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Review

Factors affecting microbial spoilage and shelf-life of chilled vacuum-packed lamb transported to distant markets: A review

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ABSTRACT

Vacuum-packaging and stringent control of storage temperatures enable the export of meat to distant markets, supplying a chilled product that can favourably compete with local fresh meats. To save fuel and reduce emissions, the speed of ships travelling to international markets has decreased resulting in requirement for the shelf-life of chilled lamb to be extended beyond the recognised time of 60–70 days. Growth of microorganisms and ability to cause spoilage of vacuum-packed lamb are dependent on many factors, including the type and initial concentration of spoilage bacteria, meat pH, water activity, availability of substrates, oxygen availability and, most importantly, storage time and temperature of the packaged product. This paper reviews the existing knowledge of the spoilage bacteria affecting vacuum-packed lamb, discusses the impact of these bacteria on product quality, shelf-life and spoilage, and concludes that under specified conditions the shelf-life of chilled lamb can be extended to beyond 70 days.

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1. Introduction

One of the key challenges for today's meat export industries is to get "fresh" product of superior quality to distant markets. The most commonly used method of preserving meat that provides the necessary product-life (without recourse to freezing or the addition of preservatives), is to vacuum-pack larger "primal" cuts, thereby excluding oxygen and preventing the growth of oxygen requiring spoilage bacteria (Gill, 1989). In order to further minimise decrease in product quality, storage life, due either to spoilage by bacteria capable of anaerobic growth or to biochemical processes affecting colour stability, a storage temperature of −1.5 °C has been recommended and is, for example, applied routinely to all chilled product shipped from New Zealand to overseas

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markets (Gill, Phillips, & Harrison, 1988; Jeremiah & Gibson, 2001). For these storage conditions, temperatures above 0 °C would be considered abusive. These conditions are different to those employed for chilled storage of fresh meats close to retail outlets, where cuts may also be stored in air or modified atmospheres at temperatures of around 2 °C, and in this situation temperatures above 5 °C are considered abusive (James & James, 2004a; Tewari, Jayas, & Holley, 1999).

To avoid economic losses to the retailer, each meat product is given a specific storage lifetime, which is the period for which that product is expected to remain safe and there is no appreciable loss of quality; that is, the point at which colour and texture changes, and bacterial metabolic activities make the meat offensive to the senses of the consumer (Gill, 1983). Currently, the storage lifetime for vacuum packed lamb held at −1.5 °C has been estimated to be between 60 and 70 days (Bell, 2001; James & James, 2002). However, pressure on shipping companies to reduce their environmental impact and fuel costs has resulted in slowing their vessels by up to 20% ("slow steaming"), thus leading to increased shipping times (Psaraftis & Kontovas, 2013). This means that the storage life of vacuum-packed meat must be sufficient to allow for this change, so that quality standards are met when the product is sold to the consumer. At present, this can be achieved based on a generic storage life of 70 days at −1.5 °C. However, further decreases in shipping speeds may make the trade unsustainable without further extension of storage life (MIA, 2012). Further, as a consequence of these prolonged transport times, the meat microbiota of vacuum-packed lamb is likely to be substantially different to that of locally-sourced product, which may result in inappropriate and unnecessary rejection or downgrades. To ensure that chilled lamb subjected to prolonged transport is not discarded unnecessarily, the characteristics of spoilage bacteria over these longer storage periods need to be investigated. Existing literature concerning the microbiology of chilled meat has primarily focused on beef (Grau, 1980, 1981; Jones, 2004), with very little recent literature on the expected product life of vacuum-packed chilled lamb. Considerable progress has been made over the last decade to extend the shelf-life of chilled lamb, including a better understanding of the impacts of meat pH and water activity (a_w) on microbial growth. Furthermore, process hygiene has been improved in order to ensure that the initial number of microorganisms on meat is as low as possible. Technical advances have reduced the oxygen permeability of barrier films and allowed greater control of temperature throughout processing and transport. As a result, with careful control a product shelf-life of up to 12 weeks is now attainable for some cuts, particularly those of low pH (5.5–5.8) (Kiermeier et al., 2013). This review discusses current understanding of the microbiology of vacuum-packed chilled lamb and focuses on how the microbiota impact on expected shelf-life and microbiological criteria set by specific customers.

