prior, 1984).

A traditional method used in home-style preparation of biltong and a modern method often used in larger scale factories have been differentiated. Essentially, the home-style method involved dipping the meat pieces in cider vinegar for 30 seconds, draining, then spreading the spices (black pepper, salt, coriander, brown sugar) on each side of the meat. The modern method involved combining the vinegar and spices together in a marinade that is then applied to the meat.

Most references recommend cutting the meat into strips along the grain but notably one study mentioned better appearance and eating quality when cut across the grain. Meat strips cut from intact muscles are up to 400 mm long and 25 to 50 mm thick. The strips may be smaller depending on the cut of meat.

The composition of biltong after drying is typically: moisture content (20 to 30%); salt (3 to 8%); pH (5.6 to 5.9); a_w (0.7 to 0.75).

Droëwors

Droëwors, translated as "dried sausage" is a shelf-stable ready-to-eat dried beef product developed in South Africa. To make droëwors, small pieces of beef are obtained from trimming and/or grinding, seasoned with salt and ground coriander seeds, stuffed into casings and dried. The sausages are made thin rather than thick as thinner sausages dry more quickly and are thus less likely to spoil before it can be preserved. Some traditional recipes state that the sausages are dipped into a mixture of boiling water (4.5 L) and vinegar (350 ml) prior to hanging the sausages over wooden rods that are thick enough in diameter to prevent the inner sausages from touching. The sausages are then dried at ambient temperatures for 24 h and then often rolled across a cutting board to flatten, so that that any pockets of air in the sausage are removed to prevent mould growth. The sausages are then left to continue to dry over the rack for approximately two weeks. Droëwors do not have the same content of curing agents that is found in traditional cured sausage and therefore it is recommended that droëwors should not be kept in moist conditions as mould can begin to form more easily than would happen with a cured sausage.

Jerky

Like biltong, jerky is ready-to-eat and today it is a popular snack, particularly in North America. Also like biltong, it can be made from various species (beef, poultry, venison, game animals, crocodile), various forms of meat (thick or thin slices, ground), various marination techniques (ingredients, volume, time, temperature) and various drying processes. Many variants have been developed including ground, sausage-type products in casings.

Jerky undergoes a heat processing step and may be considered to be a cooked product. A survey of small and very small scale producers in the US found that many processing schedules involved cooking the product to an internal temperature of 73.9°C or holding the product above 71.1°C for several hours (Lonnecker *et al.*, 2010). Sodium nitrite was commonly used.

USDA (2007) guidelines propose a maximum a_w of 0.85 and maximum moisture:protein ratio of 0.75:1 for jerky. Jerky surveyed in the US was found to have salt content in the range 2.1-11.5%, pH 5.0-6.6 and a_w 0.51-0.90 (Lonnecker *et al.*, 2010).

Charqui (Charki)

Charqui comes from South America, with much produced in Brazil, and differs from biltong in that it is a fatty product. A traditional approach to making charqui has many similarities to that used in the dry curing of bacon. A fresh side of beef is cut into three pieces that are butchered open and cut into strips similar to biltong and then hung to cool at ambient temperature for about an hour. The strips are immersed in brine for a further hour, drained, dipped in coarse dry salt, stacked 1-1.5 m high, covered in salt and left overnight. The piles are turned daily for 4 days with strips from the top going to the bottom and vice versa and the piles re-covered with salt. Drying begins on the fifth day when meat is hung over drying racks and exposed to the sun for no longer than 1 to 2 hours. It is removed from the racks and piled about 1 m high under a tarpaulin for 2-3 days to "cure". This drying and curing is repeated 5-7 times until the meat has lost 40% of its fresh weight. The best grade final product contains 20-35% fatty tissue.

Pemmican

Pemmican is a cold environment equivalent of other dried meat products, originally invented by Native Americans. It is described as consisting of dried meat of buffalo, caribou, deer and later beef, which was packed in melted fat into specially made rawhide bags. The meat was dried in the sun and pounded or shredded prior to being mixed with the melted fat. This preserving method is based on the air exclusion provided by the fat, which reduces oxidative changes and diminishes microbial growth. Pemmican was flavoured and partially preserved by the addition of dried, acidic berries. Sometimes dried fruits such as currants are added to improve palatability. It is no coincidence that this dried meat was used in regions where low temperatures slowed down rancidity development and the high calorific value provided extra energy often required in cold climates. In warmer zones this product would need to be refrigerated or heat processed.

Pastırma

Pastırma is a meat product made of salted and dried beef, typically consumed in Turkey and Egypt as well as other Muslim countries. It is also popular in some parts of the Soviet Union. In Turkey it is produced from September to November when conditions are more favourable (lower temperature, humidity, absence of flies). Meat from 5 to 6 year old beef cattle is used, taken from the hind-quarter within 6 to 12 h of slaughter. The meat is cut into long strips (500 to 600 mm) with a diameter not more than 50 mm. The strips are rubbed and covered with salt containing potassium nitrate and several slits are made in the meat to aid salt penetration. The strips are piled 1 m high and kept one day at room temperature. The process is repeated, turning the pile from top to bottom. The strips are then washed and air dried for 2 to 3 days in summer or 15 to 20 days in winter. After drying, the strips are piled up to 300 mm high and pressed with heavy weights for 12 h. They are dried for a further 2 to 3 days and pressed again for 12 h. Finally the meat is air dried for 5 to 10 days. After salting and drying, the surface of the meat is covered with a 3 to 5 mm thick layer of a paste called cemen (containing freshly ground garlic, helba, hot red paprika, kammon, mustard and water). Helba is used as a binder and the other ingredients are for flavour. The paste covered meat strips are stored in piles and dried for 5 to 12 days in a well-ventilated room. Approximately 80 kg beef gives 50 kg pastırma and the end product has 30-35% moisture and can be stored at room temperature for 9 months.

