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LITERATURE REVIEW ON MICROBIOLOGICAL HAZARDS ASSOCIATED WITH BILTONG AND SIMILAR DRIED MEAT PRODUCTS

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Summary

Biltong can be made using several similar approaches. The traditional method involves marination followed by air drying at low temperatures, around 35ºC, for one week. Other dried meats are available with jerky being the most common. Jerky is produced by marinating, cooking, and then drying the meat at high temperature (above around 60ºC). Both meat products can be produced from a variety of meats but beef is the most common.

Surveys of commercial biltong have shown total viable counts up to 7 log cfu/g; *Enterobacteriaceae* and coliforms up to 4 log cfu/g; yeasts up to 7 log cfu/g; moulds up to 5 log cfu/g; lactic acid bacteria up to 8 log cfu/g; and *Staphylococci* up to 8.5 log cfu/g. Pathogens have occasionally been found in biltong samples: *Salmonella* Dublin was isolated from a 6 month old biltong sample. In experimental work, reductions of *Salmonella* up to 3 log; *E. coli* up to 3 log; *L. monocytogenes* to 4.5 log; and *S. aureus* to 6 log have been found in making biltong. Pathogen reductions increase as water activity is reduced and rely on both the marinade and drying processes.

The two published surveys of commercial jerky showed few samples testing positive for *Salmonella* and *Listeria* and no samples showed *E. coli* O157 or *S. aureus*. The marination reduces the numbers of pathogens. Moist heat cooking before drying also reduces microbial numbers on jerky. Drying at 77ºC after marination and cooking leads to the recommended 7 log reduction in *Salmonella*, 5-log reduction in *E. coli* O157 and elimination of *L. monocytogenes*.

All studies have found that microbial counts reduce during storage. *Toxoplasma gondii* was not a concern if the meat had been previously frozen, adequate salt had been used in the marinade, and sufficient heat treatment had been used.

Guidance on the small scale production of biltong was not available but considerable advice has been prepared by the USDA on making jerky. Conclusions from published papers and guidance documents on biltong and jerky are summarised in this review. Quality raw materials, both meat and spices, must be used and stored correctly. Preparation practices must be hygienic to avoid cross-contamination. Acidic marinades should used be at 0 to 4ºC.

The air for drying biltong should be heated to around 35ºC, depending on the ambient conditions. Solar drying or using unheated air are not suitable for the UK climate. Drying to a water activity of 0.7 to 0.75 is advisable. Weight loss of the meat should be a good indicator of water activity. Jerky should be prepared according to the USDA guidelines that are summarised in this review.

Experience in working with small scale producers raises concerns that drying meats is often seen as a way of using trimmings. High quality meats must be used. Despite receiving enquiries on drying whole meat strips, more enquiries are received on making fermented meats and sausages and these raise additional concerns.

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1. Introduction

The small scale manufacture of biltong, a slowly air dried meat, is causing concern in the UK. As part of its strategy to ensure that food produced and sold in the UK is safe, the Food Standards Agency is considering providing guidance to Local Authorities for them to use in dealings with small food businesses that are manufacturing biltong, or similar dried meat products. Any guidance would need to be based on sound scientific evidence.

The purpose of this report is to provide a review of the literature in the following areas:

- Types of biltong, similar dried meat products, and their ingredients
- Processes in manufacture and equipment needed
- Identification of microbiological hazards and control factors
- Summary of outbreaks around the world involving biltong and similar products
- Published guidelines on manufacture and HACCP
- Estimated size of the market for biltong and similar product

The structure of the report follows this format.

One hundred and seventeen research papers and reports were used in the review. Contact was also made with university researchers working on dried meats in the South Africa (biltong) and Northern America (jerky). This provided several papers that are currently undergoing peer review or awaiting publication. Questions were also put to companies making or selling dried meats or the associated seasonings.

By far the greatest amount of research has been carried out on the microbiology of jerky produced in laboratories using procedures to simulate commercial, modified commercial, or domestic approaches. This research is mostly from North America and it is noticeable that there remains an interest in this subject. Much less work has been published on biltong. Most of this research, and surveys, was carried out in the 1970s and 80s in South Africa but very recent work is still ongoing. Little published information is available on the detailed microbiology of other dried meats and this probably reflects the much greater sales of jerky and biltong compared to other products. The emphasis of this review consequently lies in biltong and jerky.

2. Types of biltong and similar dried meat products

This section reviews the types of biltong and similar dried meat products that include: biltong (South Africa), jerky (United States), charqui (South America), pemmican (North America), pastirma (Turkey, Egypt, Russia), tasajo (Cuba), nikku (Canadian Arctic), sou nan and rou gan (China), carne seca (Mexico), fenalår (Norway). The emphasis of this section is on biltong because guidance on producing this product has been requested specifically. Considerable information has been included on jerky because it is a dried meat that is widely consumed in the US and has led to several outbreaks of illness.

2.1 Biltong

Biltong is an uncooked, air-dried meat product widely consumed in South Africa. The earliest written reference to "biltong" is from 1851: the word is derived from the Dutch "bil" (posterior thigh, rump) and "tong" (strip, tongue-shaped) (van der Heever, 1970). Biltong is not defined in any legislation in the UK or elsewhere but it is covered by the Food Regulations requiring that food is safe. Biltong's origins anecdotally stem from the Dutch who, whilst escaping from British rule in South Africa some 200 years ago, preserved meat by adding vinegar and spices and hung it from the back of ox wagons where it dried over 3 to 4 days.

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 and, unless manufactured and stored safely could be a source of potential food-borne pathogens. Many meat species, meat cuts, and seasonings are used in the manufacture of biltong (see Table 1). Biltong is most often made from beef or game meat (Leistner, 1987). Most muscles in the carcass may be used but the large ones are most suitable.

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 (Table 1) 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.

Van den Heever (1970) analysed 60 commercial biltong samples and found salt contents between 3 and 13% (average, 6.6%). Van der Riet (1976) analysed 20 commercial samples and found salt contents between 3.5 and 7.7 (average, 5.6%). Studies of 25 samples imported from South Africa (Shin and Leistner, 1983; Shin, 1984) showed salt contents of 5 to10% (average 7%), little sugar and nitrite, and 10-860 mg/kg nitrate which was considered unnecessarily excessive and ineffective in this form. Considering all of the literature surveyed, the overall range of salt contents found in commercial biltong samples was 3 to 13% (Table 3).

Prior (1984) treated beef with various antibiotics to restrict microbial growth in a study to assess the role of micro-organisms in biltong flavour development; some meat products, for example fermented meats, deliberately use micro-organisms in the creation of characteristic flavours. Although there were significant increases in the free amino acid and free fatty acid content of biltong made with and without antibiotics, there were no significant differences between each type of biltong suggesting that micro-organisms are not involved in flavour development and that microbial inhibitors may be added as a preservative without affecting biltong flavour, taste and aroma.

Naidoo and Lindsay (2010) differentiate between a traditional method used in home-style preparation of biltong and a modern method often used in larger scale factories. 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.

Overall, biltong can be defined by the following characteristics:

- Sources of meat are varied and include beef, antelope, ostrich, other exotics including elephant and giraffe. Most commonly, beef is used.
- Young animals are suggested to avoid toughness
- Both fresh and thawed meats can be used
- 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.

- Various muscles are used including fillet, rump and sirloin which tend to be used by connoisseurs but the most commonly used cut comes from the hindquarter: the semimembraneous muscle.
- 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.
- The 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.
- Salt, black pepper, coriander, brown sugar and vinegar are often used as ingredients with a vast array of other seasonings included according to personal preference and consumer variety.
- The use of nitrate or nitrite, often in the form of saltpetre is mentioned frequently as a source of colour enhancement. A variety of other additives and preservatives are mentioned. Any used in the UK would have to comply with relevant legislation.
- Traditional biltong making involves marination followed by low temperature drying but other approaches have been suggested and tested (see Section 3).
- The composition of biltong after drying is considered in Section 3 but typical values would be: moisture content (20 to 30%); salt (3 to 8%); pH (5.6 to 5.9); water activity (0.7 to 0.75).

2.2 Jerky

The term jerky is variously referred to as jerkey, jerked beef, charqui and even as biltong. Charqui, a dried fatty product, originated in South America whilst jerky was made by North American Indians who smoked meat over fires and sun dried it to give a characteristic smoky flavour (Thomas,1975).

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 (Calicioglu *et al*, 2002). Many variants have been developed including ground, sausage-type products in casings. These are outside the scope of this review as they have issues not associated with dried single pieces of meat.

Calicioglu *et al* (2002), in a research study, used the following recipe as being a traditional marinade for jerky: 60ml soy sauce, 15ml Worcester Sauce, 0.6g black pepper, 1.25g garlic powder, 1.5g onion powder, 4.35g hickory smoked salt, all per kg meat. The smoke flavour was provided by an ingredient. A study by Bower *et al* (2003) found the inclusion of 15% raisins in ground beef jerky gave improved antimicrobial properties by reducing pH to 5.4 and water activity to 0.64. Antioxidant and sensory properties were also enhanced.

USDA (2007) guidelines propose a maximum water activity of 0.85 and maximum moisture :protein ratio of 0.75:1 for jerky. Ingham et al (2006), in a survey of commercial products, found that 7 out of 15 samples had water activity above the recommended limit and 8 samples had a higher moisture:protein ratio than recommended. Two products had no ingredient declaration and of the remaining, one contained only two ingredients (beef and salt), ten products contained water; eight contained one or more sweeteners, and eleven products contained salt and various flavour ingredients including monosodium glutamate which was found in six products. Garlic was common to nine products and nine were cured with sodium nitrite (often with sodium erythorbate added). Three products contained soy sauce or teriyaki, five contained vinegar and two contained citric acid. One product had been dipped in potassium sorbate to prevent mould growth and ingredients unique to only one product included apple juice, papaya juice, Worcester sauce, wine, succinic acid, paprika and tomato powder.

A sample of jerky purchased at a major UK retail outlet had an ingredient list consisting of beef, water, sugar, salt, apple cider vinegar, maltodextrin, black pepper, garlic powder, onion powder, flavour enhancer: hydrolysed corn gluten protein, monosodium glutamate, citric acid, stabiliser: sodium tripolyphosphate, preservative: sodium erythorbate, sodium nitrite. An oxygen absorber sachet was included in the pack.

Overall, jerky can be defined as a meat product made from a wide variety of species and seasonings with beef being the most common type of meat. It is currently most popular in North America. Although it is similar to biltong in being a dried meat it is different in being dried at a higher temperature or smoked/cooked before drying.

2.3 Other dried meats

2.3.1 Charqui (Charki)

Charqui comes from South America, with much produced in Brazil, and differs from biltong in that it is a fatty product (Thomas, 1975). 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 5^{th} 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 1m 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. The literature is unclear whether charqui or the 'jerkey' made by the North American Indians was the original product.

Yet another definition of charqui is given by the International Dictionary of Food and Cooking (1998) as smoked and sun dried strips of beef or venison and again the term is used synonymously with jerked beef, chipped beef, jerky and jerked meat.

2.3.2 Pemmican

Pemmican is a cold environment equivalent of other dried meat products, originally invented by the American Indians. It is described by Borgstrom (1968) 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. Product supplied to polar travellers is basically the same but made from beef. 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 high calorific value provided extra energy often required in cold climates. In warmer zones this product would need to be refrigerated or heat processed.

2.3.3 Pastirma

Pastirma is a meat product made of salted and dried beef, highly esteemed in Turkey and Egypt as well as other Moslim countries (Leistner, 1987)). 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 years old beef cattle is used, taken from the hind-quarter within 6 to12 hours 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 hours. They are dried for a further 2 to 3 days and pressed again for 12 hours. Finally the meat is air dried for 5 to10 days. After salting and drying, the surface of the meat is covered with a 3 to 5mm 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 to12 days in a well-ventilated room. Approximately 80 kg beef gives 50 kg pastirma and the end product has 30-35% moisture and can be stored at room temperature for 9 months.

2.3.4 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 hours, dry salted, and finally hot air dried at 60°C until a 50% weight loss is achieved (Chenol et al, 2007).

2.3.5 Nikku

Nikku is a dried product eaten in the Canadian Artic, particularly by the Inuit population. It is one of a range of raw or partially cooked locally prepared traditional or ‘country’ foods 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 (Forbes et al., 2009).

2.3.6 Sou Gan

Sou gan are Chinese dried meat products of which at least 30 different products are known (Leistner, 2007). Consumption is large and their popularity is growing. 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. Product and process details are outlined in Table 1.

3. Processes

3.1 Process used in the making of biltong and jerky

3.1.1 Biltong

The production of biltong involves a series of steps including meat preparation, marination, and low temperature drying. The raw meat needs to be tempered or thawed if it is frozen. Selected cuts of meat are then cut into long strips and fat is trimmed from the meat as it may go rancid during subsequent processing and storage. Once the meat strips have been prepared, there are a number of variations of the marination method. The strips may be:

(a) dipped in dry spices (Taylor, 1976; van der Riet, 1981),

(b) dipped in dry spices then a hot acidic liquid, such as vinegar (Leistner, 1987)

or (b) dipped in an acidic liquid, drained, and then dipped in dry spices (traditional approach, see Naidoo and Lindsay, 2010),

or (d) dipped in an acidic liquid/spice mix (modern approach, see Naidoo and Lindsay, 2010).

Salt is included in the spice mix in each case. Dipping is used in small scale manufacture but tumbling is more likely to be used by larger producers. The meat can be hung up for drying immediately after dipping in the spices or it could be left resting in the mixture, preferably at refrigerated temperatures, and then removed and dried.

3.1.2 Jerky

Meat for making into jerky can be pieces from whole muscle or pieces made from chopped and formed meat. Many different approaches have been suggested for preparing jerky but all include drying at an elevated temperature:

(a) marinate the meat and then dry at an elevated temperature (Holley, 1985; Harrison et al., 2001). This is the traditional approach

(b) marinate, dry at elevated temperature, then high temperature heating (Harrison, 2001)

(c) marinate, boil, dry (Harrison, 2001)

(d) marinate, heat at high temperature, dry (Harrison et al., 2001)

(e) dip in acid, then marinate, then dry (Caliciouglu et al. (2002)

(f) heat in marinate, dry (Harrison and Harrison, 1996)

(g) boil, marinate, dry (Albright et al., 2003)

(h) dry a commercial meat batter containing spice (Harper et al., 2009; Borowski et al., 2009a,b).

Moves away from the traditional treatment of just marinating and drying the meat at an elevated temperature have been studied in the US as ways to reduce risk. USDA guidance (2007) for beef involves cooking to an internal temperature of 71ºC in an oven or marinade prior to drying. At that temperature, the USDA (2007) states that a 7 log reduction of *Salmonella* will be achieved instantaneously. An equivalent temperature-time treatment may be used (USDA, 2007). A further heating step is then proposed at an even greater temperature (135ºC) if the initial cooking step has not been to the required temperature-time treatment.

3.2 Process conditions important in making dried meats

Creating safe dried meats relies on achieving the correct balance of several parameters during processing and storage. This concept of using two or more factors to control or inhibit microbial growth is called hurdle technology (Betts and Everis, 2008). Using this concept, each hurdle can be applied at reduced levels to produce products that are safe and stable. The factors that could be controlled are: temperature, time, water activity (moisture content), pH (a measure of acidity), preservative content, competitive microorganisms, redox potential (a measure of the tendency to gain or lose electrons), and irradiation. In the case of dried meat products such as biltong, competitive microorganisms are not used; redox potential is difficult to measure and not used; irradiation is outside the scope of this report; and preservatives have been covered in Section 2. Values of the remaining factors are considered below.

3.2.1 Conditions used during marination

Table 2 shows the conditions used in the marination of biltong. The meat is generally held in a marinade for 18 to 24 hours, traditionally at ambient temperature, but nowadays, this storage is more likely to be at 4ºC.

For jerky, strips of whole muscle are traditionally marinated for 12 to 24 hours (Table 3). As for biltong, marination is at refrigeration temperatures (4ºC). Some authors suggest boiling the meat prior to marination (Albright et al., 2003) and others have suggested boiling the meat in the marinade (Marchelo and Garden-Robionson, 1999; USDA, 2007) or placing in a hot acidic solution after marination (Albright et al., 2003).

Jerky made from reformed meat is not marinated at it would disintegrate, instead, the spice mix is incorporated into the meat blend. The most complete survey of small and very small scale commercial jerky processing is presented by Lonnecker et al. (In press). They contacted 78 plants in the US Mid-West: 37 responded and 33 plants provided a total of 61 samples of which 56% were whole muscle jerky and 44% were from chopped and formed meats. None of the plants boiled the meat in water or a marinade.

3.2.2 Conditions used during the drying of the meat

General Factors

The drying step is very important. Water activity, which is related to the moisture and salt content of the product, is an important parameter in achieving a safe product. The water activity of raw meat is around 0.98 and this is ideal for the growth of many microorganisms. Few pathogenic microorganisms grow below a water activity (a_w) of 0.90 and few microorganisms grow below $a_w = 0.75$. Yeasts and moulds do not grow below a water activity of 0.60. Consequently achieving a low water activity in a short time is a main goal to create a safe product.

Effective drying, to reduce water activity, relies on drying time and three inter-related process factors: air temperature, relative humidity, and speed. The moisture content of a product during drying can be calculated from a set of equations. Solving these equations together requires a good mathematical knowledge, nonetheless, they can be used individually to explain why certain factors are important (see for example Fulton et al., 1987).

The rate of drying is expressed by the following equation:

$$\text{Rate of drying} = h_m A (a_w p_s - p_a)$$

where

h_m = surface mass transfer coefficient. This factor depends on air speed. Higher air speeds produce a higher mass transfer coefficient which lead to a higher rate of drying.

A = surface area of the meat. Thin strips have more surface area per unit weight than thick strips and will generally dry more quickly.

$a_w p_s$ = water activity x saturated vapour of the water at the surface temperature = vapour pressure of water at the meat surface

p_a = vapour pressure of water in the air

The rate of drying will be high if the difference between $a_w p_s$ and p_a is large. On a humid day, p_a is high and so the rate of drying is reduced. Similarly, as the product dries, the water activity (a_w) is reduced and the rate of drying falls.

The rate of heating of the meat is described by:

Rate of heating = $h A (T_a - T_s) - h_m A (\alpha p_s - p_a) \lambda$

= heat exchange due to temperature difference - heat exchange due to the cooling effect of the water evaporating from the meat

Using a high drying air temperature (T_a) causes a high rate of heating and high moisture loss from the meat surface: factors that would appear to be desirable. However, a high heating rate may dry the surface of the meat but moisture inside the meat cannot move quickly enough to the surface for it to be removed. As a result, the surface dries and becomes hard but the inside of the meat remains moist: a condition known as "case-hardening". In summary, higher air temperatures, higher air speed, and lower relative humidity tend to lead to shorter drying times but care is required to avoid case hardening. If this occurs, then extended holding at lower ambient temperatures is required to allow the moisture to equilibrate.