2. Vacuum-packaging

Vacuum-packaging refers to meat that has been placed into a bag of low oxygen permeability and a vacuum applied prior to sealing (Kropf, 2004a). As the vacuum is applied the packaging collapses ensuring close contact between the film and meat that can be further enhanced by shrink wrapping. Alternatively, vacuum skin packaging may be used on retail-sized cuts, the "skin" being thermoformed around the meat by drawing a high vacuum on both sides of the heated packaging film, then venting the upper side to air, forcing the film tightly over the product, removing the void around (though not within) the product. When meat is sealed with little headspace in oxygen-impermeable materials, the residual oxygen at the meat surface/package interface will be rapidly converted to carbon dioxide by the respiratory activity of the meat (Bell, 2001). In oxygen-depleted atmospheres, growth of aerobic spoilage bacteria is prevented and the microflora changes to one that is dominated by slow growing, CO_2 tolerant bacteria (Borch, Kant-Müermans, & Blixt, 1996). Although the shelf-life of lamb is greatly extended by vacuum-packaging, it will eventually be spoiled. Spoilage indicators include off-odours and discolouration (Bell, 2001).

Most of the published research on the microbiology of chilled lamb was carried out on meat vacuum-packed in a plastic bag with a low but measureable rate of oxygen transmission (Gill, 1996). The transmission rates for films routinely used for vacuum-packaging have improved, from the 30–40 $cm^3/m^2/24$ h at 25 °C reported in 1985 (Gill & Penney, 1985) to the 18.6 $cm^3/m^2/24$ h at 23 °C available today (Kiermeier et al., 2013). These transmission rates decrease further with temperature, particularly below 0 °C (Lambden, Chadwick, & Gill, 1985), making it difficult to determine the precise oxygen transmission into a chilled vacuum-packed sample or to determine what impact this has on the development of the bacterial microbiota at the meat/package interface long-term. Nevertheless, Gill and Penney (1985) showed that storage life was improved when lamb loins were stored at 0–0.5 °C in foil laminates of immeasurably low permeability compared to loins stored in the 30–40 $cm^3/m^2/24$ h at 25 °C plastic films.

Premature spoilage of vacuum-packed meat is usually due to "leaky" packaging — e.g. from the sharp ends of bones or poor seals (CSIRO, 2003). Most meat producers now check pack seals prior to shipment, and specially-designed bags with thicker walls are now available to pack bone-in product. Kiermeier et al. (2013) compared the storage life of bone-in versus bone-out lamb shoulders at −0.3 °C and found no significant differences between microbial communities or sensory test scores.

3. Microbiology of vacuum-packed chilled lamb

It is generally accepted that it is not feasible to produce meat without some degree of bacterial contamination (Mills, 2012a). A variety of bacterial species can be isolated from lamb carcasses post-slaughter, although the majority are poorly adapted to growth on the meat matrix under chilled anaerobic storage conditions (Marshall & Bal'a, 2001). Consequently, whilst aerobic spoilage bacteria such as *Pseudomonas* spp., and mesophilic bacteria such as *Escherichia coli*, can sometimes be detected, they are unable to rapidly proliferate. Rather, following a period of chilled storage, the resulting microbiota of vacuum-packed lamb is dominated by some strains of lactic acid bacteria (LAB), notably *Leuconostoc* spp. and *Carnobacterium* spp. (Jones, Hussein, Zagorec, Brightwell, & Tagg, 2008). Other bacteria that grow on chilled vacuum-packed lamb include some environmental species of psychrotrophic *Enterobacteriaceae*, notably *Serratia* spp., *Hafnia alvei*, *Rahnella aquatilis* and avirulent members of the *Yersinia enterocolitica* group, and specific spoilage organisms *Brochothrix thermosphacta*, *Shewanella putrefaciens* and psychrophilic "blown-pack" *Clostridium* spp. (e.g. *Clostridium estertheticum*, *Clostridium gasigenes*) (Brightwell, Clemens, Urlich, & Boerema, 2007; Gill, 2004; Pennacchia, Ercolini, & Villani, 2011; Seelye & Yearbury, 1979). Not all species are implicated in spoilage. For example, the avirulent *Y. enterocolitica*-like bacteria are not associated with spoilage events (Gill & Newton, 1979). Packaging and storage strategies aim to produce a microflora dominated by LAB to maximise shelf-life. If lamb is produced under good manufacturing practice, the initial count of microbes on the product surfaces is likely to be $10^3/cm^2$ or less (Gill, 2004; Phillips, Tholath, Jenson, & Sumner, 2013), then psychrotrophic organisms able to grow below 7 °C will be fewer still (Bell, 2001). If this condition is met and packaging material has low gas permeability (<30 cm^3 $O_2/m^2/24$ h at 25 °C) and there is very good temperature control (±0.5 °C) lamb cuts should have a storage life of 10–12 weeks (Kiermeier et al., 2013).

3.1. Pathogenic bacteria

The majority of meat-borne pathogens are mesophiles (e.g. *Salmonella*, *Campylobacter jejuni*, *E. coli* O157:H7) and require temperatures above 7 °C for growth. Therefore, the health hazard from these bacteria is not increased during vacuum-packed storage at −1.5 °C (Bell, 2001)