



Blown pack spoilage in vacuum-packaged meat: A review on clostridia as causative agents, sources, detection methods, contributing factors and mitigation strategies



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ABSTRACT

Background: Blown pack spoilage has been attributed almost exclusively to the growth of psychrophilic and psychrotolerant clostridia (PPC). It is the cause of great losses for meat industry. This spoilage is mainly caused by *Clostridium estertheticum* and it is characterised by a putrid odour, and production of large volumes of gas (mainly carbon dioxide and hydrogen), which result in severe distention of the packaging.

Scope and approach: This review summarizes the characteristics of blown pack spoilage caused by psychrophilic and psychrotolerant clostridia, factors affecting the occurrence of this spoilage, sources of contamination, methods of identification and preventive measures. A critical assessment on research needs related to blown pack spoilage is also presented.

Key findings and conclusions: In spite of recent developments, numerous facets related to blown pack spoilage research remain unclear. There is limited data on incidence and influencing factors for occurrence of spores and vegetative cells of PPC in meat and abattoir environment. In order to address this aspect, improvements in detection, isolation and typing methods are needed. Besides, more studies on source tracking of PPC from farm to abattoir are demanded. Finally, it is proposed that the reduction of losses due to blown pack spoilage should be achieved through the implementation of an integrated program that takes into account pre- and post-packaging mitigation strategies.

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1. Introduction

Meat is recognised as one of the most perishable foods due to its composition, which is rich in nutrients, has a pH between 5.5 and 6.5, and high water activity. The spoilage of meat is a complex event, which involves chemical and/or biological activities that modify the sensory characteristics, resulting in a product that is unacceptable and unsuitable for human consumption (Gram et al., 2002). The growth of undesirable microorganisms to an unacceptable level, and the degradation of the nutrients (especially carbohydrates, proteins and lipids) contribute significantly to the spoilage of meat (Ercolini, Russo, Torrieri, Masi, & Villani, 2006).

Fresh meat can be contaminated by a wide variety of

microorganisms, and the growth and predominance of specific microbial groups depend on factors that are considered environmental determinants (Doulgeraki, Ercolini, Villani, & Nychas, 2012; Ercolini, Russo, Nasi, Ferranti, & Villani, 2009; Koutsoumanis, Stamatiou, Skandamis, & Nychas, 2006; Nychas, Skandamis, Tassou, & Koutsoumanis, 2008). The main groups of microorganisms responsible for the spoilage of meat under different storage conditions have been extensively reviewed and include members of the *Enterobacteriaceae* family, lactic acid bacteria (LAB), *Pseudomonas* spp., *Clostridium* spp., and *Brochothrix thermosphacta* (Adam, Flint, & Brightwell, 2010; Doulgeraki et al., 2012; Nychas et al., 2008). Nonetheless, temperature and the availability of oxygen seem to be the most important factors driving the microbial ecology of fresh meat and the predominant microbial groups (Ercolini et al., 2009, 2011; Koutsoumanis et al., 2006; Nychas et al., 2008).

Vacuum packaging and storage under refrigerated conditions are often used to prolong the shelf life of fresh meat or cooked meat

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products (Lee et al., 2010; Nychas et al., 2008; Pennacchia, Ercolini, & Villani, 2011; Yang et al., 2013). However, the presence of microorganisms such as *Enterobacteriaceae*, lactic acid bacteria and *Clostridium* spp., which are able to grow under these conditions, may lead to meat spoilage (Brightwell, Clemens, Ulrich, & Boerema, 2007; Chaves, Silva, Sant'Ana, Campana, & Massaguier, 2012; Silva, Paulo, Sant'Ana, Chaves, & Massaguier, 2011). Often, the spoilage caused by PPC is characterised by the production of gas and distention of the packaging. These alterations are referred to as blown pack spoilage (Brightwell et al., 2007; Brightwell et al., 2009; Yang, Gill, & Balamurugan, 2010) (Fig. 1). Nonetheless, it should be highlighted that packages containing tiny amounts of gas, but presenting strong and unpleasant smell, can also be considered “spoiled” (Cavill, Renteria-Monterrubio, Helps, & Corry, 2011).

Blown pack spoilage has been attributed almost exclusively to the growth of PPC when it occurs in chilled meat that has been vacuum-packed and not exposed to temperature abuse (<4 °C) in a short storage period (2–4 weeks) (Broda, Bell, Boerema, & Musgrave, 2002; Moschonas, Bolton, Sheridan, & McDowell, 2009; Mochonas et al., 2010; Yang et al., 2010). *Clostridium estertheticum* is the most often species associated with blown pack spoilage (Adam et al., 2010; Cavill et al., 2011). Other authors have also reported that *Clostridium gasigenes*, *Clostridium algidicarnis*, *Clostridium algidixylanolyticum* and *Clostridium frigidicarnis* can also cause this spoilage in vacuum-packaged chilled meat (Broda, Lawson, Bell, & Musgrave, 1999; Broda, Saul, Bell, & Musgrave, 2000a; Broda, DeLacy, Bell, Braggins, & Cook, 1996a; Brightwell et al., 2007; Dainty, Edwards, & Hibbard, 1989; Kalchayanand, Ray, Field, & Johnson, 1989; Lawson, Dainty, Kristiansen, Berg, & Collins, 1994; Silva et al., 2011; Yang & Badoni, 2013; Yang, Balamurugan, & Gill, 2009).