Drying of Biltong

Water activity is clearly important. Table 4 shows that, in the 1970s, commercially available biltong had a water activity between 0.60 and 0.96 with a mean value around 0.7 to 0.75. Reported moisture contents lay between 11.5 and 51.5%. The lower value would be associated with an extremely dry, flaky, product. In 1970, trade opinion was that moisture content should be 30% or more, for commercial reasons, whereas research from the 1940s had indicated that 20 to 30% was ideal (van den Heever, 1970). Osterhoff and Leistner (1984) found commercial sliced biltong had water activities between 0.67 and 0.87. They also report on a product with a water activity of 0.36 and moisture content of 3.6% which corresponds to a dry powdery biltong product. Individual retailers are now selling products marked as dry, medium, or wet, and there is a trend towards consumers preferring higher moisture products (Attwell, 2003).

Traditionally in South Africa, drying of biltong was achieved by hanging the strips of meat on hooks and leaving them to ambient dry. Nowadays, home made biltong may be made

using a biltong-drying unit (Naidoo and Lindsay, 2010) whilst large scale operations use commercial dryers. The colder moisture ambient conditions in the UK, compared with South Africa, are not conducive to the making of biltong in ambient conditions.

Average of the monthly minimum and maximum temperatures, and average of the monthly relative humidity in the morning and afternoon in Birmingham (UK), Johannesburg (SA) and Bloemfontein (SA).
www.bbc.co.uk/weather

Temperature, ºC						Relative humidity, %					
Birmingham UK		Johannesburg SA		Bloemfontein SA		Birmingham UK		Johannesburg SA		Bloemfontein SA	
Av Min	Av Max	Av Min	Av Max	Av Min	Av Max	Av am	Av pm	Av am	Av pm	Av am	Av pm
6.5	12.7	9.9	22.4	8.6	23.6	82.8	69.3	69.9	40.5	64.4	32.8

A warm dry environment is required for making biltong and Table 4 indicates that an air temperature of 35ºC will enable a microbiologically stable product to be produced in a around 6 days (144 hours). A lower air temperature would require a longer drying time and increase the microbiological hazard due to the slower drying rate.

Whilst a heater can be used to raise the air temperature for drying, relative humidity of the air (related to pa in the equation above) also needs to be considered. For example, in the UK, typical weather conditions in the Summer would be 18ºC and 65% relative humidity. Heating this air to 35ºC would produce a relative humidity of 24% which is below the 30 to 40% found in Table 3. The product would dry sufficiently in less than 6 days. The drier must be ventilated to allow fresh air to enter and some moist air to leave. Adjusting the rates of air intake and exhaust would allow the relative humidity to be controlled. For Winter weather in the UK, the temperature and relative humidity might be 4ºC and 85% relative humidity and heating this air to 35ºC would create a relative humidity of 12%. The product may become over-dried if all of the air is allowed to pass into the oven and immediately out again. Restricting the flow of air out of the drier and, perhaps, slightly reducing the air temperature may be required depending on the product moistness required and the need to prevent case-hardening. Allowing some of the air to recirculate in the oven would enable the relative humidity to increase.

The speed of the air in the equipment used for drying also affects the rate of drying through the mass transfer coefficient (discussed above) because it moves hot air towards the meat and

removes moisture from the meat surface and also from the drying equipment. Few data have been reported on the air speeds used in making biltong. Traditional ambient drying relied on the wind. Some driers produced for home use rely on the convective effect resulting from the heat source in the drier: in some cases, this is nothing more than an electric light bulb. Data reported in Table 4 suggest an air speed around 2.5 to 3 m/s. Lower speeds would reduce the drying rate but higher speeds would lead to little increase in drying rate because the rate of drying would be restricted by the rate at which moisture can move within the meat to the surface.

Figures 1 and 2 show the change in moisture content, water activity, salt content and bacterial numbers during the drying of biltong in air at 35ºC, 30% relative humidity and 3 m/s. A suitably dry product is achieved after 144 hours but the microbial load would likely decrease further with longer drying. Conversely, reducing the drying time to 72 hours (3 days) would create a product with a moisture content between 30 and 40% but the microbial load would be higher.

pH may also have an influence on the safety and shelf life of meat products. Fresh beef has a pH around 5.8, generally in the range 5.4 to 6.0. Table 4 shows that biltong from fresh meat retains it pH at around 5.6 to 5.9 unless some severe acidic treatment has been used in the preparation.

Thermal Processing of Jerky

A large range of thermal treatments for producing jerky have been investigated in the scientific literature (Table 5). All of this literature and information from commercial operations report on the use an elevated-temperature drying phase that is typical of jerky production. However, the drying phase is often precluded by a heating step. The heating step reduces the microbial numbers whilst the drying phase stabilises the product and prevents microbial growth (USDA, 2007). Compliance guidelines are provided on the correct temperature-time combination for the cooking of red meat and poultry (USDA, 1999). An example would be a minimum cooking time of 91 seconds after the beef has reached 65ºC or heating to a minimum of 71ºC: at that temperature the required lethality would be achieved instantaneously. The USDA (2007) is insistent that a moist cooking step is used prior to drying if these temperature-time provisions are used as supporting documentation for a

process. The USDA guidance to consumers (USDA, 2006) recommends steaming or roasting meat to 71ºC for beef and 74ºC for poultry prior to drying.

In the US, jerky has a legal identity requiring that the water activity is 0.85 or lower and this should control the growth of bacterial pathogens of concern (USDA, 2007). (This does not take into account any possible problems associated with drying rate, such as case-hardening or the growth of *S. aerueus* and production of toxin if the meat is not dried sufficiently quickly). Although the USDA regards water activity as the appropriate indicator to verify that the jerky has been properly dried, a moisture:protein ratio of 0.75:1 or less remains part of the standard of identity for jerky. Table 5 shows that in the past, some, but not all products, have had a water activity below 0.85. Moisture content of jerky has rarely been reported due to the emphasis on water activity and moisture:protein ratios. Harper et al. (2009) report moisture contents below 20% for jerky produced using simulated large scale and small scale operations. Porto-Fett found moisture contents of 35 to 48% but those products were only heated to 37 to 41ºC (i.e. below the USDA guidance) using air at 74 or 82ºC through the process (i.e. no separate heating and drying phases).

The conditions in the heating and drying phases of producing jerky are clearly important. Moist air at relative humidity greater than 90% and at an air temperature sufficient to enable the correct for temperature-time treatment (e.g. heating to 71ºC internal temperature) are criteria given by the USDA (2007) for the heating phase. A survey of small and very small commercial plants in the US Mid-West (Lonnecker et al., In press) found that many processors heated product to 74ºC and then it held for several hours at 71ºC. The least severe treatment that they encountered was using air at 52ºC for 45 min followed by air at 57ºC for 1 h. The severest treatment consisted of heating in air at 93ºC for 9.5 h. 95% of the plants surveyed claimed to control humidity using dampers, steam injection, addition of water, or a combination of both, in the moist cooking phase.

The most severe thermal treatment found in the literature was the USDA guidance (2007) which recommended a post-drying heating step using air at 135ºC for 10 minutes. This treatment is advocated to reduce *Salmonella* levels and to provide an adequate lethality when the initial heating phase has been insufficient to achieve a 7-log reduction in *Salmonella*.

Unlike the long ambient temperature drying associated with biltong, jerky is produced by moist heating and then elevated-temperature drying (above 71ºC in commercial systems) for relatively short times (typically up to12 h). Information on air speed used in drying was scarce and limited to statements such as "fans running at maximum". Final product pH was generally in the range 5.2 to 5.9 (Table 5).

3.3 Storage conditions for biltong and jerky

Storage of the product by the producer and the consumer is also important as biltong may re-absorb moisture if stored incorrectly. Van der Riet (1976) suggested that biltong with a moisture content less than 24%, or water activity less than 0.68, was microbiologically stable with rancidity limiting the shelf life at that moisture content. However, the product could reabsorb moisture if stored in warm, moist, conditions. Butchers in South Africa, and here in the UK, sell biltong loose in paper bags or over-wrapped trays. Products manufactured at large scale are packed with nitrogen flushing or vacuum-packed (Attwell, 2003) to maintain the shelf life.

No definitive shelf life for biltong was identified in the literature although “several months”, “very long” and “indefinite” were noted in the literature, all without the need for refrigeration. One commercial producer in the UK recommends that once the pack of biltong has been opened, it should be kept cool and consumed within 3 days, another advises storing in a cool dry place and consuming on the day of opening.

The USDA (2006) advises that commercially packaged jerky, manufactured in USDA inspected plants, can be kept for 12 months and homemade jerky for 1 to 2 months if produced using the methods outlined in Table 5 (cook and then dry the meat).

4. Equipment Required for Making Biltong and Jerky

The marinating process requires bowls or tumbling equipment and refrigeration facilities for storage should be at 4ºC.

For jerky, the meat may be heated in a liquid or in an oven capable of maintaining a moist air environment. The USDA (2007) guidelines state 90% relative humidity which commercial jerky producers aim to achieve by keeping the oven door shut, having a container of water in the oven, dripping or injecting small droplets of water into the oven or injecting steam (Lonnecker et al., In press). Methods of measuring the oven air temperature and humidity are required and a further temperature probe is needed to measure the meat temperature at the end of heating. A temperature probe may be left in a piece of meat throughout the heating period provided that this does not conduct heat into the food and result in a mis-leading temperature being indicated.

Drying of biltong has been traditionally carried out at ambient conditions in warm climate countries such as parts of South Africa. However, this approach is unsuitable in the UK and would not provide sufficient product control for commercial operations making biltong or jerky. A wide range of commercial units are available for drying foods, but a batch dryer using forced convection (a fan to blow the air) is most appropriate for drying biltong or jerky. Most producers are likely to use tray dryers in which meat strips are placed on mesh trays or hung on supports that are placed in the dryer. The latter is most likely. Drying rooms or "tunnels", with product on racks, are suitable for very large scale operations. Small butchers are likely to use ovens which provide little humidity control other than using door opening and speed of the fan. Specialised dryers, with dehumidifiers, are available and provide excellent control of humidity. These are very unlikely to be used by small scale producers as they are expensive to purchase.

Lonnecker et al. (In press) found that 34 (92%) of the jerky plants they surveyed used only a smokehouse for the thermal processing, three of the plants (8%) used a commercial oven and one manufacturer (3%) used an oven and a smokehouse. 35 of the plants (95%) claimed to be able to control humidity but only ten (27%) had a method measuring of humidity. During the drying period, humidity control would appear to consist of the opening of dampers or

doors to allow the release of moist air rather then any active dehumidifying system for the air within the dryer.

5. Microbiological issues

5.1 Biltong

Published data on the microflora of biltong found in surveys have been reviewed and their findings tabulated (Table 6).

Several studies assessed the levels of naturally present organisms in a range of different types of biltong (chicken, venison and beef) from a range of outlets including street vendors, small butchers producing biltong on-site, supermarkets, convenience stores and medium scale commercial producers (Mhlambi, Naidoo and Lindsay, 2010; Naidoo, K. and Lindsay, 2010a,b; Wolter *et al*, 2000). The surveys have shown that high levels of microorganisms are commonly observed in biltong with levels of Total Viable Count (TVC) ranging from 6 to 7 log cfu/g. Enterobacteriaceae and Coliforms were observed at a level of 3 to 4 log cfu/g. Yeasts were present at levels ranging from 2 to 7 log cfu/g and mould levels up to 5 log cfu/g were found. Lactic acid bacteria were found to be present at levels as high as 8 log cfu/g and *Staphylococci* counts ranged from 4 to 8.5 log cfu/g.

Not only were high levels of potential spoilage organisms observed, some of the surveys found that pathogens can also occasionally be detected in biltong. *Salmonella* was found to be present in about 3% of samples tested by Van den Heever (1970); *E. coli* was present in 45% of samples tested by Van den Heever (1970) and 1 of 45 samples (2%) tested by Abong'o and Mamba (2009); *L. monocytogenes* was found to be present in 1.3% of samples tested by Naidoo and Lindsay (2010b), and toxin producing *Staphylococci* were present in 2% of samples examined by Naidoo and Lindsay (2010b). Some authors have also noted that mycotoxin producing moulds can be present in biltong samples. Van der Riet (1976) found that 55% of the mould population present on 20 samples of biltong belonged to the *Aspergillus* group with 16 of 26 strains identified having the capability to produce mycotoxins.

In summary, these surveys show that commercial biltong may contain fairly high levels (4 log cfu/g or greater) of many spoilage organisms and occasionally samples may contain organisms capable of causing food poisoning including *Salmonella*, *E. coli*, and toxin producing *Staphylococci* and moulds.

As the raw meat used in biltong production may well contain pathogens, it is important that the product is manufactured correctly in order to prevent growth of these organisms and prevent subsequent toxin production by *S. aureus* which will not be destroyed during the drying process.

As described earlier, raw meat for biltong is marinated in mixes that contain salt and organic acids and then dried to achieve a reduced water activity as quickly as possible. The salt concentration increases due to the reduction in moisture. The presence of organic acids, salt, and a lowered water activity achieved by drying are all controlling factors in the potential destruction of pathogens and also important in preventing microbial growth. However, the study by Naidoo and Lindsay (2010b) (Table 7) demonstrates that salt, spices and the presence of organic acids as individual factors are not sufficient to prevent growth of *S. aureus* or *L. monocytogenes*. The studies show that salt levels of greater than 20% would be required to prevent *S. aureus* growth and growth of *L. monocytogenes* and *S. aureus* is not prevented in the presence of traditional organic acids like apple cider vinegar and brown spirit vinegar.

There have been a number of studies carried out that have assessed the reductions of *Salmonella*, *L.monocytogenes*, *S.aureus*, *E.coli* O157 achieved during processing. The findings of these studies are summarised in Table 8. The reductions achieved for *Salmonella* ranged from 2 to 3 log cfu/g; *E.coli* from 2 to 3 log cfu/g; *L. monocytogenes* from 2 to 4.5 log cfu/g; and *S.* aureus from 1 to 6 log cfu/g. The reductions achieved varied depending upon the method used as Naidoo and Lindsay (2010c) found that a greater reduction of *L. monocytogenes* was achieved more quickly when a traditional method was used (vinegar dip then spiced) compared with a modern method (vinegar and spice mixed), but the opposite was observed for *S. aureus.* The reduction in pathogen level will also vary throughout the drying processing with greater reductions achieved as the water activity lowers (Burnham et al, 2008).

A few studies have assessed the effectiveness of sorbic acid or potassium sorbate as inhibitors of yeasts and moulds. Van den Heever (1972) found inhibition of the growth of yeasts and moulds for 21 days but growth was eventually observed. However, Van der Riet (1981) did not observe growth for 6 weeks on preservative treated samples but growth occurred within 1 week for control samples. The addition of potassium sorbate could prevent mould growth, but

Taylor (1976) found that it did not prevent bacterial growth. The effectiveness is dependent on pH. Van der Riet (1981) suggests that 37% of sorbate can be lost during processing. However, the decrease in moisture content will increase the concentration in the final product and should be considered as a factor when deciding upon in-going concentrations.

Taylor (1976) and Naidoo and Lindsay (2010b) studied the dominant populations of microflora and found biltong to be pre-dominated by *Bacillus* and *Staphylococci*. Taylor (1976) studied the population during processing and found that *Pseudomonas* and *Achromobacter* dominated raw meat but, after 7 h of marination, the counts had decreased to 55% of the total population and at the end of drying accounted for just 3%. The *Micrococci* population started to increase and after 7 h pickling accounted for up to 21% of the population: after drying, the percentage was 88% of the total population. This study showed that organisms more resistant to the effects of drying and low water activity values will be those that are able to survive.

The studies assessing pathogen survival have shown that the pathogens can survive for prolonged periods of time in biltong. Van den Heever (1965) isolated *Salmonella* Dublin in 6 month old biltong and in the survey (Table 8) by Wesser et al (1957), *S.* Newport was still present at 24 months in biltong associated with a *Salmonella* outbreak. Studies have also shown that *S .aureus* is able to survive for 64 days (Van den Heever, 1970) and Naidoo and Lindsay (2010c) found that *S. aureus* was still detected after 96 h in samples processed by either a traditional or modern method of processing. *L. monocytogenes* was not detected.

In summary, biltong is likely to contain high levels of spoilage organisms and may contain food poisoning organisms. Whilst some significant reductions in pathogen levels have been observed, survival has also been demonstrated over prolonged time periods and processing method can influence the potential reduction in pathogen level. The reduction in pathogen level increases as the water activity decreases and therefore it is important that water activity is reduced quickly. Growth studies have demonstrated that salt, presence of organic acids and spices are not in themselves inhibitory and therefore a hurdles approach to biltong manufacture is important.

5.2 Jerky

Raw meat is likely to be contaminated with food poisoning organisms such as *Salmonella*, *Listeria*, *E. coli* O157 and *S .aureus* but there have been just two surveys carried out on the microbiological quality of commercial jerky. Levine *et al*. (2001) found 0.31% of samples testing positive for *Salmonella* and 0.52% positive for *Listeria*. Velasco Ramos (2007) detected neither organism in the samples tested. Neither survey detected *E.coli* O157 or *S. aureus* in any of the samples tested.

Much research has been carried out on the microbiological issues associated with jerky and this has evaluated the decrease in pathogen levels caused by marination, heating, drying, and post-drying heating. The findings of this research are summarised in Table 9 and key points are described below.

5.2.1 Marination of jerky

Many studies have assessed the potential for pathogen survival when jerky has been produced with or without a marination/curing step. Porto-Fett *et al* (2009) found that marination affected the lethality of the drying process (73.8^{o}C/2.5h) with respect to reduction of the levels of *Salmonella*, *Listeria monocytogenes* and *E.coli* O157 present. They found that the lethality of this process was increased if the raw beef had been marinated prior to drying. Porto-Fett *et al* (2008) also found that there was no survival of *E.coli* or *Salmonella* in marinated samples dried at 80^{o}C compared with non-marinated samples in which survival was noted. This could be due to the much increased level of salt (2.24% before drying, 5.56% after drying) in the marinated samples compared to that of the non-marinated samples (<0.1%). The water activity of the samples also varied with the marinated samples having a final water activity of 0.67 compared to 0.72 for the non-marinated samples.

