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Sustainable and consumer-friendly emerging technologies for application within the meat industry: An overview

Declan J. Troy [a,*], Kumari Shikha Ojha [a], Joseph P. Kerry [b], Brijesh K. Tiwari [a]

[a] Teagasc Food Research Centre, Ashtown, Dublin 15, Ireland
[b] Food Packaging Group, School of Food and Nutritional Sciences, University College Cork, Cork, Ireland

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ABSTRACT

New and emerging robust technologies can play an important role in ensuring a more resilient meat value chain and satisfying consumer demands and needs. This paper outlines various novel thermal and non-thermal technologies which have shown potential for meat processing applications. A number of process analytical techniques which have shown potential for rapid, real-time assessment of meat quality are also discussed. The commercial uptake and consumer acceptance of novel technologies in meat processing have been subjects of great interest over the past decade. Consumer focus group studies have shown that consumer expectations and liking for novel technologies, applicable to meat processing applications, vary significantly. This overview also highlights the necessity for meat processors to address consumer risk–benefit perceptions, knowledge and trust in order to be commercially successful in the application of novel technologies within the meat sector.

1. Introduction

The responsibility to produce high quality, sustainable and cost effective meat products rests with producers, manufacturers, distributors and retailers to ensure that consumer demands are met. Dealing with such a perishable product in a dynamic market place, it is not surprising that new and innovative technologies are constantly being developed and applied within the muscle-food processing sector in an attempt to enhance certain meat quality attributes and extend shelf-life and storage stability. Consistent and high quality meat production is one of the most important requirements of the meat industry in order to maintain and expand markets. The continually increasing demand to improve meat quality and safety has challenged meat processors, the scientific community and food process engineers to develop innovative techniques to produce sustainable meat products, while minimising environmental impact. Preservation and consumption of meat require adequate processing techniques to ensure microbial safety and maintain quality with extended shelf-life. With increasing competition and tighter cost margins, the meat industry is eager to engage in a search for novel innovative ways of processing meat, while maintaining quality and safety attributes. Meat quality evaluation methods involving the detection of microorganisms using traditional microbial techniques, the use of chemical tests to determine physicochemical properties and sensorial evaluation to predict consumer behaviour towards meat products have several drawbacks. These traditional techniques are laborious, time-consuming and costly and require complex sample preparation. In this regard meat processors are constantly looking for alternative, non-invasive techniques for meat quality assessment in an attempt to enhance productivity and profitability.

Research on novel processing and assessment technologies is ongoing around the world with a range of potential meat industry applications. While emerging technologies have demonstrated numerous advantages and potential for the food industry, there are limited commercial applications due to a number of factors. In some instances industry uptake of new technologies is stifled by a lack of knowledge about these new technologies and their impact on product quality and safety. Currently, sustainability is defined along the three social–environmental–economic pillars which are often referred to as triple bottom line or people–planet–profit (Elkington, 2004). Novel innovative meat processing techniques are targeted to achieve these key elements of sustainability by reducing the environmental impact of meat processing by reducing waste, minimising the use of natural resources (e.g. energy and water) and providing safe, nutritious and high quality products for consumers. Achieving sustainability in meat production systems requires a holistic view encompassing everything from production to end product, including operation of the entire supply chain. Conventional methods of meat processing and preservation (e.g. heat processing, low temperature preservation or dehydration) have been used for hundreds of years. Over the last century a dramatic increase in the development of new technologies, which have in many cases been hyped as replacements for conventional methods, has occurred. In

* Corresponding author at: Teagasc Food Research Centre, Dublin 15, Ireland.
E-mail address: declan.troy@teagasc.ie (D.J. Troy).

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spite of much excitement relating to their discovery and potential application, the anticipated uptake of these novel processing techniques by the meat industry has not occurred owing to several factors associated with; cost, scale-up issues and potential consumer perception of these novel technologies. However, novel meat quality assessment has shown some commercial uptake and has assisted in realising the sustainability of meat production processes by allowing process monitoring in real time, facilitating process monitoring and control. This paper provides a comprehensive overview of the application of novel processing technologies and quality and safety assessment techniques available for meat applications and considers the challenges to their ultimate commercial exploitation.

2. Novel processing technologies

With increasing consumer awareness and demand for fresh, safe, nutritious and healthy meat products, meat processors are continually investigating new and innovative food preservation technologies for potential commercial application. Novel thermal and non-thermal food processing and preservation technologies, including radiofrequency (RF), microwave, infrared, ohmic heating, high pressure processing (HPP), pulsed-UV light, pulse electric field (PEF), power ultrasound, cold atmospheric plasma and ozone processing have gained much attention in recent years. These technologies can offer several benefits, including increased process efficiency, improved product safety, enhanced quality attributes and extended shelf-life stability of products.