PPC do not pose risks to food safety, but the changes caused by them makes meat improper for consumption, which leads to financial losses for the meat industry in many countries (Adam et al., 2010). Because of this, several studies have been performed aiming to assess the incidence of PPC in vacuum-packaged chilled meat (Cavill et al., 2011), slaughterhouse environment (Boerema, Broda, & Bell, 2003; Broda et al., 2002; Broda, Boerema, & Brightwell, 2009), and spoiled meat cuts (Dainty et al., 1989; Silva et al., 2011). In addition, the factors driving the occurrence of blown pack spoilage as well as control measures have been studied (Bell, Moorhead, & Broda, 2001; Broda, 2007; Moschonas, Bolton, Sheridan, & McDowell, 2010). Despite the considerable progress



Fig. 1. A vacuum-packaged meat cut with characteristic signs of blown pack spoilage.

that has been made, many gaps remain regarding the causes, sources of contamination, species of *Clostridium* involved in blown pack spoilage of meat and methods of detection and mitigation. In this review, the characteristics of blown pack spoilage caused by psychrophilic and psychrotolerant clostridia, factors affecting the occurrence of this spoilage, as well as sources of contamination, methods of identification and preventive measures are reviewed. A critical assessment of study needs related to blown pack spoilage is also presented.

2. Blown pack spoilage

Blown pack spoilage is characterised by a putrid odour, and production of large volumes of gas (mainly carbon dioxide and hydrogen), which result in severe distention of the packaging (Adam et al., 2010; Broda et al., 1996a). Butyric compounds (which are the result of fermentative metabolism) and volatile sulphur compounds, ammonia and diamines (which are generated by amino acid decarboxylation) are responsible for the unpleasant odour of meat with this type of spoilage (Broda, Saul, Lawson, Bell, & Musgrave, 2000b). The presence of butanol, and butyric acids and esters is the main indicator of blown pack spoilage caused by *Clostridium estertheticum* (Adam et al., 2010; Broda et al., 1996a; Dainty et al., 1989).

The first report of blown pack spoilage caused by *Clostridium* occurred in the late 1980s in the UK from chilled, vacuum-packed meat that originated in South Africa (Dainty et al., 1989; Helps, Harbour, & Corry, 1999) and in the USA (Collins, Rodrigues, Dainty, Edwards, & Roberts, 1992; Dainty et al., 1989; Kalchayanand et al., 1989). Since then, blown pack spoilage caused by *Clostridium* has been reported in several countries, including New Zealand, Ireland, Canada, and Brazil (Broda et al., 1996a; Byrne, Monaghan, Lyng, Sheridan, & Bolton, 2009; Kalchayanand et al. 1989; Moschonas et al., 2009; Silva et al. 2011; Yang et al., 2009).

Blown pack spoilage can occur in raw or cooked meat from different types of animals during storage after few to several weeks post-packaging. These include beef, lamb, pork, venison vacuum-packaged in containers that are airtight to oxygen and stored at temperatures between –1.5 °C and 4 °C (Adam et al., 2010; Broda et al., 1996a; Kalchayanand, Ray, & Field, 1993; Kalinowski & Tompkin, 1999; Moschonas & Bolton, 2012). This spoilage is initially perceived in few packs of a batch, but the number of spoiled packs tends to increase during the storage period (Dainty et al., 1989).

Blown pack spoilage can be caused by *Enterobacteriaceae* (*Serratia liquefaciens*, *Enterobacter aerogenes* and *Hafnia alvei*) and psychrotolerant lactic bacteria (Brightwell et al., 2007; Chaves et al., 2012). Regardless of this, when caused by these two microbial groups, blown pack spoilage normally occurs at the end of the storage period. In addition, blown pack spoilage caused by *Enterobacteriaceae* and psychrotolerant lactic bacteria is more likely to occur in conditions of temperature abuse (>4 °C) and involves moderate distension of packaging. These features provide relevant information to assist in the investigations of the microbial group responsible for this spoilage (Brightwell et al., 2007; Chaves et al., 2012; Moschonas, Bolton, McDowell, & Sheridan, 2011; Silva et al., 2011).

3. Clostridia as causative agents of blown pack spoilage in vacuum-packaged chilled meat

The *Clostridium* genus is very heterogeneous, containing over 200 species of Gram-positive, negative catalase, anaerobic and spore-forming bacteria. Nineteen clusters are used to

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