Other authors have concluded that a marination step increased the log reductions of pathogens observed. These include Harrison *et al* (1998) who observed a >5.0 log cfu/g reduction of *E.coli* O157 when product was marinated compared to a <5.0 log reduction if it was not marinated before drying. Harrison *et al* (1997) found *Salmonella* and *Listeria* levels were reduced by about 1.0 log cfu/g more on marinated than non-marinated samples during the initial stages of drying. Borowski *et al* (2009b) also found that the spice mix used in curing can have an effect on the overall reduction of pathogens.

Calicioglu *et al* (2003 a-d, 2002 a,b) found the reduction in *Salmonella*, *E.coli* O157, and *L. monocytogenes* levels was increased if beef strips were dipped in 1% Tween followed by 5% acetic acid before curing and drying at 60^{o}C for 10hours. This treatment resulted in >4 log cfu/g reductions of each of the pathogens and no survival of *Salmonella* or *E.coli* O157. These authors and Yoon *et al* (2006, 2009) also found that other dips including 5% acetic acid enhanced pathogen reductions.

5.2.2 Heating and drying of jerky

Heating before drying is used to reduce the microbial load on the meat before drying. Albright *et al.* 2002,2003 found that immersing beef in hot pickling brine (78^{o}C for 90s) enhanced log reductions over traditional processing. A similar finding was reported by Allen *et a.l* (2007) who evaluated a range of treatment times and temperatures. Boles *et al* (2006) found that dipping raw meat in hot water also reduced microbial levels before processing.

Harrison et al (1997) assessed the effectiveness of heating raw beef to 71.1^{o}C prior to drying and found that this usually increased the overall log reduction of *Salmonella* and *E.coli* O157. Harrison and Harrison (1996) observed a >5 log cfu/g reduction of *E.coli* O157 and *Salmonella* and >4 log cfu/g reduction of *L. monocytogenes* after heating at 71^{o}C and no survival of these organisms after further drying at 60^{o}C. Survival was observed in product that had not been heated.

Buegge et al. (2006) concluded that reductions of *Salmonella* and *E. coli* O157 were best achieved by ensuring high wet bulb temperatures were achieved and maintained during the early part of the process (eg 54ºC for 60 min, 57ºC for 30 min, or 60ºC for 10 min) followed by drying at 77ºC (dry bulb).

The reduction of *Salmonella* and *E.coli* O157 was found to be >5.0 log cfu/g by Borowski et al (2009a) who used a drying process of 68.3^{o}C for 12h and by Harper et al (2009) who used a variable temperature starting at greater than 50^{o}C with a final temperature of 77^{o}C being reached.

Porto-Fett *et al.* (2009) tested a range of processes for drying turkey strips and concluded that drying at 78^{o}C for 3.5h or 82^{o}C for 2.5h would meet the requirements for a 7 log

reduction of *Salmonella*, a greater than 5 log reduction of *E.coli* O157, and meet the zero tolerance policy with respect to *L. monocytogenes* for poultry jerky.

Holley *et al* (1985a) evaluated the use of home style drying regimes (around 50^{o}C or 60^{o}C) and found that there was a minimal reduction of *Salmonella* and no reduction in *S. aureus* or *B. subtilis*. Nummer et al (2004) also found that *E.coli* O157 could survive a home style drying process of 63^{o}C for 10hours. These results indicate that home-style processes might not be safe.

5.2.3 Post-drying heat treatment for jerky

A further variation that can be considered in jerky processing is the application of a post drying heat treatment. Borowski et al (2009a) found that a 135^{o}C/10min post drying cook increased the reductions of *Salmonella* and *E.coli* O157 by up to 3 log cfu/g compared to non cooked samples. Harrison *et al* 2001 found that beef jerky heated in an oven (163^{o}C/10min) after drying increased the reduction of pathogens by 2 log cfu/g. This post-drying heat treatment is stated by the USDA (2007) guidelines for processes that do not result in an adequate reduction in *Salmonella* from the pre-drying heat treatment.

5.2.4 Storage of jerky

Whilst the processing of jerky is important in pathogen reduction, storage after final drying can also influence pathogen survival. Harrison *et al.* (1996) found that no *Salmonella*, *E.coli* O157 or *Listeria monocytogenes* survived on jerky after 8 weeks storage despite being present after drying. Ingham *et al* (2006) found that reductions of *L. monocytogenes* and *S.aureus* increased over a 4 week storage period. These authors also noted that reductions were increased as water activity decreased. Ingham *et a*l (2005) noted that over a 4 week storage period there was a 3 to 4 log reduction of *S. aureus*. Ingham *et al.* (2004) who also assessed survival over a 4 week period found that *L. monocytogenes* was no longer detected. However, it was 90 days until *E. coli* O157 was no longer detected. Albright *et a.l* (2003, 2002) found that pathogen survival decreased over time and after 30 days *E. coli* O157 no longer survived on jerky.

5.2.5 Other factors considered in making jerky

Faith *et al.* (1998) found that depending upon drying temperature fat content can influence the reduction in level of pathogens. They found that at lower drying temperatures of 52 and

57°C a 5 log reduction in *E.coli* O157 was observed quicker in products with 5% fat content than 20%. However, at the higher drying temperatures of 63 or 68°C there was no difference in pathogen reduction.

5.2.6 Toxoplasma

The literature suggests (Table10) that eating dried meat is a potential contributing factor to *Toxoplasma gondii* infection. However, a study by Mie *et al.* (2008) has shown that if dried meat is processed correctly, frozen meat is used, sufficient heat treatment is applied, the correct combination of salt/maturation time is used, then the likelihood of survival in dried meat is minimal and therefore the risks are low.

Overall, the literature shows that a marination step is likely to increase the reduction of pathogens during the drying process. It may also decrease the survival rate. Heating and drying are important stages in jerky processing. Heating in moist heat followed by drying is recommended by the USDA (2007). The microbial load in jerky decrease during storage provided that cross-contamination is prevented.

6. Outbreaks and Recalls

Table 11 lists the reported outbreaks of food poisoning attributed to various biltong and jerky products. Reported outbreaks fall into four distinct groups:

a) those caused by enteric bacteria such as *Salmonella* and *E.coli O157*

b) those caused by *Trichinella*

c) those caused by *Staphylococcus* enterotoxin

d) those caused by *Clostridium botulinum*

The cause of the greatest number and largest sized outbreaks are the enteric bacteria. These may be present as 'natural contaminants' of the raw meat used to produce biltong and jerky, be present in any raw untreated spices used to coat the meat, or find their way onto the meat products through cross contamination within poorly controlled production environments.

In the production of traditional biltong no high temperature heat process is applied to the meat and any enteric pathogens present on the raw meat will only be inactivated either by coatings or marinades (if these were acidic enough) or by very low water activity conditions. However, very low water activity conditions can very effectively 'preserve' bacteria in a viable, but non-growing state.

In jerky production, one or more heat processes should be applied. In all of the outbreaks listed where temperature data is known the temperature applied was 60ºC or less. In some cases, the time given at 60ºC would look to be equivalent to a 70ºC for 2 minute process, however some processors enter their heating step with frozen or semi frozen meat, which could reduce the process efficacy. Additionally, these organisms will have an increasing heat resistance as the water activity drops as it will in the drying process and some survival may be anticipated if numbers in the raw material were high enough.

The presence of potential pathogens in the spices used in coatings must be considered a risk although in none of the outbreaks noted in Table 11 has this been indicated as a possible route cause. Recent events in the USA with black and red pepper coated salami being linked with a large multi-state outbreak of *Salmonella* Montevideo infections shows the risk exists (.http://www.fda.gov/NewsEvents/Newsroom/PressAnnouncements/ucm202128.htm).

Many of the outbreaks appear to be from very small commercial producers or from home produced biltong or jerky. In a number of outbreak reports from the USA, there are indications that the hygiene at some small producers is very poor, and that the potential for cross contamination from raw materials to finished product may have occurred leading to a scenario where even if meat had received a process good enough to eliminate pathogens, it may have been contaminated after the process due to poor production hygiene.

Trichinella may be present in a range of farmed (particularly pork) and wild animals and its likely source in biltong and jerky is from contaminated raw meat. Control can be achieved through freezing prior to other processing (Anon. 1995; EU. 2005), or applying a heat process. A heat process designed to eliminate enteric bacteria would also inactivate *Trichinella*. U.S. Federal information gives examples of 2 hours at 52.2° C, or 15 minutes at 55.6° C, and for 1 minute at 60° C centre temperatures as being enough to eliminate *Trichinella*. In the outbreaks reported in Table 11, there is little information given as to the route cause, however use of meat that had not been frozen, and then had received an inadequate heat process, is likely.

Staphylococcus aureus (enterotoxin producing *Staphylococci*) may be found as a natural skin and mucosal organism in most animals. In order to cause food poisoning it needs to grow to a level at which its enterotoxin causes food poisoning. *S. aureus* is not heat resistant, but can grow at water activities that would stop the development of many other food poisoning organisms. There is no information in the available reports, on the possible route cause of the outbreaks of *Staphylococcal* enterotoxin poisoning. It may be judged that the raw material was contaminated with enterotoxin producing *staphylococci*, and improper storage and/or incorrect or slow drying allowed this flora to develop and produce toxin.

Clostridium botulinum has been associated with one outbreak linked to venison jerky. The investigation done of this outbreak showed that toxin could be repeatedly demonstrated in the jerky, but the organism was only isolated once. It was never isolated from any of the raw materials used to make the jerky and no conclusions were drawn as to how the organism came to produce toxin within the product.

7. Existing guidance on manufacturing biltong and jerky and associated HACCP (excluding chemical and physical hazards)

Guidelines have been produced to aid the safe production of dried meats, in particular jerky. No specific guidance was found on the small-scale manufacture of biltong. The guidelines listed below are from the US or New Zealand, although some EU-based generic guidelines exist for the production of a range of products as listed in : *http://ec.europa.eu/food/food/biosafety/hygienelegislation/register_national_guides_en.pdf* However, none of this EU-based guidance is specific to dried meat products.

7.1 Guidance from New Zealand

Anon (1999) Appendix X.6: Generic HACCP plan for manufacture of beef jerky. In A guide to HACCP systems in the meat industry. New Zealand Food Safety Authority.

Lake, R., Hudson, A. and Cressey, P. (2003) Risk profile: shiga-like toxin producing *Escherichia coli* in uncooked comminuted fermented meat products. Institute of Environmental Science and Research Ltd / New Zealand Food Safety Authority.

Anon (2009) Draft risk management programme manual for animal product processing. New Zealand Food Safety Authority

Anon (2009a) Further processing code of practice. Part 3 Good operating practice. New Zealand Food Safety Authority.

Anon (2009b) Draft code of practice: production of processed meats: Part 3 GMP - process control. New Zealand Food Safety Authority.

7.2 Guidance from the US

Anon (2007) Quick guide on processing jerky and compliance guideline for meat and poultry jerky produced by small and very small plants. United States Department of Agriculture. Food Safety and Inspection Service.

Anon (2006) Fact sheets: Meat preparation: food safety of jerky. United States Department of Agriculture.

Anon (2005) Generic HACCP model for heat treated, shelf stable meat and poultry products. United States Department of Agriculture. Food Safety and Inspection Service.

Getty, K.J.L., Boyles, E.A.E., Roberts, M.N. et al. (2006) Thermal process for jerky provides proper lethality for controlling pathogens. Final report (June 2005 to October 2006) Jerky validation for small and very small meat and poultry businesses. Executive summary. United States Department of Agriculture.

7.3 Conclusions from guidance

Several key factors that can help prevent the contamination of dried meats are discussed in the guidelines and the main practical points are:

- Knowledge of the source and quality of the raw materials (meat and spices) is important. Good quality materials must be used and stored properly at the correct temperatures to avoid microbial growth and cross-contamination. Pork should be frozen to eliminate *Trichinella*.
- If frozen, thaw the meat under hygienic conditions at chill temperatures (0-4ºC) to reduce the potential for microbial growth.
- Preparation practices such as slicing of meat should be carried out hygienically to avoid cross contamination.
- Marination, in conjunction with subsequent processing, is a key process and the microbial quality of spices should be considered to avoid cross contamination particularly with spore formers. Use good quality (heat treated) spices.
- The product formulation and marination process must be defined.
- For jerky, the meat must be heated before drying begins. The USDA guidance is to heat beef in moist air to an internal temperature of 71ºC (or use an equivalent temperature-time process).
- The drying stage is critical in preventing the growth of microorganisms and production of microbial toxins. Therefore, the drying process should be fully defined and recorded including time, temperature and humidity.

- Water activity is the primary preservation factor of the final product and as such must be low enough to prevent the growth of pathogens. Less than 0.85 is required by the USDA for jerky.

  Although not mentioned in any guidance, the use of weight loss during the drying of biltong could provide a useful indicator of water activity. Raw meat has a water content of around 75%. Reducing the weight of the meat by a factor between 3.75 and 2.5 during drying will produce a product with the required moisture content of around 20 to 30% and corresponding water activity around 0.7 to 0.75.

  In addition, the drying process should designed to decrease the water activity quickly to prevent microbial growth but not so quickly that case hardening occurs.
- The overall manufacturing process and the combined effects of each individual process must be considered. For example, controlling factors other than water activity, such as salt, nitrite, or antimicrobials should be considered. The USDA recommends meat is heated to 71^{o}C prior to drying, or the meat is dipped in 5% acetic acid for 10 min, or dipped in a calcium sulphate mix for 30 sec or pre-treated with 500-1200ppm of acidified sodium chlorite, before drying. If pathogen destruction cannot be guaranteed a post-drying heating process (163^{o}C/10min) is recommended for jerky.
- Jerky processes should be designed to give a 5 log reduction of *E.coli* O157 in beef and poultry jerky, a 6.5 log reduction of *Salmonella* in beef jerky and a 7.0 log reduction of *Salmonella* in poultry jerky.
- Care must be taken to avoid cross-contaminating product when packing and use of appropriate packaging materials should be used to prevent cross contamination and moisture uptake.
- "Use before dates" or "Best before dates" should be provided on packaged products.
- Effective pre-requisite programmes such as hygienic processing, personal hygiene and cleaning procedures should be in place.

Tables 12 and 13 also summarise the key processes and factors to consider when manufacturing biltong and jerky.

8. Market Size

8.1 Biltong

Little data is available on the size of the market for biltong. Osterhoff and Leistner (1984) reveal that 100 tonnes of biltong was produced each year in South Africa. Attwell (2003) noted that new producers were constantly starting up in South Africa but few survived because of the high cost of the raw meat, consumer demand for quality and consistency, and "virtually non-existent opportunities for export without an EU and HACCP-certified factory". Biltong was also seen as a seasonal product making it unreliable as an income for small companies.

Attwell (2003) reported that Gull Foods, supplying to Woolworths, was the largest producer of biltong in South Africa with a further large market share held by Stormberg. PJ's Biltong was another manufacturer cited in the article. In 2003, Gulls Foods was producing 80000 to 90000 units per month.

The article by Attwell (2003) also notes that UK and EU bans on South African meat had been lifted in 2002 but the standards for export would preclude many companies from these markets. She also highlights the huge number of internet sites offering to send biltong to anywhere in the world. In the UK, biltong has accompanied the migration of South Africans resulting in a variety of sources supplying this product. Attwell (2003) specifically mentions Susman's Best Biltong Company, in the UK, which was cited as the only EU-accredited biltong manufacturing facility in the world.

Figures on the sales of biltong and jerky spice mixes to butchers and similar small outlets may have provided some indication of the size of the market for biltong manufactured from these sources in the UK. Companies providing these spice mixes considered this information to be commercially confidential.

8.2 Jerky

Roberts (2003) reported that sales of meat snacks in the US grew by 147% from 1997 to 2003 with beef jerky being the most common product with 44% of sales in 2002. Remaining products included meat sticks and other types of product such as kippered or pickled meats. Beef products represented 80% of the market. ConAgra held 27%, Oberto Sausage held

21%, and Link Industries held 15%, of the market. Only 2% of meat snacks were private label. No data is given for the percentage of products manufactured by small processors.

Bowser et al. (2009), based on data from elsewhere, reported that an estimated 39% of all US families regularly buy meat snacks. Beef jerky is so popular that it is also included in the US Army's "First Strike Ration" pack (Bowser et al., 2009). Recent data (Anon, 2009) reports on total sales of jerky, including pemmican, of 613.9 million dollars in the US in the year August 2008-09 with future increases expected.

As for biltong, obtaining reliable figures on the sales of jerky or the spice mixes used to manufacture jerky by small manufacturers, was not possible for the UK. Butchers, markets, and specialist food shops are the likely outlets as used in the survey by LACORS and HPA in 2008. Biltong and jerky are both sold by large retailers but these products have been sourced from large manufacturers.

9. Gaps in existing information

The following are the main gaps identified from this review:

- No legal definition exists for biltong.
- No guidance exists for manufacturing biltong. Specific defining properties and guidance on the production of jerky have been produced by the USDA.
- Market data for dried meat products and the sales of associated spices could not be found.

Enquiries received by Campden BRI from small scale manufacturers of meat products raises specific concerns on:

- The quality of meat being used by some producers is low: often drying meats is seen as a way of using trimmings.
- More enquiries are received on fermented meats and sausages than those relating to biltong or jerky. The lack of experience and proposed manufacturing methods raise concerns over the safety of the proposed products.

10. Conclusions

The main conclusions are:

10.1 Products

No legal definition exists for biltong. Traditional biltong making uses marination followed by low-temperature drying to a water activity around 0.7 to 0.75. Higher water activity may be used for some biltong.

Prescriptive definitions are defined by the USDA for jerky (water activity < 0.85; moisture:protein ratio <0.75:1).

10.2 Processes

The manufacture of biltong relies on acidic marination followed by drying. One of these processes used alone is insufficient for microbial reduction and inhibiting growth.

No guidance documents have been published on the manufacture of biltong.

Forced convection, heated air drying is required in the UK for making biltong. Ambient air or solar drying are not suitable. Drying with air at 35ºC, 30% relative humidity and 3 m/s is suitable for making biltong within 6 days.

Tray dryers are the best low-cost option for small-scale operations producing biltong. Ovens may be used provided that the door opening is used to adjust the humidity of the air. Obviously, the oven could not be used for other purposes during the drying period.

The manufacture of jerky uses marination, heating, drying, and if necessary an additional post-drying heating step.

Several guidance documents are available on the manufacture of jerky. These documents come from the US and New Zealand and provide details on the process conditions to make a safe product.

Smokehouses and commercial ovens are used in the US for making jerky.