2.1. Novel thermal processing

Thermal processing of meat is considered to be the most common preservation technique used alone, or in combination with other novel food processing techniques. Various thermal processing techniques are employed for preserving meat and developing new products which can be classified as conventional dry (e.g. roasting), moist (e.g. steaming) or novel thermal (e.g. microwave, RF, infrared or ohmic heating) applications. Novel thermal techniques used alone, or in combination with conventional thermal techniques have been employed to improve product safety and shelf-life, while minimising changes in meat quality. Conventional oven cooking employs high velocity, forced hot air convection which can cause surface deterioration, overheating and oxidation, thereby leading to a poor quality product. Some of the major disadvantages of conventional cooking of meat and meat products are longer cooking times and non-uniform heating of products (Chen et al., 2012; McKenna, Lyng, Brunton, & Shirsat, 2006). Conduction-based cooking generally results in longer cooking times and in the non-uniform heating of products, whereas in the case of novel thermal methods, food is heated mainly by radiation and/or convection due to the generation of heat within the product and by conduction to some extent. Generation of heat within the products consequently reduces cooking times and this can potentially lead to a more uniform heating without compromising meat safety and quality.

Dielectric heating (RF or microwave heating) is regarded as a volumetric form of heating which achieves quicker cooking times and can potentially lead to more uniform heating (Chen et al., 2012) due to dielectric energy. Dielectric energy induces molecular friction in water molecules to produce heat, which is partly dependent on the moisture content of food. Jeong et al. (2007) studied the effect of fat level, both with and without the addition of salt, on the cooking pattern and physicochemical properties of ground pork patties cooked by microwave energy. The authors observed that temperatures at the edge of the pork patties increased faster than those at the centre or in the mid-way positions within the microwave cooker. Total cooking loss, drip loss, and reduction in diameter and thickness were higher in patties with 20% fat compared to those with 10% fat, thereby indicating the influence of fat content and salt on cooked meat using microwave energy. Yarmand and Homayouni (2009) investigated the effect of domestic microwave (700 W), industrial microwave (12,000 W) and conventional oven heating/cooking of goat and lamb meat to reach an internal temperature of 70 °C. They observed higher cooking losses in microwave heating/cooking compared to conventional oven cooking, probably due to the separation of fat cells from the muscle matrix when in the presence of an electromagnetic field.

Radiofrequency (RF) heating employs electromagnetic energy for heating of food, thereby resulting in a shorter cooking time and a more uniformly heated product. In a study by Tang, Cronin, and Brunton (2005) it was shown that rapid RF cooking of turkey meat accelerated cooking time by a factor of 4 when compared to steam cooking, with no detectable sensory differences determined between samples. Unlike microwave and RF heating, infrared cooking involves heating of products by radiant energy which is generated externally and absorbed by food surfaces. Infrared heating has the distinct advantage of cooking food products in a shorter processing time, while still maintaining product quality and safety. For example, Sheridan and Shilton (1999) studied the efficacy of cooking hamburger patties by mid infra-red ($\lambda_{max} = 2.7$ μm) and far-infrared ($\lambda_{max} = 4.0$ μm) sources. They observed that the change in core temperature follows closely the change in surface temperature which results in a short cooking time and is independent of the fat content of the samples when subjected to the higher energy source. However, with the lower energy source, the rate of core temperature rise is dependent on the fat content and a target core temperature can be achieved quickly for samples containing high fat. Gande and Muriana (2003) conducted a study that involved a radiant heat oven for pre-package pasteurisation of various meat products, including; turkey bologna, roast beef, corned beef and ham. The treatment time varied from 60 to 120 s, and the air temperature ranged from 246 to 399 °C. The authors reported a 1.25 to 3.5 log inactivation of *Listeria monocytogenes* after the products were passed through a radiant oven. Similarly, Huang (2004) obtained a 3.5 to 4.5 log reduction of *L. monocytogenes* in turkey frankfurters with an average initial inoculum of 10^6 to 10^7 CFU/cm^2.

Ohmic heating or direct resistance heating of food is another novel thermal process technique which employs electrical resistance to heat the food product. Ohmic heating can penetrate throughout the food instantly, compared to dielectric heating and radiant energy. Ohmic heating has shown several food industry applications with an aim of producing high quality, convenient and safe food products. Application of ohmic heating in meat was extensively reviewed by Yildiz-Turp, Sengun, Kendirci, and Icier (2013). Ohmic heating has shown its effectiveness in inhibiting microbial growth by providing uniform temperature distribution throughout the product and cooking faster and instantly inside the product. Studies have shown that meat products processed using ohmic heating resulted in shorter cooking times, higher cooking yields, more consistent appearances and better eating quality properties compared to conventionally-processed products (Dai et al., 2013; Engchuan, Jittanit, & Garnjanagoonchorn, 2014).

2.2. Novel non-thermal processing

Several novel non-thermal technologies have been widely investigated for extending the shelf-life of meat, while maintaining a fresh-like meat quality. Many of these technologies have been exploited by meat processors for niche applications. Scientific literature suggests that these technologies will assist meat processors in meeting both consumer demands for high quality, superior nutrition and safer products, in addition to conscientious demands for energy efficient processes (Jermann, Koutchma, Margas, Leadley, & Ros-Polski, 2015). Non-thermal techniques, including HPP, ultrasound, cold plasma, pulsed-UV light, pulsed electric field and ozone processing have some promising commercial applications for the meat industry.

In the meat industry, HPP involving pressures over 100 MPa is mainly employed to increase shelf-life, improve the food safety profile and alter key quality parameters, including texture, colour and water