Tasajo

Tasajo is a salted meat based product made in Cuba as a version of charqui. Traditionally, the meat is salted then sun dried, a process that takes at least three weeks. Industrially, it is made by wet salting in a saturated salt brine (1%) for 8 h, dry salted, and finally hot air dried at 60°C until a 50% weight loss is achieved.

Nikku

Nikku is a dried product eaten in the Canadian Arctic, particularly by the Inuit population. It is one of a range of raw or partially cooked locally prepared traditional foods and derived from wild game meat. Traditionally, nikku was made by cutting caribou meat into strips and hanging them in the sun until dried. Seal meat has also been used.

Sou Gan/Rou Gan

These are Chinese dried meat products of which at least 30 different variants are known. Consumption is large and growing in popularity. They are valued for their flavour, storage (no refrigeration) and transport properties (light) as well their nutritive value. Products vary according to the species of meat, the type of technology and the spices used. Water activity can lie between 0.6 to 0.9 (Intermediate Moisture Food) or be less than 0.6 (Low Moisture Food). Three basic processes are used to achieve either dried meat slices, dried meat cubes or strips, or shredded dried meat.

Fenalår

Fenalår is a Norwegian style cured leg of lamb or mutton. Mutton can be bought in slices, pieces or whole leg. The product is salted and dried, and usually served sliced, alone or as an accompaniment to other food. Curing takes approximately three months. The product is considered to be similar to prosciutto, but uses mutton rather than pork.

Prosciutto

Prosciutto is the Italian word for ham and is almost always used for the uncooked, dry-cured ham (prosciutto crudo), (prosciutto cotto is cooked ham), in particular from central and northern Italy such as Prosciutto di Parma, Prosciutto di Emiliano and Prosciutto di San Daniele. It is also produced in Australia. Similar products are made in Spain (Jamon Serrano/ Iberico), Portugal (Presunto) and France (Jambon traditionale). Parma Ham on the other hand, is prosciutto from that area of Emilia-Romana defined by European law as the region of Parma and is regarded as perhaps the only true prosciutto.

Carne seca

Translated as “dried meat’ from Spanish. Dried salted meat, essentially the same as jerky.

Bak Kwa

Chinese salty-sweet dried meat similar to jerky, made in thin sheets.

Dendeng

Dendeng is thinly sliced dried meat in Indonesia. It is preserved using a mixture of sugar and spices, and drying through a frying process.

8 APPENDIX 2: OVERSEAS CONTROL MEASURES

8.1 USA

Following a jerky-related salmonellosis outbreak in 2003, the United States Department of Agriculture (USDA) introduced Compliance Guidelines for Meat and Poultry Jerky Produced by Small and Very Small Plants (USDA, 2007).

The Guidelines identify the importance of having a heating step that is separate from the drying processing, and the importance of this heating step being applied at high humidity. Lethality guidelines are referenced as a source of information on times and temperatures for heating (USDA, 1999).

The Guidelines identify seven production steps, at which some level of microbial intervention can be achieved:

- Strip preparation
- Marination
- Interventions e.g. preheating, antimicrobial chemical treatments
- Lethality treatment
- Drying
- Post-drying heat step
- Handling

The American Association of Meat Processors (AAMP) subsequently published a special report to provide interpretation of the Guidelines for their members and to offer suggestions of how the lethality treatment could be achieved:
http://www.meathaccp.wisc.edu/validation/assets/AAMP%20Jerky.pdf accessed 22 June 2012

USDA's Food Safety and Inspection Service have also prepared a factsheet on jerky food safety:
http://www.fsis.usda.gov/factsheets/jerky_and_food_safety/index.asp accessed 22 June 2012

8.2 European Union (EU)

Production of some varieties of dry-cured raw ham is strictly controlled through 'Protected Designation of Origin' (PDO), 'Protected Geographical Indication' (PGI) or 'Traditional Speciality Guaranteed' (TSG) specifications. A register of all products under designation in the EU is maintained in the DOOR database[25]. Examples include:

Prosciutto di Parma (Parma Ham)
http://www.parmaham.org/quality/guarantee-specifications.pdf
http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:C:2007:086:0007:0011:EN:PDF
http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:047:0006:0007:EN:PDF

Prosciutto di Sauris
http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:C:2009:188:0035:0037:EN:PDF

[25] http://ec.europa.eu/agriculture/quality/door/list.html

Bresaola della Valtellina
http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:C:2010:321:0023:0027:EN:PDF

Jambon de l'Ardèche
http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:C:2010:076:0036:0042:EN:PDF

While specifications do not specifically include food safety aspects, the high level of raw material and process specification is likely to contribute to production of safe product.