10.3 Microbiology

Several surveys of microorganisms on commercial biltong have been carried out. Total viable counts up 7 log cfu/g; *Enterobacteriaceae* and coliforms up to 4 log cfu/g; yeasts up to 7 log cfu/g; moulds up to 5 log cfu/g; lactic acid bacteria up to 8 log cfu/g; and *Staphylococci* up to 8.5 log cfu/g, have been found in recent surveys.

Pathogens have occasionally been found in biltong samples. Raw meat may contain pathogens and these can survive for long periods in biltong: *Salmonella* Dublin was isolated in 6 month old biltong. Pathogen reductions occur during the processing of biltong. Reductions of *Salmonella* up to 3 log cfu/g; *E. coli* up to 3 log cfu/g; *L. monocytogenes* to 4.5 log cfu/g; and *S. aureus* up to 6 log cfu/g have been found.

Reductions in pathogens increase as water activity is reduced. Reducing water activity using salt, or reducing pH using acidic marinades, are not sufficient in themselves to produce a safe product. Drying is also required to reduce the water activity.

Fewer surveys of commercial jerky products have been carried out. Few samples tested positive for *Salmonella* or *Listeria*, and none tested positive for *E. coli* O157 or *S. aureus*.

Many studies have investigated the microbiological issues associated with producing jerky. The marination step reduces the numbers of pathogen on the final product. Moist heating before drying has a significant effect on microbial numbers on jerky provided that temperature-time guidance is followed. Drying at 77ºC after heating leads to the recommended 7-log reduction in *Salmonella*, 5 log reduction in *E. coli* O157, and elimination of *L. monocytogenes*.

A post-drying heat treatment of 135ºC for 10 min may be used if previous heating has not been carried out using the recommended temperature-time treatment.

All studies have found that microorganism counts reduce during storage. *Toxoplasma gondii* was not a concern provided that the meat had been previously frozen and sufficient heat treatment or salt/maturation treatment has been used.

The most frequent and significant outbreaks have arisen from enteric bacteria coming from the raw meat and from cross-contamination and poor handling. The use of contaminated spices may also pose a risk.

10.4 Information gaps and recommendations

No legal definition or guidance on manufacturing exists for biltong. The current project has provided a literature review and outline requirements for a HACCP approach to the small scale manufacture of biltong and jerky. The information could be used as the basis for developing detailed guidance to assist manufacturers of biltong and similar products.

As part of this review, some guidance on the manufacture of fermented meat products was located. There would be benefit in this information being brought together to develop risk-based guidance for small companies considering making such products.

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Figure 1 Changes in moisture content, water activity, and salt content during the manufacture of biltong (taken from Taylor, 1976) Air temperature = 35°C; relative humidity = 30%; speed = 3 m/s.

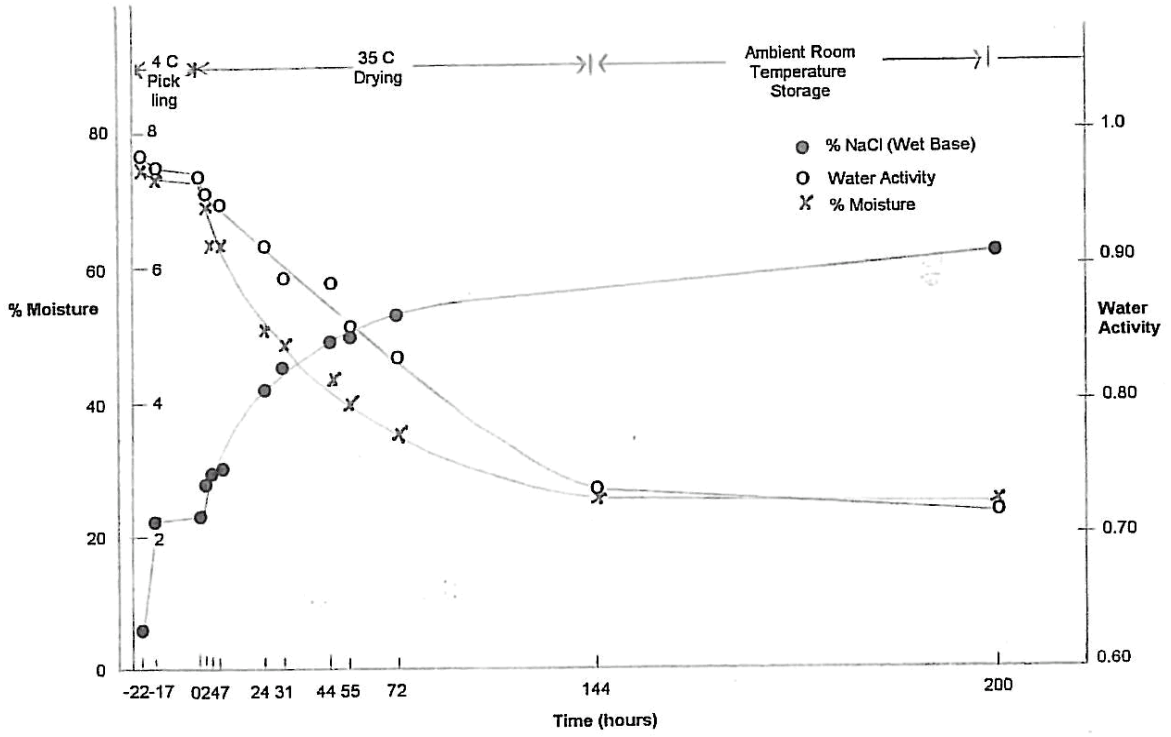

Figure 2 Changes in bacterial numbers during the manufacture of biltong (taken from Taylor, 1976) Air temperature = 35°C; relative humidity = 30%; speed = 3 m/s

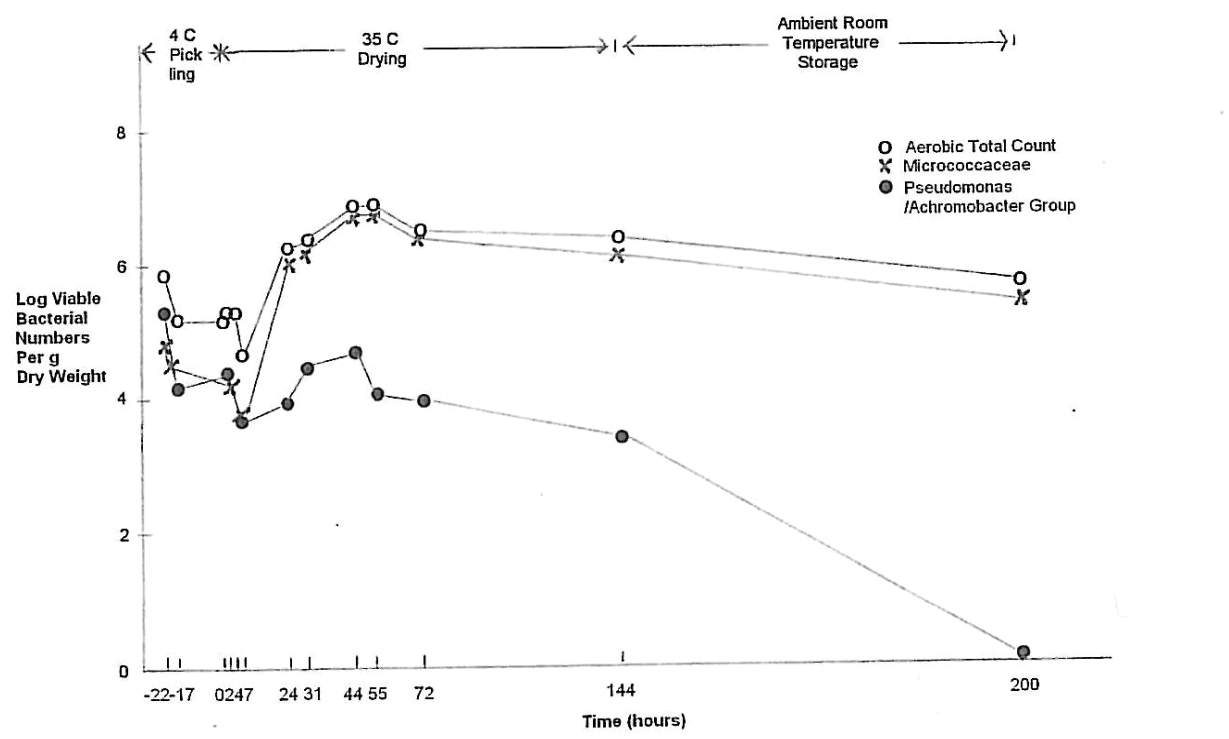

Figure 3 The relationship between moisture content and water activity of biltong (data taken from van der Riet (1976) and Osterhoff and Leistner (1984))

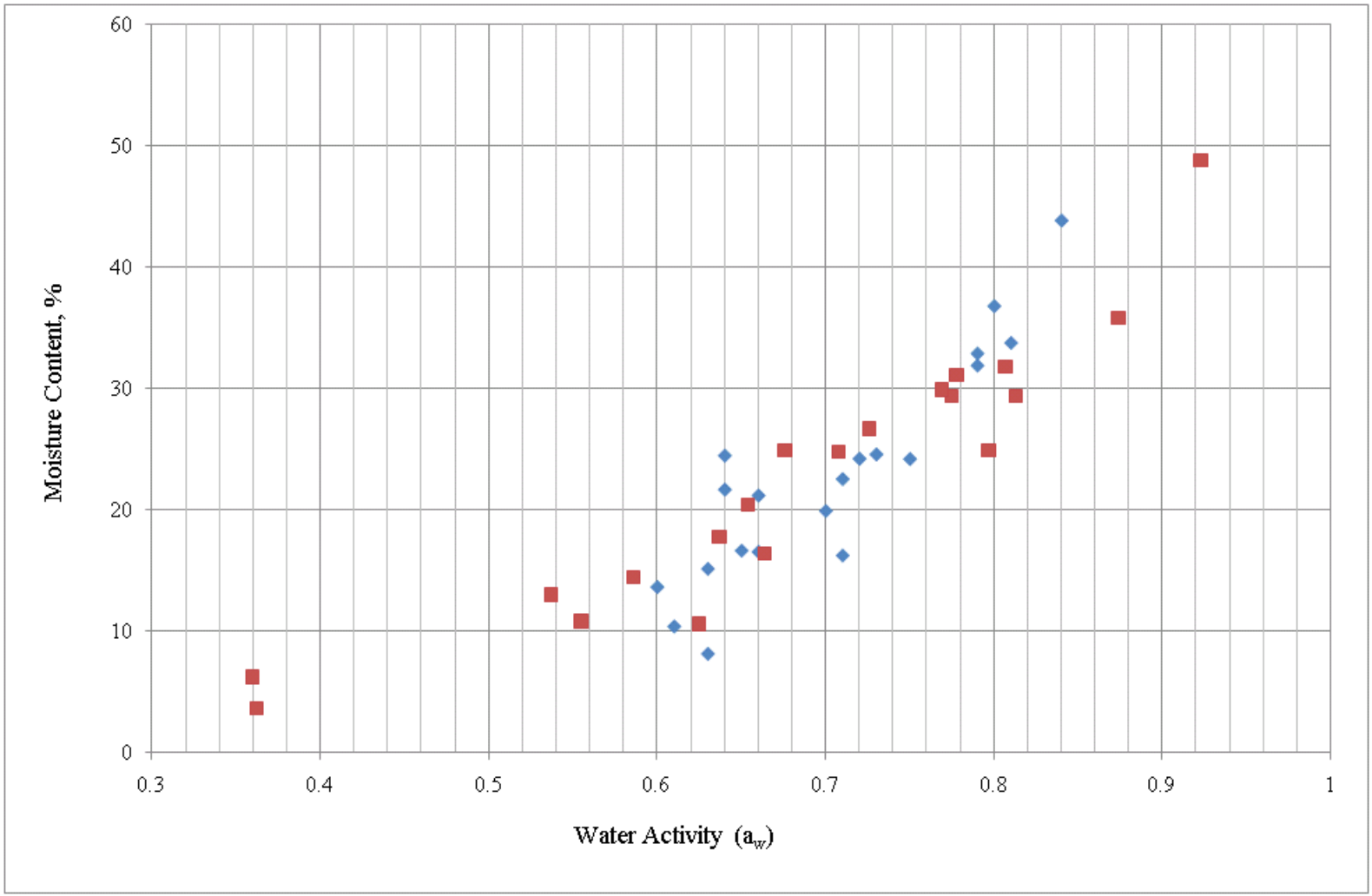

Table 1 Summary of the types of dried meat products and their ingredients

PRODUCT	DESCRIPTION	MEAT SPECIES	MEAT CUTS/PROCESS	SEASONINGS	COMMENTS	REFERENCE
Biltong	Australian study into manufacture of dried meats to utilise surplus supplies for times of demand		Fillet steak (binnebiltong or ouma se biltong) or eye muscle (garing biltong) for connoisseurs. Generally hindquarter muscle. Young animals are best otherwise too tough. Cut into strips 25-30cm long, 5-10cm diam. Hang to dry in sun on first day then in shade until ready for salting by brining and dry salting. Fatty meat takes longer to absorb salt.	Aniseed, allspice, garlic, coriander, pepper, salt, sugar, sugar, saltpetre for colour, sodium bicarbonate for mould prevention	A lean hindquarter yields 70% biltong, 12% trim, 18% bone. Drying gives 60% loss of mass.6kg rump gives 2.5 kg biltong	Thomas (1975)
Biltong	Trials at Hawkesbury Agric. College, Richmond, N.S. Wales, Australia to evaluate process conditions and likely shelf life.	Beef	Boned out beef strip loin and cut into 5cm slices, removing most fat. Dip in cure solution 1 min and dry @ 60°C for 9 hr.	Cure solution (salt, sodium nitrite, ascorbic acid).	Moisture content of 20-22%. Vac packed but bag punctured and after 5 months mouldy due to air ingress. Approx 1kg dried meat equivalent to 3.6 kg fresh. 3-8% salt best for flavour and shelf life. Nitrite good colour	Anon (1979)
Biltong	Study of role of micro-organisms in flavour development.	Antelope or cattle	Beef semimembranosus (SM) muscle strips 40cm long, 4.0x2.5cm cross-section. Dry salted (25g/kg meat), hold overnight to allow salt penetration. Dry @ 35°C, R.H. 30%,air speed of 3m/s for 5 days.		Typical Aw 0.80. Dried to 30% moisture.	Prior (1984)
Biltong	South African Delicacy	Beef or game	Most muscles-largest ones most suitable. Cut meat with grain into long strips and place in brine for several hours. Often dry salted, dipped in hot water with vinegar and hung 1-2 weeks in air to dry	Salt is principal curing agent. Sugar, vinegar, pepper, coriander and other spices used. Preservatives used include boric acid, Pimaricin, potassium sorbate.	Sold in sticks, slices and ground form. May be stored for months without refrigeration.	Leistner (1987)
Biltong			Prime cuts semi-thawed, sliced	Chilli, roasted coriander, coarse black pepper, cloves, ginger,	Seasoned meat dried for 4 days, sliced and vac packed or N2 flushed. Dry, moist and	Attwell (2003a)

				mace, garlic, thyme. Original products used salt, black pepper and brown sugar. New varieties use chilli, garlic, curry spices.	semi-dry varieties	
Biltong	South African biltong -6 month journey.	Almost all wild game: gazelles, elephants, ostriches, giraffes and other exotic species.				Fearnley-Whittingstall (2004)
Biltong	Sensory study in Brazil looking at traditional Brazilian seasonings	Beef	Hindquarter muscles cut into strips along the grain 15-20 cm long, 2.0x1.5 cm cross section. Formulation 1:sprinkled with seasoning both sides, turned every 30 mins for 4 h, dried @ 35°C for 36h. Formulation 2:Meat dry salted with spices and held overnight at 10°C then dried @ 35°C for 36h. Formulation 3:meat immersed in pineapple juice for 15m @5°C then as formulation 2.	Formulation 1: Commercial seasoning from South Africa. Formulation 2: South American spices-3%salt, 0.72% sugar, 150mg/kg nitrite, pepper, allspice, aniseed, garlic, onion and coriander. Formulation 3: As formulation 2 but added pineapple juice	No differences in flavour, slight preference for formulations 2 and 3 for lighter colour and tenderness of 3.	Edite, Dzimba, Assis, Walter (2007)
Biltong	Used a traditional method (as in home preparation) and modern method (as in factories) in this study	Meat pieces	Traditional: place meat in tray of apple cider vinegar for 30sec per side. Drain and add spice mix. Modern: combine spice and vinegar together 1:1 ratio and spread onto meat pieces. Both methods-chill @4° 18-20hrthen dry @25°C for 96 hours.	Spice mix: black pepper, salt, coriander, brown sugar.		Naidoo and Lindsay (2010c)
Biltong	South African dried, spiced,		Relies on a vinegar rinse, spicing step and drying		Aw of 0.77 and pH 5.5.	Mhlambi,

	ready to eat product		stages for microbiological safety and stability.		Moister products have 40% moisture, Aw 0.85-0.93	Naidoo, Lindsay (2010)
Biltong	Traditional South African meat product. Origins: meat preserved by Dutch escaping British rule 200 years ago, added vinegar &spices, hung at back of Ox wagons where it dried in 3 to 4 days.	Beef (topside), game, ostrich	Fillets cut into strips across muscle grain, 0.5 inch thick.	Black pepper, vinegar, salt, roasted coriander, ground nutmeg, cracked coriander, Worcester sauce. Nitrite may be added for red colour-personal preference.	Biltong will lose 40-50% of weight.	Email from large UK ingredient supplier (2010).
Jerky	Original product made by North American Indians				Dried over fires to give a smoky flavour	Thomas (1975)
Jerky	Produced by native Americans smoking and sun drying meat. Popular in N. America. Lab study.	Beef , poultry, game	Thick, thin slices, ground beef Lab study: vac packed ex-frozen, inside rounds. Sliced 0.6cm tick, 8.7x4cm.Traditional marinade (34ml) spread on 450g meat. Cover and hold 4°C for 24H. Dry @60°C for 24h.	Various drying regimes	Various seasonings. Traditional marinade: 60ml soy sauce,15ml Worcs. Sauce,0.6g black pepper,1.25g garlic powder, 1.5g onion powder4.35g hickory –smoked salt.Per kg meat.	Calicioglu, Sophos, Samalis, Kendall and Smith. (2002)
Jerky	Study of antimicrobial properties of raisins	beef		15% raisins	Decreased pH to 5.5 and Aw 0.64.Increased antioxidant potential.	Bower, Schilke, Daeschel (2003)
Jerky	Dried meats		Salt to inhibit surface growth then heat in low temp convection ovens.		Remove at least two-thirds of meat weight and 75% of its moisture	Mc Gee (2004)
Jerky	Study of purchased samples	Beef		Salt, sweeteners,, msg, garlic, nitrite, sod. erythrobate, soy sauce, teriyaki sauce, vinegar, citric acid, pot. sorbate, apple juice, papaya juice Worcs sauce, wine, succinic acid, paprika, tomato	USDA MPR 0.75:1 or lower, Aw 0.80 max.	Ingham, Searls, Mohanan, Buege. (2006)

