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Review

Meat packaging solutions to current industry challenges: A review

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ABSTRACT

Many advances have occurred in the field of smart meat packaging, and the potential for these to be used as tools that respond to challenges faced by industry is exciting. Here, we review packaging solutions to several immediate concerns, encompassing dark cutting, purge and yield losses, product traceability and provenance, packaging durability, microbial spoilage and safety, colour stability, environmental impacts, and the preservation of eating quality. Different active and intelligent packaging approaches to each of these were identified and are discussed in terms of their usefulness – to processors, retailers and/or consumers. From this, it became apparent that prior to selecting a packaging solution, industry should first define their criteria for success (e.g. How much purge is too much? What is a reasonable shelf-life to facilitate product turnover? Is the customer willing to pay for this?), and understand that packaging is not the sole solution, but acts as part of a holistic response to these issues.

1. Introduction

Meat packaging is dynamic and its innovation has been the topic of much recent review [e.g. Ahmed et al., 2017; Fang, Zhao, Warner, & Johnson, 2017; Ghaani, Cozzolino, Castelli, & Farris, 2016; Kerry, O'Grady, & Hogan, 2006; McMillin, 2017; Pereira de Abreu, Cruz, & Paseiro Losada, 2012; Realini & Marcos, 2014]. These are valuable – however, their categorisation of recent technology and inventions in terms of their functional pathways and within *smart packaging* definitions may limit their application as a troubleshooting tool for industry, retailers and other stakeholders. We should note that smart packaging encompasses *intelligent* and *active* packages designed to provide a 'cost-effective barrier against hazardous contaminants that simultaneously contributes to the longevity of product quality and enhancement of consumer appeal' (Holman, Kerry, & Hopkins, 2017).

Based on our experience, consultation with industry and a survey of scientific literature; several topics of interest which presently challenge red meat's economic and societal potential were identified. We aimed to review packaging options that respond to these concerns to provide practical alternatives to conventional practice. Doing so, our discussions were focused on red meat industry issues (lamb and beef) and their fresh, unprocessed products (summarised in Table 1). We do acknowledge the overlaps and broader applications of this review.

2. Dark cutting or dark, firm and dry meat

Discoloured red meat that fails to match consumers' preference for bright cherry-red colouration is often rejected or subject to significant discount. Dark cutting (DC) refers to red meat with dark, firm and dry characteristics – to the detriment of its display and organoleptic appeal (Ponnampalam et al., 2017). DC is deemed to result from insufficient glycogen reserves to drive *post-mortem* acidification during the muscle-to-meat transition, and in turn, this undermines its myoglobin's ability to oxidise and develop normal water-holding capacities (Ponnampalam et al., 2017). Because DC is identified (or graded) prior to carcass deconstruction, it is processors and producers that bear the financial burden. Yet, all stakeholders are impacted by costs associated with lost opportunity. It is beneficial, therefore, to identify packaging solutions to *salvage* or *recover* DC meat, enhance its retail-potential and counter consumer discrimination.

Variations to modified atmospheric packaging (MAP) gaseous profiles have been explored in response to DC. For example, Zhang et al. (2018) held DC beef in 0.4% carbon monoxide (CO-MAP) and found it lightened (increased L*) and improved redness (a* values) within 4 d of packaging, relative to vacuum packaged (VP) samples. Wills et al. (2017) also demonstrated enhanced DC beef redness using CO-MAP and compared to overwrap, but similar results when compared to 80% oxygen alternatives (HiO_2-MAP). Further, HiO_2-MAP was shown to increase DC beef colour stability more so than vacuum skin packaging (VSP) when the beef was aged for 21 d and then displayed (López-

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Table 1
A summary of packaging solutions for red meat industry concerns and challenges.[a]