				powder		
Jerky		As above	As above	Similar to above	Similar to above but heated to 55deg C and cooked to desired weight loss	Email from large UK ingredient supplier.
Carne seca Charqui Jerky Kilshi Rou gan	From Mexico From S. America From USA From Sahel From China					Naidoo, K., Lindsay, D. (2010a)
Charqui	Produced in South America(Brazil makes much)		Fatty meat used Beef side cut into 3 primals. Butchered, cooled at air temp, Brine, drain, salt and leave stacked 4 days turning pile. Staggered drying/curing until product loses 40% fresh weight.			Thomas, P.L. (1975)
Charqui/jerked beef/chipped beef/jerky/jerked meat	USA	Beef or venison	Smoked and sun dried strips of meat.			International Dictionary of Food and Cooking. Peter Colin Publishing,1998
Charqui/jerky/ jerked beef	South American	Normally beef, also from sheep, llama and alpaca	Strips of meat cut lengthways and pressed after salting then air dried.		Final form is flat, thin, flaky sheets, unlike long strips of biltong.	Benders Dict of Nutrition and Food Technology. 7th edition.Wood head Publishing Ltd/CRC press, 1999.
Charqui	Study on spent hen meat in Brazil	Spent Leghorn hen meat	Breast and thigh treated with BHA and BHT and $NaNO_2$,dry salted, restacked for 4 days, desalted and vacuum packed.		Successful intermediate moisture product with Aw 0.75 and salt uptake 1 to 17%	Garcia, Yossef, Souza, Matsushita, Figueiredo, Shimokomaki, (2003)
Pemmican	Invented by American Indians, used in polar regions	Buffalo, caribou, deer, and later beef.	Meat dried in the sun and pounded or shredded prior to being mixed with melted fat.	Dried acid berries originally, currants.	Used in cold climates	Thomas (1975)
Pastirma	Turkey, Egypt, Armenia, other Moslem countries.	Beef cattle 5-6 years	Hind-quarters butchered 6-12 hours post-slaughter. Meat cut into 50-60cm strips, <5cm	Cemen paste (fresh ground garlic,	80 kg beef gives 50 kg pastirma.	Leistner (1987)

		old	diam. Slits made and salt/potassium nitrate rubbed in. Stack 1m high @room temp. For 1 day, turned and stored 1 more day. Wash and air dry (2-3 days summer,15-20 days winter).Pile to 30cm,press with weights for 12 hr. Dry 2-3 days and press again. Dry 5-10 days. Cover surface with 3-5mm layer cemen paste and pile for 1 day.dry 5-12 days in well ventilated room.	helba, hot red paprika, kammon, mustard, water)	End product has 30-35%moisture and can be stored @room temp. for 9Months.	
Tasajo	Salted and dried product made in Cuba, a version of charqui.		Traditionally meat is salted and sun dried forat lease 3 weeks. Industrially it is salted in saturated brine (21%) for 8 hours, dry salted to achieve a constant weight ten air dried at 60°C		A 50% weight loss from original weight	Chenoll, Heredia, Segui, Fito (2007)
Nikku	Dried meat from Canadian Arctic	Caribou and seal	Meat is cut into strips and hung in the sun until dry	No seasoning		Forbes, Measures, Gajadhar,. (2009)
Sou Gan	Chinese dried meats More than 30 exist and vary according to species/technology/spices used.	Process type1 - Pork slices or beef slices Process Type 2 Beef, pork, chicken Process type 3 Pork(shredded/floss/flakes)	Process type1 - Lean meat from hams or loins is cut along the grain to 0.2cm slices. Held in pickle 24 hr @room temp or 36hr @ 4°C.Dried at 50-60°C until 50% original weight. Cut into squares, charcoal grill dry @room temp. to Aw,0.69 Process Type 2 Pieces, cubes, strips. Remove fat, cut into large chunks, cook with 10%water until tender, cool, drain, cut into pieces, cubes or strips. Add seasonings to meat and liquid and cook until almost dry. Rack up and dry @ at 50-60°C until 50% original weight. Aw<0.69 Process type 3 Cut pork along grain and cook in equal amounts of water until soft. Drain. Reduce liquid to 10% volume and season. Mash meat to fibres, add to liquid, cook until evaporated. Stir flakes @80-90°C until water activity of 0.6.	Process type1 - Pickle (sugar, salt, soy sauce, msg and spices). Nitrate/nitrite may be added in conjunction with vac packing to reduce rancidity Process Type 2 5-spice,curry, chillies, cayenne pepper, ginger, fruit juice, wine. Process type 3 Sugar, salt, soy sauce, wine, msg, fennel, ginger, other spices. Can cook dried meat in hot oil to make crispy/drier:a_w<0.4	Textbook from mainland China does not cover this process type probably due to health risks. Can be kept in glass jars or metal boxes for 3-5 months. Store in clean glass for 6 months.	Leistner (1987)

Table 2 Conditions used during the marinating process for biltong
(UN = Unknown)

SIZE OF STRIP mm x mm x mm	TEMPERATURE ºC	TIME hours	SALT CONTENT OF MARINADE, %	COMMENTS	REFERENCE
UN	4	22 (estimated)	2.5%	No liquid is used. Laboratory tests.	Taylor (1976)
UN	UN	Several hours	UN	In spices, then hot vinegar solution, then dry	Leistner (1987)
(250 to 300) long x (50 to 100) dia.	Ambient	Variable	UN	Australian summary document that suggests salting is done after drying	Thomas (1975)
50 thick	UN	0.02	UN	Experimental work. Dip for 1 min then dry.	Anon (1979) reporting on Sponcer (1978)
40 x 25 x 25	4	24	Dry salt	Experimental work. Dry salt used.	Van der Riet (1981)
40 long x 40 x 25	5	Overnight	Dry salt added or dry salt and antibiotics	Experimental work Dry salt added or dry salt and antibiotics prior to drying.	Prior (1984)
25 thick	UN	17 to 26 days	UN	Sprayed with peracetic acid before slicing. Then tumbled with spices and vinegar in bags.	Burnham et al. (2008)
300 x 150 x 25	4	18 to 20		Traditional method (vinegar, drip, spice, dry) Modern method (shake with vinegar and spice, then dry)	Naidoo and Linsay (2010)

Table 3 Conditions used during the marinating process for jerky

SIZE OF STRIP mm x mm x mm	TREATMENT, TEMPERATURE AND TIME ºC	COMMENTS	REFERENCE
6 mm thick whole raw muscle or cured whole muscle	Raw muscle marinated for 12 h at 4ºC. Cured muscle stored for 12 h at 4ºC	Experimental work	Holley (1985)
6 mm thick whole raw muscle	Marinated for 12 h at 4ºC.	Experimental work	Holley (1985)
15 x 15 x 15	(a) marinate at 4ºC for 1 h or (b) heat in marinate to 71ºC	Experimental work	Harrison and Harrison (1996)
Minced beef formed into 25 x 7.5 x 335 strips	Four treatments: (a) meat alone, (b) meat with cure mix (c) meat without cure mix and cooked and (d) meat with cure mix and cooked. All included a spice mix and were later dried. Cooking in oven at 71ºC until final temp of 71ºC	Experimental work	Harrison, Harrison and Rose (1998)
Unknown but mentions strips and minced meat. Three recipes from elsewhere are reported : (a) no advice on cutting (b) cut across the grain, remove fat (c) cut with grain and remove fat	"Use refrigerated ground meat within 2 days and whole red meats within 3 to 5 days" Marinate in refrigerator (a) heat to 71ºC (b) boil meat in marinade (c) sprinkle on seasoning and stand for 24 h in refrigerator. Dip in liquid smoke. Immerse in boiling brine for 1 to 2 min	Describes recipes from elsewhere	Marchelo and Garden-Robinson (1999)
150 x 15 x 15	Four alternative treatments: (a) Marinate overnight at 4ºC -traditional (b) Marinate overnight at 4ºC, dry at 60ºC, heat at 135ºC for 10 min (c) Marinate overnight at 4ºC, boil for 10 min, dry at 60ºC (d) Marinate overnight at 4ºC, heat at 165ºC for 10 min and dry at 60ºC	Experimental work to include traditional	Harrison et al. (2001)
87 x 40 x 6	Four treatments used; (a) marinade (traditional; pH=4.3); (b) modified marinade (pH=3.0); (c) dip in acid the marinade; successive immersion in Tween 20 and acid	Experimental work	Calicioglu et al. (2002)
87 x 40 x 6	(a) Boiling water 94ºC for 15 s then marinate 4ºC for 24 h (b) Marinate 4ºC for 24 h then brine 78ºC for 90 s (c) Vinegar soln. 57.5ºC for 20s then marinate 4º for 24 h (d) Marinate 4ºC for 24 h then vinegar soln. 57.5ºC for 20s	Laboratory work using preservation spice recipe and home food dehydrators	Albright et al. (2003)
87 x 40 x 6	Two treatments used (a) marinade or (b) dip in 5% acetic acid for 10 min at 25ºC, drain for 2 min, and then marinade. Marinading carried out at 4ºC for 24 h	Experimental work	Yoon at el. (2005)
50 to 150 long	UN	Data for 15 commercial beef jerky samples	Ingham et al. (2006)
5 to 7 mm thick	Tumble for 5 min in spiced marinade and then held for 22 to 24 h at 5ºC	Testing in commercial	Buegge, Searls

		smokehouse	and Ingham (2006)
87 x 40 x 6 mm strip of whole muscle	Traditional marination, or acid dip and then marinate (4ºC for 24 h)	Experimental work and modelling	Yoon et al. (2006)
UN	Heat the meat to 71ºC in the marinade or other liquid, or dip in 5% acetic acid for 10 min and then into the marinade, or dip in calcium sulphate or acidified sodium chlorite solutions.	Guidance document	UDSA (2007)
6 to 7 mm thick whole muscle strips or restructured beef trim	Whole muscle marinated in spice mix overnight at 2ºC Restructured meats has spice incorporated. Some whole muscle strips added to spice mix but not marinated	Experimental work	Allen et al. (2007)
6 mm thick	Vacuum tumbled for 20 min in a mix containing soy sauce, then dried. Subsequently packed, packed and heated or dipped in sodium lactate.	Experimental work After drying, products were vac-packed, or vac-packed and dipped in water at 72ºC, or dipped in sodium lactate.	Boles, Neary and Clawson (2007)
250 x 27.5 x 5.5 strips of whole muscle	Add marinade mix, tumble (2 min at 23ºC) hold for 13 min at 4ºC in wet marinade	Testing of commercial process	Porto-Fett, Call and Luchansky (2008)
152 x 25 x 6 strip of chopped and formed beef with commercial flavour mix	No marinade treatment was applied as commercial batter containing flavour mix was used from the start	Experimental work based on schedules used by large and small scale processors	Harper et al. (2009)
102 x 25 x 6 strip of minced beef formed with commercial flavour mix	No marinade treatment was applied as commercial batter containing flavour mix was used from the start	Experimental work of drying with three home-style dehydrators and one small commercial unit	Borowski et al. (2009a)
127 x 25 x 7 strip of minced beef formed with commercial flavour mix	No marinade treatment was applied as commercial batter containing flavour mix was used from the start	Experimental work with small scale dehydrator or large scale smokehouse	Borowski et al. (2009b)
87 x 40 x 6 mm strips of whole muscle	Marinate or acid dip then marinate (4ºC for 24 h)	Experimental work and modelling	Yoon et al. (2009)
100 x 40 x 5	Wet marinade for 24 h	Experimental work with beef and pork	Yang et al. (2009)
150 x 40 x 7 strips of turkey breast	Held in non-acidic soy sauce based marinade at 4ºC for 15 min	Experimental work	Porto-Fett (2009)
UN	Dry marinade or wet marinade mixes used. Salt content varied from 1 to 85%. Pick up of wet marinade ranged from 3 to 100%	Survey of small and very small commercial operations	Lonnecker et al. (In press)

Table 4 Conditions used during the drying process for biltong
UN = Unknown
MPR = Moisture:Protein ratio

AIR TEMP ºC	AIR SPEED m s^{-1}	RELATIVE HUMIDITY %	TIME hours	FINAL WATER ACTIVITY	FINAL MOISTURE CONTENT %	FINAL pH	NaCl, %	EQUIPMENT	COMMENTS	REFERENCE
UN	UN	UN	UN	0.70 to 0.96 (av = 0.74)	9.6 to 51.5 (av = 25.2)	5.6 to 6.6 (av = 5.9)	Approx. 3 to 13 (av = 6.6)	UN	Survey of 60 commercial samples	Van den Heever (1970, 1972)
UN	UN	UN	UN	0.60 to 0.84 (av = 0.70)	8.1 to 43.8 (av= 22.9)	5.5 to 5.9 (av = 5.7)	3.5 to 7.7 (av = 5.6)	UN	Survey of 20 commercial samples (11 stick; six sliced; 3 game)	Van der Riet (1976)
UN	UN	UN	UN		11.5	UN	3.4 to 12 (av = 6.6)		Data for commercial biltong	Taylor (1976)
35	3	30	144	0.72	24	5.8	6.2	Drier	Final conditions apply after storage	Taylor (1976)
70 and 55 and 60 (Too high for traditional biltong)	UN	UN	8 and 14 and 9 (mech. tenderise reduced drying time to 5h)		20 to 22		3 to 8 for flavour and shelf life		Meat too dry at 70ºC Too long to dry at 55ºC Meat acceptable at 60ºC drying temperature	Anon (1979) reporting on Sponcer (1978)
30	2.5	40	After salt 48 144		73.7 (in) 72.2 (out) 64.8 (in) 50.4 (out) 49.6 (in) 32.6 (out)		1.0 (in) 2.3(out) 4.9 (in) 4.3 (out) 8.5 (in) 6.1 (out)			Van der Riet (1981)
35	3	30	120	0.77	26.9		5		Experimental work	Prior (1984)
Ambient	Ambient	Ambient	170 to 340	UN	UN	UN	UN	None	Spiced, then hot	Leistner

									vinegar solution, than dry	(1987)
UN	UN	UN	UN	0.67 to 0.87 (slices) 0.54 to 0.80 (sticks) 0.36 to 0.64 (powder) 0.92 (vac-pack stick)	16 to 36 (slices) 13 to 27 (stick) 3.6 to 18 (powder) 49 (vac-pack stick)	5.2 to 5.7 (slices) 5.5 to 5.8 (stick) 5.3 to 5.6 (powder) 4.8 (vac-pack stick)	4.1 to 8.2% (slices) 5.4 to 17.0 (stick) 6.1 to 9.1 (powder) 4.4 (vac-pack stick)		Survey of 20 samples.	Osterhoff & Leistner (1989)
22 (actual (20 to 22)	UN	50 (actual 38 to 64)	408 to 624	0.62 to 0.75. 0.85 for comm-ercial product	UN. MPR = 0.31:1 to 0.50:1. 0.53:1 for commercial product)	5.5 to 5.6. 5.6 for comm-ercial product	15.4 to 21.5 in water phase. 13.5 in comm-ercial product		Sprayed with peracetic acid before slicing.	Burnham et al. (2008)
25	UN	UN	96					Home dryer (with 40W bulb)		Naidoo and Lindsay (2010)

Table 5 Conditions used during the drying/cooking processes for jerky

Air speed not given in this table as not specific except in one paper by Harper et al. (2009)

MPR = Moisture:Protein ratio

AIR TEMP ºC	RELATIVE HUMID. %	TIME hours	FINAL WATER ACTIVITY	FINAL MOISTURE CONTENT %	FINAL pH	EQUIPMENT	COMMENTS	REF.
68ºC set point (53ºC actual) for 4 h plus 60ºC (48ºC actual) for 4 h		8 h	0.65 to 0.71	UN	UN	Home dehydrator. aw <0.86 achieved in around 3.5h	Home dehydrator	Holley (1985)
53ºC for 4 h plus 48ºC for 4 h		8 h	0.64	MPR ~ 0.35.MPR ~0.75 in around 3.5 h	5.6	Home dehydrator. 3 h to aw < 0.86	Home dehydrator	Holley (1985)
60	UN	10		(a) not heated prior to drying - 23.8% (b) heated in marinate - 18.5%		Dehydrator		Harrison and Harrison (1996)
60	UN	8	0.70 after 8 h (not pre-cooked) 0.70 after 6h (pre-cooked)	UN	UN	Convection oven for cooking. Dehydrator for drying		Harrison,. Harrison, and Rose (1998)
Cook to 71ºC then (a) dry at 52ºC for 20 h or 57ºC for 8 h or 63ºC for 7 h or 68ºC for 4 h (b) 60 to 66ºC (c) 49 to 66ºC for 9 to 24 h	UN	See air temp	UN	Meat should crack when bent in half but not break	UN	(a) dehydrator (b) dehydrator, oven, or smoker (c) dehydrator or oven	Guidance from various sources (a) to (c)	Marchelo and Garden-Robinson (1999)
60	UN	"Until dry"	UN	UN	UN	Dehydrator		Harrison et al. (2001)
Heat to 93ºC	UN	1.5 h	0.4 to 0.8 depending on raisin concentration		4.4 to 5.6 depending on raisin concentration	Convection oven	Experimental testing of use of raisins as a preservative in minced meat jerky	Bower, Scholke and Daeschel (2003)

62.5	UN	10	0.93 to 0.94 during marinating and curing. 0.84 to 0.89 after 4 h drying. 0.75 after boiling in water and marinate. 0.5 to 0.59 for other treatments (b) to (d) in Table 3	UN	5.2 to 5.9 after marinate/curing. 5.4 to 6.0 after drying	Home food dehydrators	Laboratory tests. Drying carried out after marinating and pickling	Albright et al. (2003)
UN	UN	UN	0.75	UN	5.6	UN	Data for commercial beef jerky sample	Ingham et al. (2004)
			0.68 to 0.82	UN	5.7 to 6.4		Data for 4 jerky products after storage. MPR of 0.4 to 0.8	Ingham et al. (2005)
60	UN	10 h	After drying -0.43 (control); 0.48 (marinade); 0.54 (acid treated and then marinade)	UN	At start of drying pH = 5.4 (control); 5.3 (marinade); 4.2 (acid treated and then marinade. No change during drying.	Dehydrator	Experimental work	Yoon et al. (2005)
UN	UN	Unknown	0.47 to 0.87 (all except one ≥0.63 and 7 samples		5.3 to 6.3	UN	Data for 15 commercial beef jerky samples. 8 samples had MPR>0.75:1	Ingham et al. (2006)

			above 0.80					
7 different temp-time treatments	Depends on treatment (27 to 56%)	Upto 10 h	0.65 to 0.91	UN	UN	Commercial smokehouse	Testing in commercial smokehosue High wet and dry bulb preffered initially	Buegge, Searls and Ingham (2006)
52, 57, or 63ºC		10 h	0.44 to 0.6 depending on air temp	UN	UN	Home dehydrator. Required temps reached after 2.5 h	Experimental work and modelling	Yoon et al. (2006)
Cook to final meat temp of 71ºC (meat) or 74ºC (poultry) then dry in air at 54 to 60ºC	UN	UN	UN	UN	UN	UN	Cook the meat and then dry it. Guidance	USDA (2006)
Cook to 71ºC. High humidity (≥90% rh) is essential at this stage. Then dry and then heat in an oven at 135ºC for 10 min	See air temp	See air temp	≤0.85 after drying				Guidance document	USDA (2007)
Cook at 77ºC for 1 h then dry at 54 for 4 h or Cook in marinade at 54ºC for 2 h then dry at 54 for 4 h Or Cook in marinade at 60ºC for 12 min then dry at 54 for 4 h Or Cook in marinade at 70ºC for 1s then dried at 54 to aw <0.85	34%	See temps	0.83 to 0.87	MPR 0.45 to 0.78 after cooking		Smoke-house. Cooking in marinade can be used if followed by drying.	Experimental work	Allen et al. (2007)
60ºC for drying and 72ºC for subsequent in-pack heating of some samples	UN (dampers open and fans running at max)	Up to 12 h	0.74 after 3h and 0.49 after 12h			Smoke-house	Experimental work After drying, products were vac-packed, or vac-packed and dipped in water at 72ºC, or dipped in sodium lactate.	Boles, Neary and Clawson (2007)
81ºC	63% initially 29% (av),	1.5 h	0.82 0.67	UN	UN	Commercial smokehouse	Testing of commercial process	Porto-Fett, Call and

	around 21% final		0.67					Luchansky (2008)
11 different temp-time treatments used with temps between 52 and 85ºC	Various	7 to 9.5 h	0.67 to 0.90	UN	UN	Small scale dehydrator or large scale smokehouse	Experimental work Shows that high initial air temps needed and initial high rh is preferred.	Borowski et al. (2009a)
Target air temps of 52, 57, 63, or 68 in home-units or 71ºC in commercial unit. Some products further heated at 135ºC for 10 min	12 to 55% depending on time and model. rh not controlled.	12 h in home-type or 24 h on commercial unit. Additional 12 min at 135ºC in some cases.	0.44 to 0.65 depending on the dehydrator	UN	UN	3 home-style dehydrators and one small commercial unit. Plus use of conventional oven at 135ºC in some cases. Come-up time was 164 min with one unit.	Experimental work to test dryers	Borowski et al. (2009b)
Two treatments, both in a smokehouse, were considered: (large scale, LS) 44 min at 56ºC then 7 h at 78ºC, or (small scale, SS) temp ramped from 52 to 77ºC over 6.75 h	<10% throughout for LS and SS	(LS) 7.75 h (SS) 6.75 h	(LS) 0.59 (SS) 0.60	(LS) 16.8 (SS) 19.6	(LS) 5.2 (SS) UN	Smoke-house	Compares large and small scale operation. MPR of SS-product was 0.82:1 which is greater than the 0.75:1 required for USDA legal (LS) 4 m/s for 1.5 h then 5.8 m/s for 6.25 h (SS) 4 m/s for 2.5 h then 5.8 m/s for 4.25 h labelling.	Harper et al.(2009)
70ºC	40 to 70	8	0.83 (beef) ~0.81 (pork)	27 (beef) 26 (pork)	5.8 (beef) ~5.7 (pork)	Laboratory drier	Experimental work with beef and pork	Yang et al. (2009)
52, 57, or 63ºC	Unknown	10 h	0.47 to 0.67		5.4 (control),		Experimental work	Yoon et al.

		(surface temps reached target values after 5 h)	dependent on temp or treatment		5.4 (marinated; ~4.6 (acid and marinate)		and modelling	(2009)
Smoke applied throughout. 74ºC or 82ºC. Meat reached 37 or 41ºC.	Between 23 and 39	Up to 3.5 h	0.89 (2.5h, 74ºC) to 0.80 (3.5h, 82ºC)	48% (1.5 h, 82ºC) to 35% (3.5h, 74ºC)	5.9	Commercial smoke-house. 40 to 50 air changes per h. Cool by opening the door.	Experimental work	Porto-Fett (2009)
Least severe treatment - 52ºC for 45min + 57ºC for 1h. Medium - 60ºC for 45 min + 63ºC for 45 min (total 3.75 h). Severest - 93ºC for 6 to 7 h. Many schedules cooked to 74ºC held at 71ºC for several hours.	UN (27% of plants measured rh)	1.75 to 7 h	0.74 (beef)	UN	5.9	92% of plants used a smoke-house; 8% a commercial oven and the other used both. 95% claimed to be able to control humidity: 35% using dampers; 51% by steam injection.	Survey of 37 small and very small commercial operations.	Lonnecker et al. (In press)

Table 6 Summary of microbiological data from surveys of biltong

PROPERTIES	NO. OF SAMPLES	SAMPLE TYPE	ORGANISMS Log cfu/g					REFERENCE
-	26 Local retailers, butchers and street vendors	Spiced & traditional beef/chicken/ venison.	**Product**	**TVC**	**Yeasts**	***Staphylococcus***		Mhlambi, Naidoo, and Lindsay (2010)
			Chicken/venison Traditional beef Spiced	>7.0 7.0 6.0	>6.0 ~5.5 5.5	>7.0 6.0 ~5.0		
			Staphyloccus succinus, S.*piscifermentans*, *S. aureus* found. Enterotoxin B produced by *S.aureus* & *S. equorum*. 45% of isolates were *S. equorum*					
-	150 butchers biltong bars, convenience stores, biltong shacks, confectionery shops		**TVC**	**Enterobacteriaceae**	**Coliforms**	***Staphylococcus***	***E. coli***	Naidoo and Lindsay (2010b)
			6.4-7.0	2.21-4.0	1.73-3.0	3.0	1.5	
			Lower levels present in pre-packaged samples Pathogens: *Salmonella* absent in all samples. *L. monocytogenes* present in 2 chicken biltong samples. Enterotoxin producing *Staphylococcus* present in 3 samples					
Dry Aw 0.77 Medium 0.85 Wet 0.93	84 36 A - medium butchers (on-site) B - boutique distributors (home made), C - medium industrial manufacturer	Environmental (air, surfaces, utensils). beef, chicken, game spiced with chilli or salt + vinegar or spices, dry, wet and moist)		**TVC** All >100 log cfu/cm^2 **TVC** 6 - 7.5 7.5 7 - 7.5	**Enterobacteriaceae** - **Enterobacteriaceae** 3.0 – 4.0 3 - 4 3.0	**Coliforms** All >2.5 log cfu/cm^2 **Coliforms** 2 – 3.0 2.5 - 4.0 2 – 3.0	***E. coli*** - ***E. coli*** <1 1 - 1.5* <1 * x2 samples chilli+wet	Naidoo and Lindsay (2010a)

PROPERTIES	NO. OF SAMPLES	SAMPLE TYPE	ORGANISMS Log cfu/g		REFERENCE
			Similar Enterobacteriaceae and coliforms levels across individual retailers Traditional samples from A were about 1 log lower in TVC. Dominant populations: A - *Bacillus* 31%, *Staph* 27% B - *Staph* 67% C - *Staph* 63%		
Salt: 3.5-7.7% pH: 5.5-5.93 Moisture: 10.35-43.805 Aw: 0.60-0.84	20		**Yeasts** <1to 6 log cfu/g dominant species *Torulaspora hansenii, Candida zeylanaides* and *Trichosporon cuteneum*	**Moulds** <1to 5 log cfu/g in 6/20 samples 55% *Aspergillus*, 13% *Penicillium*. *A. flavus* found 16/26 strains produced mycotoxins B1 and B2. Mycotoxin produced at Aw 0.85 not 0.80 Mould growth prevented at aw <0.70, presence of sorbate or good hygiene. 2000ppm sorbate at pH 5.7 not inhibitory to A. *flavus*.	Van der Riet (1976)
	1324 including biltong		*L. monocytogenes* detected in 57 samples, none biltong		Morobe *et al.* (2009)
	45 butchers, supermarkets, markets		1 sample positive for *E. coli* O157:H7		Abong'o and Momba (2009)
Mean values pH 3.77 Salt: 5.84% Moisture: 19.7 Aw: 0.72 (0.62-0.86) Cured 3 - 4 days, dried 3 - 4 weeks	9		**Log cfu/g**		Wolter *et al* (2000)
			Yeasts *Lactococci* *Lactobacillus* Total Viable Counts *Staphylocci*	2 - 7 4 - 8 4 - 8 5 – 8 4 - 8.5	

PROPERTIES	NO. OF SAMPLES	SAMPLE TYPE	ORGANISMS Log cfu/g	REFERENCE
10-12 % salt Home produced	2 (A&B)		Associated with *Salmonella* outbreak. A contained *S.* Newport after 4, 8, 12, 24 months. B contained *B. subtilis Streptococcus faecalis*, *E. coli* and *S.* Newport	Neser *et al* (1957)
-	121		1 contaminated *S. poona*. *E. coli* present in 34	Bokken-heuser quoted in Van den Heever (1965)
Mean values Salt: 6.6% pH 5.82 Moisture : 25.2% Aw: 0.742		60	*S. aureus* absent *Salmonella* present in 3.3% samples *E. coli* present in 45% samples Faecal streptococci present in 98.3% samples Yeasts and moulds present in 68.3% samples	Van den Heever (1970)
	141	Dried meat (6.0% of total samples, Biltong 93% of these.	97.2% satisfactory, 2.8% acceptable, 0% unsatisfactory, 0% hazardous. Satisfactory = <20 *L. monocytogenes*, *E.coli*, *Listeria* sp, *S. aureus*, *Salmonella* not detected in 25g. Acceptable 20-<10^2 *L. monocytogenes*, *E.coli*, *Listeria* sp, *S. aureus*.	Gormley, F.J. *et a l*(2010)

Table 7 Summary of microbiological growth data on biltong

FACTORS	ORGANISMS			REFERENCE
	L. monocytogenes	*S. aureus*,	*S. pasteuri*	
5.0 - 25% salt	Strains (x2) isolated from Biltong Growth at 5,10,15% No growth at 20 & 25%	Strains (x3) isolated from Biltong Growth at 5,10,15% One strain grew at 20% No growth at 25%	Strains (x3) isolated from Biltong Growth at 5,10% Two strains grew at 15% One strain grew at 20% No growth at 25%	Naidoo and Lindsay (2010b)
Temp 4, 25, 30, 37, 45°C	Strains (x2) isolated from Biltong Growth at 4,25,30, 37^{o}C No growth at 45^{o}C	Strains (x3) isolated from Biltong Growth at 25,30,37^{o}C No growth at 4 and 45^{o}C	Strains (x3) isolated from Biltong Growth at 25,30,37^{o}C No growth at 4 and 45^{o}C	
Glacial acetic acid	No growth	No growth	No growth	
Brown spirit vinegar	One strain grew	All strains grew	One strain grew	
Apple cider vinegar	One strain grew	One strain grew	One strain grew	
Water	All strains grew	All strains grew	All strains grew	
Spices. Mock biltong agar with beef extract & spices. Variations with no salt, no spice, no spice and sugar tested	Growth on agar with no NaCl, no beef and spice, no spice or sugar or no spice. One strain grew with no brown sugar. No growth observed with no beef extract	Growth on agar with no NaCl, no beef and spice, no spice or sugar or no brown sugar. No growth observed with no beef extract	Growth on agar with no NaCl, no beef and spice, no spice or sugar or no brown sugar. No growth observed with no beef extract	

Table 8 Summary of the effects of processing methods on the microbiological counts on biltong

PROPERTIES	PROCESSING	ORGANISMS			REFERENCE
pH 5.0-5.8	3.5 -7.0% acetic acid blended vinegar, 4% acetic acid & salted	3 log cfu/g *S. Typhimurim* not detected 3d after curing. *S.* Dublin inoculated 3h before curing survived 45 days. 3.5 % acetic *S.* Dublin isolated up to day 10. 7.0% acetic *S. Dublin* isolated up to day 28. Inoculating with 4 log cfu/g *S. Typhimurium* 4h before salting allowed survival for 12d Commercial biltong inoculated at days 2, 38, 41 allowed *Salmonella* to survive for 8, 8 + 1d			Van den Heever (1965)
Salt%1:24 (w/w)	1h at ambient then salted and stacked overnight	Strips inoculated then processed, *S. aureus* remained constant over 64d, *S. Typhimurium* decreased by 2 log cfu/g, *E. coli* decreased by 3 log cfu/g and *S. faecalis* level remained constant			Van den Heever (1970)
		Strips processed then inoculated. *S. aureus* detected at 40d. Growth studies found *S. faecalis* could be recovered from broth with 20% NaCl 37°C/24h. *S. faecalis* survived 72h in 40% NaCl broth, *S. aureus* 25%, *E. coli* and *Salmonella* 9% only *S. aureus* survived in 17.5%			
-	**Traditional:** Meat strips dipped in apple cider then spice (black pepper, corriander, salt, brown sugar) **Modern:** spice combined with apple cider vinegar **Processing:**4°C 18/20h, dried 25°C/3d	***L. monocytogenes*** **Log reduction cfu/g**	***S. aureus*** **Log reduction cfu/g**	***S. pasteuri*** **Log reduction cfu/g**	Naidoo and Lindsay (2010c)
		12h & 24h 1.0 36h & 48h 1.5 60h 1.6 traditional, 3.3 modern 72h ~2.7 84h 4.68 (=<1 cfu/g survived) traditional 3.8 modern 96h both 4.68 and <1	12h-72h 0.56 - 1.5 84h 1.7 traditional, 2.6 modern 96h 1.6 traditional, 3.07 modern Survival observed with modern method, 2-4 log reduction after drying, 4-6 overall	Traditional <1 log @ 96h. Modern 0.7 - 1.88. 1-2 log reduction after drying, 3-4 overall	
		TVC = 4.7 log cfu/g after marination. Increase of ~ 1 log cfu/g after drying traditional product, decrease of ~ 1 log cfu/g after drying of modern product. Yeasts and Gram positive rods dominated during processing. Gram negatives dominate raw meat Traditional method better for reducing *L. monocytogenes* but not *S. aureus*. Processing method effected survival			

<table>
<tr><th>PROPERTIES</th><th>PROCESSING</th><th>ORGANISMS</th><th>REFERENCE</th></tr>
<tr><td></td><td></td><td>Note: drying for 60-72h (moist products), would not destroy
L. monocytogenes</td><td></td></tr>
<tr><td>Salt
Pickling:2.5%
Drying 6.6%
pH
Fresh meat 5.72
biltong 5.80
Moisture
Pickling:73-75%
Drying: 3d 35% 6d~25%
Aw:
Fresh meat 0.986
Drying: 3d 0.86-0.87
6d~ 0.70</td><td>Dried 35°C, 30% RH air for 6d, stored ambient 6d</td><td>6-7 log cfu/g TVC.
Dominant flora: Micrococci, Bacilli and Staphylococci
Fresh meat: Pseudomonas, Achromobacter dominate, decreases to 40-55% on pickling, 7h of drying reduces from 40% to 3%. Micrococci decreased in pickling to 25-36%, increases to 36-83% of overall population on drying. Dominant species S. saprophyticus.
Sorbate added @ 1000ppm did not prevent bacterial growth, 1000ppm at pH 5.8 equivalent to 100ppm</td><td>Taylor (1976)</td></tr>
<tr><td>Aw ~ 0.60</td><td>Dried at 20 - 22°C, 38 - 64% RH. Seasoned beef strips 2.5cm thick, treated with 0.13% (v/v) peracetic acid spray before use. Dried for 17-26d VP and stored 7d at 22°C</td><td>Log reductions cfu/g
<table><tr><th>Aw during drying</th><th>@ aw 0.85</th><th>@ aw 0.60</th><th>After VP storage</th></tr><tr><td>Salmonella</td><td>2-3.3</td><td>3.0-3.3</td><td>3.1-4.2</td></tr><tr><td>E. coli O157:H7</td><td>2-2.8</td><td>2.8</td><td>2.8-4.4</td></tr><tr><td>S. aureus</td><td>-</td><td>1.2-1.7</td><td>1.7-2.6</td></tr><tr><td>L. monocytogenes</td><td>-</td><td>-</td><td>2-4.0</td></tr></table></td><td>Burnham et al.(2008)</td></tr>
<tr><td></td><td>beef strips immersed in 15% NaCl with 2-8 w/v K sorbate, before dry salting and stacking</td><td>8 log cfu/g yeasts and moulds present in commercial samples. Yeasts and moulds isolated from biltong inoculated onto product prior to processing. No growth observed on samples at room temperature or 30°C at 5 days. Sorbate treated samples showed no growth at day 21.
During normal commercial practice fungal growth would be controlled by salting in 20% NaCl + 2% K sorbate before drying</td><td>Van den Heever (1972)</td></tr>
<tr><td>Product aw 0.77, 30% moisture, preservative treated</td><td>0.1g K sorbate, 192h of drying at 28°C</td><td>Inoculated with Aspergillus glaucus group. No growth in 6 weeks for product + sorbate, if no preservative growth in 1 week. 2000ppm sorbic acid legal maximum in South Africa. Must account for lowering of moisture = increase in K sorbate concentration. 37% preservative can be lost in processing</td><td>Van der Riet (1981)</td></tr>
</table>

PROPERTIES	PROCESSING	ORGANISMS	REFERENCE
Meat from animal with S. Dublin made into biltong 27% moisture 7.7% salt 22% aqueous phase *Cysticercus bovis* contaminated meat used		S. Dublin present at 6 months even when vinegar dipped C. bovis present up to 15h after curing, 50% cysts viable after 40h and 0% at 136h	Van den Heever (1965)