Challenge	Description	Reference
Microbes	ZnO nanoparticle loaded active films were assessed in their antimicrobial capacity.	Akbar and Anal (2014)
Dark cutting	Lactic acid solution was evaluated as an injectable (enhancement) to counter the colouration of dark cutting beef.	Apple et al. (2011)
Microbes	A sakacin-A anti-Listeria (bacterocin) active packaging was tested using veal.	Barbiroli et al. (2017)
Colour stability & Environment	Raw paper was coated with biopolymeric solutions using citric acid as an antimicrobial and antioxidant agent for packaging beef.	Battisti et al. (2017)
Eating quality	Super-chilled storage effects on the shelf life of lamb held in VSP or 40% oxygen MAP were examined.	Bellés et al. (2017)
Purge & Environment	Beef was packaged using edible film produced with different concentrations of chitosan and gelatin.	Cardoso et al. (2016)
Eating quality	A total of 11 different MAP were compared to VSP and VP, with regards to their effects on aged beef.	Clausen et al. (2009)
Colour stability & Eating quality	Oregano extract was used as an active packaging coating for VP beef repackaged and further aged in HiO_2-MAP.	Djenane et al. (2016)
Microbes	The effects of antimicrobial packaging material containing poly(TBAMS) on microbial growth were determined.	Dohlen et al. (2017)
Purge & Environment	VP steaks and sub-primals were compared in terms of microbial loads, colour, eating quality and purge losses.	Eastwood et al. (2016)
Traceability	ZnO thin film biosensors with gold nanoparticle-enhanced attachment surfaces for increased thiol-modified probe DNA sensitivity to pork DNA hybridisation were developed.	Foo et al. (2016)
Eating quality	Lamb held in VSP and HiO2-MAP effects on organoleptic traits and colour were compared.	Frank et al. (2017)
Colour stability	Beef packaged in air-permeable packaging, VP and HiO_2-MAP were evaluated for colour and oxidation characteristics.	Fu et al. (2017)
Traceability	Full length DNA barcoding methods were compared with “mini” alternatives using shorter base-pair sequences, in their ability to identify meat species in food products.	Hellberg et al. (2017)
Purge & Microbes	Beef steaks refrigerated for 5 weeks in VP, VP and HiO_2-MAP were evaluated for oxidation, microbial loads, and moisture traits.	Kameník et al. (2014)
Environment & Durability	Gelatin was modified with different concentrations of stearic acid to prepare a biodegradable gelatin film.	Karnnet et al. (2005)
Colour stability	Aged lamb was displayed in either HiO_2-MAP or overwrapped and lean colour was evaluated.	Kim et al. (2012)
Dark cutting	Adhesive methyl red and bromocresol purple-based sensor labels were tested to detect pH changes in packaged beef and buffalo	Kuswandi et al. (2014); Kuswandi and Nurfawaidi (2017)
Eating quality	VP beef aged for 7 d was repackaged in VSP, VP or HiO2-MAP and further aged, with these effects on eating quality, yield losses and colour explored.	Lagerstedt et al. (2011)
Purge	The quality and yield traits of beef aged in VP and HiO_2-MAP were compared.	Lindahl et al. (2010)
Traceability	Antimony trioxide was added to polypropylene packaging material to improve its capacity for high contrast marking.	Liu et al. (2018)
Microbes	LISTEX™ P100, a commercial bacteriophage product, effectiveness was tested on turkey meat.	Lone et al., 2016
Purge & Microbes & Eating quality	Beef was held in different MAP containing different levels of oxygen, and effects shelf life was tested.	Łopacka et al. (2017)
Environment & Eating quality	Beef was aged in VSP, HiO2-MAP and a combination of these packages for 12 d and their effects on colour, microbial loads, oxidation parameters and eating qualities were assessed.	Łopacka et al. (2016)
Dark cutting	Response of DC beef appearance to HiO_2-MAP and VSP was examined.	López-Campos et al. (2014)
Durability	Honeycomb-like oxygen sensitive polystyrene nanospheres were tested as colorimetric indicators of exposure to air.	Lu et al. (2016)
Dark cutting & Colour stability	Different levels of lactate enhancement were applied to beef held in VP, HiO_2-MAP or CO-MAP and its effect on colour was examined	Mancini et al. (2009)
Microbes	Collagen and thymol film was applied to inhibit microbial growth and biofilm formation.	Michalska-Sionkowska et al. (2017)
Colour stability & Eating quality	Beef held in VSP, HiO_2-MAP or a combination of both was evaluated for colour and tenderness parameters.	Moczkowska et al. (2017)
Traceability & Durability & Microbes & Environment	Multi-walled carbon nanotubes synthesised from fuel oil waste were used to fabricate DNA biosensors, with their function explored.	Mohammed et al. (2017)
Colour stability	Sodium nitrite embedded packaging film (FreshCase®) was used to VP bison meat that was aged and tested for colour and microbial loads.	Narváez-Bravo et al. (2017)
Microbes & Eating quality	The minimal inhibitory concentration of TEO and REO for *Brochothrix thermosphacta* control was established and trials with beef held in MAP. Effects on eating quality and microbial loads were observed.	Nowak et al. (2012)
Microbes & Colour stability	A coating of CEO encapsulated in a chitosan-myristic acid nanogel was tested in its antioxidant and antibacterial activity for beef.	Rajaei et al. (2017)
Durability	EVOH containing shrink bags were tested as alternatives to PVDC in terms of their ability to preserve VP beef.	Rodrigues et al. (2017)
Traceability	Matrix-assisted laser desorption ionisation mass spectroscopy was used to identify PET.	Romão et al. (2010)
Microbes	VP and 100% CO_2-MAP where compared in terms of their ability to preserve high and normal-pH beef.	Rousset and Renerre (1991)
Eating quality	A colorimetric sensor that changes from green to red when ammonia and biogenic amines are detected by the pH indicator dye immobilised onto cellulose microparticles.	Schaude et al. (2017)
Microbes & Colour stability & Eating quality	Beef slices wrapped with REO coated films were compared to controls, each held in 50% oxygen-MAP, VP or overwrap.	Sirocchi et al. (2017)
Purge	Individual T-bone cuts were compared with sub-primals in terms of packaging portion effects on colour and yield.	Strydom and Hope-Jones (2014)
Microbes	The microbiota changes in lamb aged in 50%, 65% or 80% oxygen MAP were evaluated.	Wang et al. (2016)
Colour stability	Described a nanoparticle-labelled biosensor for the rapid detection of *E. coli* in broth.	Wang and Alocilja (2015)
Colour stability	Overwrap and HiO_2-MAP effects on lamb meat (dis)colouration were compared using different muscles and breeds.	Warner et al. (2017)

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