Table 9 Microbiological data on the effects of processing method on jerky

PROPERTIES	PROCESSING	ORGANISMS			REFERENCE
Marinated - Salt % 2.24 @0h, 5.26@3.5h pH: 5.37 @0h, 5.53@3.5h moisture %: 62.8 @0h, 22.5@3.5h a_w: 0.98@0h, 0.67@3.5h Non Marinated - Salt % 0.01 @0h, 0.09@3.5h pH: 5.49 @0h, 5.60@3.5h moisture %: 70.9 @0h, 15.1@3.5h aw: 0.96@0h, 0.72@3.5h	Beef Commercial, +/- marinade 2 mins @23^{o}C, 13 min@4^{o}C drying @80.7^{o}C (63.1% RH) Smoked Temp (^{o}C) increased to 67.5^{o}C @ 1.5h 75.1 ^{o}C @ 2.5h and 75.8 ^{o}C @3.5h	*E.coli* Marinated: No survival @1.5h Non Marinated: No survival @2.5h	*Salmonella* Marinated: detected in 8/27 samples @ 3.5h Non Marinated: detected in 22/27 samples @ 3.5h	*L.monocytogenes* Detected in 2/3 out of 27 samples for marinated/non-marinated	Porto-Fett *et al* (2008)
		An average decrease of >6.90 log cfu/g was observed.			
Aw: @5h A 0.854 @3.5-4h B 0.866, C 0.842, D 0.830 156ppm nitrite present	Beef A non marinated 76.6^{o}C 1h B cook in marinade 54.4^{o}C 121 mins C cook in marinade 60^{o}C/2mins D cook in marinade 70^{o}C/1s	About a 2 log reduction in TVC was observed for processes C&D. A had the lowest counts. Cooking in marinade is an alternative to monitoring the temperatures and RH during drying			Allen. *et al(*2007)
Aw <0.85 within 4-5h, final aw 0.44-0.65	Beef 12-24h commercial or home-style Home style: 51.7 – 68.3^{o}C (come up time up to 164 mins Commercial: 71.7^{o}C (come up time up to 47 mins) RH 12.4-55.5%	Log reductions (cfu/g)	*E.coli* O157	*Salmonella*	Borowksi *et al* (2009a)
		57.2^{o}C/4h	1.5	1.7	
		68.3^{o}C/12h	6.4	6.0	

		>5.0 log cfu/g reduction in 0,10 and 27% of samples 4-6h after drying Post drying treatment of 135^{o}C for 10 min 4/6h after drying increased reductions by ~ 3.0 log cfu/g Evaluated *Pediococcus* as a surrogate for *E.coli* O157 and *Salmonella* in processing. Reductions correct in 28 % and 78% of cases respectively				
-	Beef Large scale : 44min@55.6^{o}C 46min@77.8^{o}C <10% RH Small scale**:** 45min@52^{o}C, 60 min@57^{o}C, 45min@60^{o}C, 45min@63^{o}C, 90min@68^{o}C, 30 min@77^{o}C 15-2% RH	>5.0 log cfu/g reduction of *Salmonella* and *E.coli* O157				Harper *et al* (2009)
pH 5.56-6.44 aw: large scale no smoke 0.67-0.83 + smoke 0.75-0.90 Small scale 0.78	Commercial small and large scale Ground and formed beef mixed with dry spice + cure Small scale	log cfu/g reductions during processing	*E.coli* O157	*Salmonella*		Borowski *et a*l (2009b)
		Large scale	4.50-8.11	4.40-7.45		
		Small scale	3.88	3.27		
		Reductions varied depending upon spice mix and were greater in the absence of smoke				
pH 4.4-5.6 Aw 0% raisin present 0.80, 10% ~0.70, 50% raisins present 0.50. Aw decreased on storage		10% raisin beef jerky (aw 0.70) – no growth of *S.aureus*, *E.coli* O157, *L.monocytogenes* Jerky with no raisins allowed growth of *S.aureus* Overall log cfu/g reductions (0.5-3.50) increased with increasing raisin % No TVC was present in samples stored for 10 weeks@30^{o}C and *Salmonella* or *L.monocytogenes* was present at week2, *S.aureus* survived in all samples ~ 1.5 log cfu/g at 4 weeks. Action probably due to decrease in aw associated with presence of raisins.				Bower, *et al* (2003)
Marinade pH 4.5 and contained salt		log cfu/g reduc.	*E.coli* O157	*L.monocytogenes*	*Salmonella*	Harrison *et al* (2001)
		Marinating Drying/oven	0.5 >5.78	1.79 >3.90	*0.53* *>5.24*	
	Home style food dehydrators used. Beef jerky made +/- marinade	Non marinated drying/oven cook (processes A,B,D).	3.0-4.6			

	A = marinade 4°C overnight, dehydrate @60°C B= marinade4°C overnight,, dehydrate @60°C, heat 135°C /10 min in oven C= marinade 4°C overnight, boil 5 mins, dehydrate @60°C D= marinade 4°C overnight, heat 163°C /10 min in oven dehydrate @60°C	Non marinated C	> 5.77	>3.91	> 5.59	
		final drying for B,C, D	>5.77	>3.91	4.0-5.0	
		dehydrated@60°C heated at 135°C for 10 min marinated	1.86	3.39	2.15	
		dehydrated@60°C heated at 135°C for 10 min non marinated	2.36	3.09	2.27	
		Salmonella survived the traditional process, an additional heating step after drying produces a safe product as is a safe alternative to cooking at 71.1°C before drying.				
2% salt (w/w), 156ppm sodium nitrite Aw: varied depending upon process but final samples ranged from 0.65 - 0.91	Beef jerky Marinated @pH 5.3 for 22-24h @5°C	Log cfu/g reduction	*Salmonella*	*E.coli* O157		Buege *et al* (2006)
		wet-bulb temp are achieved/ maintained early (51.7°C or 54.4°C for 60 min, 57.2°C for 30 min or 60°C for 10 min (RH 27,32,37,43%) and drying @ 76.7°C for 90 min.	>6.4	>6.4		
		heating/drying@76.7°C within 90 min or heating for hourly intervals @ 48.9, 54.4,60°C and drying @ 76.7°C or heating at 56.7°C and drying@76.7°C before the aw is <0.86	>5.0	>5.0		

<table>
<tr><td></td><td></td><td>Marination only reduced levels ~0.4 log cfu
Reductions were not as great (~4.0 log cfu/) if dry heat (61 or 71.1^{o}C) with no added humidity was used but heating at 82.2^{o}C resulted in ~5.0 log cfu. decrease.

Sublethal drying can make Salmonella more resistant to heat and was shown by reductions being lower if drying began at aw 0.72 or 0.81.
Concluded that wet bulb temperature and humidity are important factors in production of safe jerky.</td><td></td></tr>
<tr><td></td><td></td><td>E.coli O157
Log reduction cfu/g

Non heated | Heated
3h drying ~3.0 10h drying ~ 5.5 | >5.0 before drying 10h Not detected

S.Typhimurium
Log reduction cfu/g

Non heated | Heated
3h drying ~3.0 10h drying ~ 5.5 | >5.0 before drying 10h Not detected

L.monocytogenes
Log reduction cfu/g

Non heated | Heated
3h drying ~1.8 10h drying ~ 6.0 | 4.5 before drying 10h Not detected

After 8 weeks storage no pathogens detected</td><td></td></tr>
<tr><td>Moisture:
non heated ~70% @0h to 23.8% @4-5h
heated 59% @0h to 18.5% @4-5h</td><td>Marinated 1h@4^{o}C or Marinated & heated @ 71.1^{o}C
Followed by drying in food dehydrator@60^{o}C and @aw 0.75,0.84,0.94 and in air</td><td></td><td>Harrison and Harrison (1996)</td></tr>
<tr><td>Heat treated samples
Aw: cured @0h 0.96, 6h 0.74
Uncured: @0h 0.99, 6h 0.85
unheated samples
Aw: cured @0h 0.95, 6h 0.73
Uncured: @0h 0.99, 6h 0.69</td><td>Commercial beef jerky mix used
Cured/uncured dried@60^{o}C for 8h with/without heating to 71.1^{o}C before drying</td><td>Salmonella (log reduction cfu/g)
Drying time 2h | 6h(H) | 8h (N)
Heated (H) cured: 4.5 | 4.9
Heated (H) non-cured: 1.8 | 3.9
No heating (N) cured: 2 | 4.2
No heating (N) non-cured: 0.5 | 3.2

L.monocytogenes (log reduction cfu/g)
Drying time 2h/oven | 6h(H) | 8h (N)
Heated (H) cured: 2.8 | 3.2
Heated (H) non-cured: 2.0 | 3.7
No heating (N) cured: 0.9 | 4.02
No heating (N) non-cured: 0.2 | 2.5

Curing and heating increased the reductions observed.</td><td>Harrison, Harrison and Rose (1997)</td></tr>
<tr><td><table><tr><td></td><td>73.8oC</td><td colspan="2">82.2oC</td></tr><tr><td>Marinated</td><td>0h</td><td>3.5h</td><td>2.5h</td></tr><tr><td>Salt %</td><td>1.75</td><td>5.66</td><td>2.84</td></tr><tr><td>Moist</td><td>71</td><td>35.2</td><td>37.67</td></tr></table></td><td>Turkey strips dried @73.8^{o}C for 2.5/ 3.5h or 82.2^{o}C for 1.5 or 2.5h
Hickory smoked
Product was dried +/-</td><td><i>Salmonella</i>, <i>L.monocytogenes</i> and <i>E.coli</i> O157 inoculated onto turkey strips before drying.
Drying @73.8^{o}C for 3.5h reduced levels by $\geq$7.1log cfu/strip for all organisms +/- marinade
2.5h drying resulted in 5.4-6.2 log cfu/strip reduction.
Drying marinated samples @82.2^{o}C resulted in $\geq$7.1log cfu/strip reduction</td><td>Porto-Fett et al (2009)</td></tr>
</table>

<table>
<tr><td>ure%</td><td></td><td>7</td><td></td><td>marinade
Only strips that were marinated and dried for 3.5h@73.8oC achieved an aw <0.80 and MPR of ≤0.75:1.0</td><td colspan="2">for all organisms
Drying non marinated samples @82.2°C resulted in ≥7.4log cfu/strip reduction for E.coli O157 and Listeria and 6.8 log cfu/strip for Salmonella.

Marination affected lethality at 73.8°C for 2.5h for all 3 pathogens and Listeria at 82.2°C

Marinated raw turkey mean TVC 5.25 log cfu/g and lactics 4.18 log cfu/g
Non marinated raw turkey mean TVC 4.22 log cfu/g and lactics 4.17 log cfu/g

All processes meet requirements for 5 log reduction of E.coli O157, 7.0 log reductions of Salmonella and zero tolerance for Listeria monocytogenes.

Table continues on next page....</td><td></td></tr>
<tr><td>aw</td><td>0.96</td><td>0.80</td><td>0.84</td></tr>
<tr><td>pH</td><td>6.29</td><td>5.87</td><td>5.88</td></tr>
<tr><td colspan="4">Non- marinated</td></tr>
<tr><td>Salt %</td><td>0.05</td><td>0.02</td><td>0.11</td></tr>
<tr><td>Moisture%</td><td>72.3</td><td>39.06</td><td>43.18</td></tr>
<tr><td>aw</td><td>0.99</td><td>0.94</td><td>0.95</td></tr>
<tr><td>pH</td><td>6.99</td><td>6.01</td><td>6.14</td></tr>
<tr><td colspan="4">Salt: 9.8-34.0% (waterphase)
pH 5.3-6.3
aw 0.47-0.87</td><td>15 types of jerky x 3 samples of each examined</td><td>L.monocytogenes
Log reduction (cfu/g)

1 week: 0.6-4.70
4 weeks : 2.3-5.60
Largest reductions in product aw 0.83,0.81, 0.73
No growth observed</td><td>S.aureus
Log reduction (cfu/g)

1 week: 0.2-1.8
4 weeks : 0.6-5.3
Largest reductions in product aw 0.74,smallest 0.80
No growth observed</td><td>Ingham, S.C. et al (2006)</td></tr>
<tr><td colspan="4">pH ~5.5-5.65
aw 0.94 in 1.25h , <0.86 in 2.5-3.0h
moisture 60% at start, 30% 4h, 20% at 8h</td><td>Beef
Domestic food dehydrator
52.9°C +/- 0.8°C for 4h, 48.2°C+/- 0.8°C for 4h, marinated</td><td>S.aureus
Log reduction (cfu/g)

No decline in 8h</td><td>B.subtilis
Log reduction (cfu/g)

~1.0-1.5 in 8h</td><td>Salmonella
Log reduction (cfu/g)

~1.0in 8h survival observed</td><td>C.perfringens
Log reduction (cfu/g)

~3.0 in 8h
no survival</td><td>Holley (1985a)</td></tr>
<tr><td colspan="4"></td><td colspan="4">Further broth studies: 52.9°C for 4h + 48.2°Cfor 4h
2h : No survival of Salmonella or C.perfringens
4h : No survival of S.aureus
8h: No decline on B.subitlis
Salmonella did not survive on jerky @25d chilled or ambient. C.perfringens present @25°C not 20°C, Staphylococci present at 26d @25°C not 20°C</td></tr>
</table>

	pH		aw				
	Dried	60d	0h	Dried	60d	Beef Marinated 24h@4°C,dried 60°C/10h, 25°C/60d Processes: **1.** No marinade **2.** Traditional marinade **3.** Double traditional + 1.2% lactate.9% acetic acid, 5% ethanol, 68% soy sauce **4.** dip in 5% acetic acid, traditional **5.** dip 1% Tween, 5% acetic acid, traditional	*Salmonella* inoculated before processing. Larger reductions observed for process 5. (4.8-6.0 log cfu/g) than other treatments. Efficacy of processes: 5>4>3>2.>1 Tested acid adapted and non adapted cells, non adapted cells were more resistant. Majority of the reduction within 4h. Survival was observed for 1-5 @day 0 and 1,2,4 @day 60. Modified marinades are effective in reducing *Salmonella* levels.	Calicioglu, *et al* (2003a) (similar findings in Calicioglu M. *et al* (2003c))
1	5.87	5.91	0.96	0.66	0.65		
2	5.88	5.90	0.96	0.64	0.64		
3	4.84	4.98	0.95	0.56	0.61		
4	4.79	4.98	0.94	0.73	0.62		
5	4.71	4.98	0.95	0.69	0.65		

Process	pH (mean)	aw	Beef Processes **1**. No marinade **2**. Traditional **3**. 5% acetic acid/10 min All above 52,57,63°C for 10h Temp reached in 5h.	*Salmonella* decreased up to 2.40 log cfu/cm before drying with process 3. About 1.5 log cfu injured cells were present after acid treatment. Rapid decrease in level 2-8h of drying, greater at 63oC ~ 1.5 log cm^2/h 1+2 gave 0.29-0.63 log cm^2/h Model developed for inactivation of Salmonella at different times/temps of drying.	Yoon *et al* (2009)
1	5.49	52°C up to 0.617			
2	5.37	57°c up to 0.666			
3	4.36	63°C up to 0.555			

	pH (60d)	Aw (60d)	Beef Marinated 24h@4°C,dried 60°C/10h, 25°C/60d Processes: **1.** No marinade **2.** Traditional marinade **3.** Double traditional + 1.2% lactate.9% acetic acid, 5% ethanol, 68% soy sauce **4.** dip in 5% acetic acid, traditional **5.** dip 1% Tween, 5% acetic acid, traditional	*Listeria* inoculated before processing. *S*urvival rate was lower with processes 2-5 @ day 42 but by day 60 they were similar. Tested acid adapted and non adapted cells, non adapted cells were survived better on control and traditional samples. Levels were lower than the limit of detection by day 42,28 and 42 for treatments 3-5 non adapted and 60,42,42 for adapted cells. Modified marinades are effective in reducing *Listeria* levels.	Calicioglu *et al* (2003b) (similar findings in Calicioglu *et al* (2002a))
1	~5.70	0.648			
2	~5.50	0.597			
3	~4.80	0.618			
4	~4.70	0.621			
5	~4.70	0.645			

Process	pH (mean)	aw	Beef Processes **1**. No marinade **2**. Traditional **3**. 5% acetic acid/10 min All above 52,57,63^{o}C for 10h Temp reached in 5h.	*Listeria* reductions (log cm^{2}/h) ranged from 3.9-5.1 for process 2 , to >6.0 for process 3. A rapid decrease was observed in 2h and no difference in reduction rate at 52-63^{o}C.	Yoon *et al* (2006)
1	5.49	52^{o}C up to 0.617			
2	5.37	57^{o}c up to 0.666			
3	4.36	63^{o}C up to 0.555			
Salt: 14.4% (water phase) pH: 5.6 aw: 0.75			beef	*L.monocytogenes* inoculated after processing. Level reduced by 2.8 log cfu/g @ 7d/21^{o}C Not detected (3.6 log cfu/g reduction) @ 5 weeks	Ingham, S.C. , *et al* 2004
Salt: 1.8% Mean aw 3h 0.64, 6h 0.65, 9h 0.57, 12h 0.49			Cured and spiced beef Dried @ 60^{o}C for 3,6,9,12h 1. VP 2. Hot water 72^{o}C/20s VP 3. 2% sodium lactate added	*L.monocytogenes* initially reduced by ~0.4 log cfu/g with process 2, @ 3 weeks ~ 3 log cfu/g @ 6 weeks process 1+2 lower than limit of detection Treatment 2 more effective	Boles *et al* (2006)
	pH (60d)	Aw (60d) Adapted/non	Beef Marinated 24h@4^{o}C,dried 60^{o}C/10h, 25^{o}C/60d Processes: **1.** No marinade **2.** Traditional marinade **3.** Double traditional + 1.2% lactate.9% acetic acid, 5% ethanol, 68% soy sauce **4.** dip in 5% acetic acid, traditional **5.** dip 1% Tween, 5% acetic acid, traditional	*E.coli* O157 (acid adapted/non-adapted) inoculated prior to processing. Reductions of 4.9-6.7 log were achieved after drying for process 5 and 2.8-4.9 log for processes 1-4. Efficacy of processes: 5>4>3>1.>2 Acid adapted cells decreased faster than non adapted cells for processes 4&5. Levels lower than limit of detection achieved on days 60,60,30,30,15 for processes 1-5 adapted and 60,60,30,60,30 non adapted. Survival @60d was observed for control and traditional samples. Acid-adapted cells were no more resistant and processes 2-5 plus 60d storage will give 6.50 log decrease as will traditional method @60d.	Calicioglu *et al* (2002b)
1	~5.70	0.66/0.69			
2	~5.70	0.65/0.73			
3	~5.0	0.67/0.6			
4	~4.80	0.67/0.68			
5	~4.80	0.67/0.67			
Aw: ranged from 0.577-0.664			As Calicioglu M. *et al*	*E.coli* O157 Efficacy of processes: 5>4>3>1.>2	Calicioglu *et al*

	2002b except dried jerky inoculated	Reduction of 5.0 log within 7 days for processes 4 & 5 and >60d for 1&2. No survival detected on days 28 for processes 3-5 with acid adapted cells and 42 for 4-5 with non adapted cells. Modified marinades and low aw can reduce levels if post process contamination occurs.	(2003d)
aw: 0.70 after 6h drying	Beef used +/- cure and +/- pre-cook to 71.1°C. Dried in dehydrator at 60°C for 8h.	*E.coli* O157 inoculated into beef before processing. No cook or cure reduced level by 4.3 log cfu/g @8h, no cook plus cure by 5.2, cook no cure by 4.8 @6h, and cook plus cure 5.2 @6h. A greater decline is observed when cure mix was used.	Harrison *et al* (1998)
-	62.8°C for 10h	New Mexico Environment Dept (1989) recommends cooking & drying jerky for 3h with an internal temp of 63°C for beef,lamb, fish and 74°C for poultry with a final aw of <0.85 *E.coli* O157 was still recovered after this treatment	Nummer, *et al.* (2004)
Finished product pH : 5.39-6.0 Aw: 10h drying ~0.65 marinated 10h drying (62.5°C) non marinated 0.83	Beef slices prepared +/- marinade, dried at 62.5°C or 68.3°C for 10h. Stored for 90 days @21°C. Home-style food dehydrator used.	Inoculated with *E.coli* O157 before processing. marination reduced levels up to 0.6 log cfu/cm^2. No difference in reduction +/- marinade during drying. Most reduction in 4h. @62.5°C reductions were ~3.0 log cfu/cm^2 unmarinated ~ 2.2 marinated. At 63.5°C reduction of 3.0-4.6 marinated. No treatment achieved 5.0 log reduction until product was stored for 30d. Aw higher for non marinated samples and mould growth could be observed.	Albright *et al* (2002)
	Beef mix with 5 & 20% fat prepared and inoculated with *E.coli* O157. Dried @ 52,57,63,68°C for 2-20h.	*E.coli* O157 levels reduced by 5 log cfu/g by 4 or 8h at 68°C and 63°C regardless of fat content. At 57°C 5 log reduction @ 10h @5% fat, 16h@20% fat. At 52°C 5 log reduction @10h@5% and 20h @20%. Survival was observed in 1 sample at each temp. Fat content and drying time/temp are important for pathogen survival.	Faith *et al* (1998)
pH: ranged 5.7-6.0 aw: 0.93-0.94 @0h, 4h of drying 0.84-0.89 Time to aw 0.68 for each process: 1 .>10h (0.75@10h)	Beef jerky. Home style dehydrators Process: 1. Immerse in water 94°C/15s- marinate	Inoculated with *E.coli* O157 before drying. Dipping in hot water, seasoning, dipping in water/vinegar and hot pickling gave 2.4 l, 0.8,0.8, and 2.3 log cfu/cm^2 reductions. If samples were marinated and then dipped in water/vinegar a slight increase was observed. Drying gave reductions of 3.8,5.6 log cfu/cm^2 for treatments 1-2 and 4.4-4.9	Albright *et al* (2003)

2. 8h 3/ 4 . 10h	(4^oC/24h) 2. season (4^oC/24h) immerse in picking brine (78^oC/90s) 3. immerse 50:50 vinegar/water(57.5^oC/20s) 4. marinate (4^oC/24h) 1-4 dried at 62.5^oC for 10h	for treatments 3-4. A further decrease of up to 0.8 log cfu/cm^2 was achieved @10h. Final products stored @21^oC @aw 0.75,9.84,0.94) for up to 90 days. <1 log cfu/cm^2 detected @30,60,90days for all products. >5.0 log cfu reduction only achieved by season/hot pickling. Other processes only achieved a 4.0-5.0 log cfu reduction@10h.	
aw: 0.86 @1-2.5h for beef and 3-3.5h for corned beef	Fresh beef marinated 4^oC/12h in commercial mix Corned beef not marinated stored 4^oC/12h Domestic food dehydrator used 68.3^oC 4h then 60^oC 4h actual temperatures were 52.9 and 48.2^oC respectively	TVC decreased @4h, coliforms decreased from 0h Sporeformers increased @2h for corned beef & 4h beef @8h 75% reduction of TVC on corned beef, 50% on beef *S.aureus* inoculated before processing only 15% survival at 8h, and 5% survived after 1 week @2.5^oC Good quality meat and rapid drying will produce safe jerky	Holley (1985b)
Aw $\leq$ 0.82 pH 5.7-6.4 Salt% water phase: 10.6-18.4		Dried jerky inoculated with *S.aureus*. Log reduction of 1.0-2.6 log cfu/g @ 1 weeks, 3.2-4.5 log cfu/g @ 4 weeks pH and moisture protein ratio correlated to survival but pH and aw or ph and % salt could be used to predict survival.	Ingham *et al* (2005)

Table 10 Data on *toxoplasma* in jerky

STUDY DETAILS	REFERENCE
Toxoplasma gondii infection linked to consumption of undercooked meats. Study assesses effectiveness of process steps in production of dried meats. Cysts should be inactivated by freezing (3d@≤-12^{o}C or 28h@≤-20^{o}C) , heat treatment (55^{o}C/20min, 61^{o}C/3.6min, 67^{o}C/7s) and interaction of salt and maturation time ahs effect depending on concentration/temperature and time. (e.g. 10,15,20^{o}C for 3-35d 6% salt has an effect, lower salt % requires longer times at lower temperatures to have an effect). If processed correctly risk of *Toxoplasma gondii* should be minimal in dried meats.	Mie *et al(*2008)
Toxoplasma gondii survival assessed in nikku (seal meat dried for 45h @20-22^{o}C 35% RH) stored at 4^{o}C for up to 132 days. Cat infectivity used to monitor presence in samples. None of nikku samples were positive but source meat was.	Forbes *et al* (2009)
Studied of infected women in Canada showed that infected women four times more likely to have eaten dried seal meat.	McDonald *et al* (1989)
Brazilian study found that eating cured/dried or smoked meat increased risk of infection.	Jones *et al* (2006)

Table 11 Summary of Outbreaks and Recalls
UN = Unknown

DATE	TYPE	NUMBER OF CASES	LOCATION	MANUFACTURER'S CONDITIONS	SCALE	ORGANISM	REFERENCE
1949	Game Biltong	UN	UN	UN		*Salmonella Lanita*	Jansen (1949)
1957	Biltong	21 (1 death)	UN	UN	UN	*Salmonella* Newport	Neser *et al* (1957)
1963	Biltong	UN	UN	UN	UN	*Salmonella* Anatum	Bokkenheuser (1963)
1966	Venison Jerky	3	California	UN	Home	*Clostridium botulinum* F	Midura *et al.* (1972)
1966	Beef Jerky	97	New Mexico	UN	Commercial	*Salmonella* Thompson	Eidson *et al*. (2000)
1982	Beef Jerky	15	New Mexico	38°C to 43°C	Commercial	*Staphylococcus aureus*	Eidson *et al*. (2000)
1985	Carne Seca	29 (44)	New Mexico	Solar dry 3-4 days, marinated before dry	Commercial	*Salmonella* Cerro	MMWR, 25/10/85, **34**(42), 645-646. Eidson *et. al*., (2000) reports 44 cases from beef Jerky
1986	Beef Jerky	5	New Mexico	60°C	Commercial	*Salmonella* Montevideo	Eidson *et al*., 2000
1987	Jerky	4-7	New Mexico	UN	Probably small scale	*Salmonella* Newport	Eidson *et al*., (2000)
1988	Beef Jerky	23	New Mexico	Improper control of dehydrators, 27°C-32°C for 5h	Two commercial processors taking beef from same source	*Salmonella* Newport	Eidson *et al*. (2000)
1995	Venison Jerky	11	Oregon	52°C - 57°C, 12 to 18h	Home	*E. coli* O157:H7	Marchello, M.J. and Robinson, J.

							UDSU. Keene *et al*., (1997), 227 (15), 1229-1231.
1995	Cougar Jerky	10	Idaho	Brined smoked, smoking cool	Home	*Trichinella*	MMWR, 15/03/96, **45**(10), 205-206
1995	Beef Jerky	93	New Mexico	Frozen beef, 60°C/3h, then 46°C/19h	Commercial	*S. Typhimurium, S. Montevideo, S. Kentucky*	MMWR, 27/10/95, **44**(42), 785-788
1995	Antelope Jerky	5 one case consumed Jerky twice and became ill twice	New Mexico	UN	Home	*Staphylococcus aureus*	Eidson *et al*., (2000)
1997	Bear Jerky	5	Montana	Dry cure, heat not reported	UN	*Trichinella*	MMWR, 25/07/03, **52**(5506), 1-8
1999	Pork Jerky	2	Illinois	UN	Commercial	*Trichinella*	MMWR, 25/07/03, **52**(5506), 1-8
2002	Biltong	17	Botswana	UN	UN	Unknown agent	Tshekiso (2002)
2003	Jerky	22	New Mexico	Aw 0.30, 82°C oven, 30°C wet bulb	Commercial	*Salmonella kiambu*	Smelser (2004)
2008	Beef Biltong	16	London	UN	Commercial	*S. Typhimurium* DT 104	HPR, **3**(10)

Table 12 Key factors to include in a HACCP plan for the small scale manufacture of biltong

Raw Materials and Other Inputs

RAW MATERIAL / OTHER INPUT	DESCRIPTION / SPECIFICATION
Beefs cuts (frozen or fresh, boneless)	High quality, low microbial load
Spice mix including any acid if used	Provided by supplier
Packaging materials	Suitable for food contact

Summary of Process and Requirements

Microbial hazards include *Salmonella* spp., *E. coli* O157:H7, *Campylobacter jejuni*, *Clostridium* spp., *Bacillus cereus*, *Listeria*, *S. aureus*, and mycotoxin producing moulds.

PROCESS STEP	HAZARD ID (eg chemical or microbial)	CONTROL MEASURE	CRITICAL LIMITS	MONITORING PROCEDURES	CORRECTIVE ACTION
Raw material intake	Presence of enteric pathogens, associated with faeces, due to poor quality meat	Visual inspection of meat	Ensure good quality meat	Check good quality meat	Disposal of meat if poor quality
Storage of meat	Growth of enteric pathogens, associated with faeces, due to incorrect storage temperature	Control of freezer or chiller temperature	≤-18ºC frozen storage; ≤ 4ºC chilled storage for correct time	Air temperature measurement. Time of chilled storage.	Disposal of meat if extreme temperature abuse or adjust storage temperature
Thawing/tempering of meat	Growth of pathogens due to incorrect thawing conditions	Control of thawing temperature and meat temperature	0 to 4ºC air temperature. 0 to 4ºC meat temperature. Time dependent on size of cut	Room and meat temperature and time.	Adjust temperature and time of thawing conditions.
Prepare meat into strips and trim-off fat	Introduction of pathogens due to cross-contamination from surfaces, people and equipment	Effective hygiene procedures (cleaning, tidying)	All staff trained. Hygiene procedures to be followed at all times.	Ensure surfaces are visually clean. Ensure cleaning procedures carried out correctly.	Repeat hygiene procedures. Re-train as necessary.
Prepare meat into strips	Survival of organisms	Strip size.	Not above defined size.	Assess thickness.	Sort, size, and cut strips if

and trim-off fat	during pre-drying due to incorrect strip size				necessary.
Spices intake	Presence of spore forming organisms in spices obtained from supplier.	Use recognised good quality supply.	Only use spices from good suppliers.	Check supplier credentials.	Change supplier if necessary.
Marination	Growth of organisms due to poor marination conditions of temperature, time, and marinade composition.	Control temperature and time and amount of ingredients	≤4ºC. Maximum 24 h. Measure amounts of ingredients to ensure correct.	Marinade temperature Quantity of ingredients added.	Correct the storage temperature, input correct levels of ingredients
Drying	Growth of organisms due to incorrect treatment.	Control temperature, time and humidity.	Use heated ambient air.	Air temperature and time. Measure weight loss to assess water activity.	Adjust drying temperature and time if required.. Dry for longer if weight loss not sufficient.
Packaging	Presence of organisms on packaging due to contaminated supply.	Use recognised good quality supply.	Only use packaging from good suppliers.	Check supplier credentials.	Change supplier if necessary.
Packaging	Introduction of organisms due to contaminated packaging.	Store packs in hygienic conditions. Train staff to storage packs in correct location and keep area clean.	Good handling practices to avoid cross contamination.	Ensure that storage conditions are hygienic.	Clean and disinfect storage area if needed. Re-train staff if needed.
Storage of un-packed biltong by manufacturer	Growth of mycotoxin producing moulds due to moisture uptake during storage	Store in clean and dry conditions.	Maintain dry air conditions. Avoid sources of moisture such as cookers and dryers.	Examine surface condition of jerky. May measure relative humidity of the air.	Dispose of product if necessary.
Storage of packed biltong by manufacturer	Growth of mycotoxin producing moulds due to moisture uptake during storage	Use correct packaging material to prevent moisture ingress.	Only use packaging with good moisture barrier..	Check packaging is adequate, correctly sealed and product is visually acceptable.	Dispose of product if necessary.
Storage by consumer	Growth of moulds	Provide instructions on pack (clean, dry conditions and avoid light) or advise verbally if unwrapped. Provide guidance on shelf life.	Ensure instructions are clear.	Ensure instructions given.	Recall if necessary.

Table 13 Key factors in HACCP Plan for the small scale manufacture of jerky (based on USDA, 1999 and 2007)

Raw Materials and Other Inputs

RAW MATERIAL / OTHER INPUT	DESCRIPTION / SPECIFICATION
Beefs cuts (frozen or fresh, boneless)	High quality, low microbial load
Spice mix including any acid if used	Provided by supplier
Packaging materials	Suitable for food contact

Summary of Process and Requirements

PROCESS STEP	HAZARD ID (eg chemical or microbial)	CONTROL MEASURE	CRITICAL LIMITS	MONITORING PROCEDURES	CORRECTIVE ACTION
Raw material intake	Presence of Enteric pathogens, associated with faeces, due to poor quality meat	Visual inspection of meat	Ensure good quality meat	Check good quality meat	Disposal of meat if poor quality
Storage of meat	Growth of Enteric pathogens, associated with faeces, due to incorrect storage temperature	Control of freezer or chiller temperature	≤-18ºC frozen storage; ≤ 4ºC chilled storage for correct time	Air temperature measurement. Time of chilled storage.	Disposal of meat if extreme temperature abuse or adjust storage temperature
Thawing/tempering of meat	Growth of pathogens due to incorrect thawing conditions	Control of thawing temperature and meat temperature	0 to 4ºC air temperature. 0 to 4ºC meat temperature. Time dependent on size of cut	Room and meat temperature and time.	Adjust temperature and time of thawing conditions.
Prepare meat into strips and trim-off fat	Introduction of pathogens due to cross-contamination from surfaces, people and equipment	Effective hygiene procedures (cleaning, tidying)	All staff trained. Hygiene procedures to be followed at all times.	Ensure surfaces are visually clean. Ensure cleaning procedures carried out correctly.	Repeat hygiene procedures. Re-train as necessary.
Prepare meat into strips and trim-off fat	Survival of organisms during pre-drying due to incorrect strip size	Strip size.	Not above defined size.	Assess thickness.	Sort, size, and cut strips if necessary.
Spices intake	Presence spore	Use recognised good	Only use spices from good	Check supplier credentials.	Change supplier if necessary.

	forming organisms in spices obtained from supplier.	quality supply.	suppliers.		
Marination	Growth of organisms due to poor marination conditions of temperature, time, and marinade composition.	Control temperature and time and amount of ingredients	≤4ºC. Maximum 24 h. Measure amounts of ingredients such as salt, nitrite, sorbate are correct.	Marinade temperature Quantity of ingredients added.	Correct the storage temperature, input correct levels of ingredients
Transferring meat to pre-drying heating equipment	Introduction of organisms due to cross-contamination	Effective hygiene procedures	All staff trained. Hygiene procedures to be followed at all times.	Ensure surfaces are visually clean. Ensure cleaning procedures carried out correctly.	Repeat hygiene procedures. Re-train as necessary.
Pre-drying heating	Survival of organisms due to incorrect treatment.	Control temperature, and time, and humidity.	71ºC internal for beef ≥90% relative humidity of the air	Meat temperature. Air temperature and relative humidity.	Continue treatment if needed to achieve required meat temperature-time treatment.
Drying	Growth of organisms due to incorrect treatment.	Control temperature, time and humidity.	a_w<0.85 (in US) MPR <0.75:1 (in US) Do not add moisture to the air use ambient air and allow to escape from oven.	Air temperature and time. Measure weight loss for combined pre-drying and drying treatment.	Adjust drying temperature and time if required.. Dry for longer if weight loss not sufficient.
Post-drying heating (if previous pre=-drying conditions not adequate)	Survival of pathogens due to poor conditions	Control temperature and time.	135ºC for 10 min (in US)	Air temperature and time	Repeat process if not achieved correctly or dispose of product.
Packaging	Presence of organisms on packaging due to contaminated supply.	Use recognised good quality supply.	Only use packaging from good suppliers.	Check supplier credentials.	Change supplier if necessary.
Packaging	Introduction of organisms due to contaminated packaging.	Store packs in hygienic conditions. Train staff to storage packs in correct location and keep area clean.	Good handling practices to avoid cross contamination.	Ensure that storage conditions are hygienic.	Clean and disinfect storage area if needed. Re-train staff if needed.
Storage of un-packed jerky by manufacturer	Growth of mycotoxin producing moulds due to moisture uptake during storage	Store in clean and dry conditions.	Maintain dry air conditions. Avoid sources of moisture such as cookers and dryers.	Examine surface condition of jerky. May measure relative humidity of the air.	Dispose of product if necessary.
Storage of packed jerky	Growth of mycotoxin	Use correct packaging	Only use packaging with	Check packaging is	Dispose of product if

by manufacturer	producing moulds due to moisture uptake during storage	material to prevent moisture ingress.	good moisture barrier..	adequate, correctly sealed and product is visually acceptable.	necessary.
Storage by consumer	Growth of moulds	Provide instructions on pack (clean, dry conditions and avoid light) or advise verbally if unwrapped. Provide guidance on shelf life.	Ensure instructions are clear.	Ensure instructions given.	Recall if necessary.