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Effect of different packaging materials containing poly-[2-(tert-butylamino) methylstyrene] on the growth of spoilage and pathogenic bacteria on fresh meat

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ABSTRACT

The objective of this study was to investigate the effect of novel antimicrobial packaging materials containing poly-[2-(tertbutylamino) methylstyrene] (poly(TBAMS)) on the growth of typical spoilage and pathogenic bacteria present on meat.

The antimicrobial activity of materials containing different poly(TBAMS) concentrations was determined by comparing the bacterial counts on reference and sample materials at different temperatures and times and in the presence of meat components. Storage tests with poultry fillets and veal cutlets were conducted with samples vacuum packaged in the reference foil and foil containing 10% poly(TBAMS). After specific time intervals, typical spoilage microorganisms, total viable count (TVC), sensory changes and pH value were analysed.

The results of the different poly(TBAMS) containing packaging materials showed an increase of the antimicrobial activity with an increasing amount of poly(TBAMS) in the base polymer. A high antimicrobial activity against inoculum of spoilage and pathogenic organisms typical for meat products was detected of a multilayer foil containing 10% poly(TBAMS) in the inner layer after 24 h at 7 °C. Gram positive-bacteria were more sensitive to poly(TBAMS) foil than gram-negative bacteria. In storage tests however, over the entire storage, a significant effect of this poly(TBAMS) foil on microbial growth on chicken breast fillets and veal cutlets could not be identified.

Poly(TBAMS) packaging materials showed very good antimicrobial properties against a wide range of bacteria. However, for a significant inhibition of microbial growth on fresh meat, a higher amount of poly(TBAMS) was necessary to prolong the shelf life of meat.

1. Introduction

Meat safety and the length of shelf life are influenced by several different factors, like the product characteristics and ingredients, hygienic conditions during production and processing, the logistic structures, and especially the temperature conditions in the chain (Kreyenschmidt and Ibald, 2012). Besides these factors, the packaging conditions have a significant influence. In the past, huge efforts have been made to develop multilayer foils based on different polymers, such as linear low-density polyethylene (LLDPE), low-density polyethylene (LDPE), polyethylene (PE), polypropylene (PP), polyamide (PA), to improve the water and gas barriers and provide optimal mechanical strength properties to prolong shelf life (Scetar et al., 2010; Siracusa et al., 2014).

In recent years, several papers have been published about the use of antimicrobial mechanisms in foils to decrease the spoilage rate by directly inhibiting the microbial growth or killing the microorganisms (Appendini and Hotchkiss, 2002; Quintavalla and Vicini, 2002; Kenawy et al., 2007). Reduction of the initial bacterial count of fresh poultry by one $\log_{10}$ unit results in prolonging the shelf life for several days (Bruckner, 2010).

Three general types of antimicrobial polymers can be described: biocide-releasing polymers, polymeric biocides and biocidal polymers. Biocide-releasing polymers contain biocides which are released from polymers to the packaging environment. In polymeric biocides, the biocidal molecules are attached to a polymer backbone. The third group are the biocidal polymers, in which the whole macromolecule is biocidal (Siedenbiedel and Tiller, 2012).

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Antimicrobials can be integrated into polymers in foils for shrink, skin or vacuum packaging. Most of the antimicrobial polymers are based on a biocide-releasing killing mechanism, meaning that a release of active agents from the polymer into the food product or environment is required. A variety of migrating antimicrobial agents have been developed and investigated for the application in packaging material. Even if several antimicrobials are effective against various organisms under standardized labor conditions, it has proven difficult to develop foils that are adequate antimicrobial in contact with food (Balasubramanian et al., 2009). The presence of proteins effects for example the antimicrobial activity of silver negatively (Asharani et al., 2009; Ilg and Kreyenschmidt, 2011; Liau et al., 1997; Martinez-Abad et al., 2012; Matsumura et al., 2003). Furthermore, the antimicrobial action of different agents can be reduced at cool temperature conditions, which are typical in meat chains (Asharani et al., 2009; Cushen et al., 2013; Kampmann et al., 2008; Lee et al., 2011; MacKeen et al., 1987; Russel and Hugo, 1994; Simon et al., 2008).

In contrast to the migration mechanisms of antimicrobial agents the effect of polymeric biocides and biocidal polymers is based on a contact-active killing mechanism (Siedenbiedel and Tiller, 2012). Example for a biocidal polymer is chitosan. The antimicrobial property of the polymer is possible due to interactions between the positively charged chitosan and negatively charged cell components resulting in an outflow of microbial cytoplasm (Dehnad et al., 2014; Dutta et al., 2009; Higueras et al., 2013; Shahidi et al., 1999; Soysal et al., 2015). Sustainable active microbicidal (SAM®) polymers are a new class of contact antimicrobials with antimicrobial activity without a release of antimicrobials. The antimicrobial activity of these polymers such as the polymer poly-[2-(tert-butylamino)ethyl methacrylate] (poly(TBAEMA) is based on their three-dimensional helical structure with a high concentration of protonated, functional amino groups (Hewitt et al., 2004; Thölmann et al., 2003). The protonation of the functional amino groups leads to electrostatic interactions between the positively charged polymer and the negatively charged surface of bacteria. The cytoplasmic membrane is depolarized and permeabilized resulting in cell death. The relatively new developed polymer poly-[2-(tert-butylamino) methylstyrene] (poly(TBAMS)) shows very good antimicrobial properties against different pathogenic and spoilage bacteria at cool temperatures and in the presence of different meat components after 24 h (Dohlen et al., 2016).

Furthermore, the polymer exhibits good mechanical-chemical properties, like the high glass transition temperature (T_G) and the low water uptake. Depending on the isomer compositions of the TBAMS monomers, the T_G ranges between 68 °C and 91 °C, and can be raised by copolymerization with other monomers from 80 °C to 160 °C. The water uptake is $<$ 2% and comparable or better than a lot of polyamides. Due to this adaption of properties by copolymerisation, the polymer can effectively be compounded with several matrix polymers and further be adapted for the demands of packaging solutions such as multilayer foils and pads (Brodkorb et al., 2015). Therefore, SAM® polymer poly (TBAMS) and its copolymers are bearing promising potential for application as a packaging material to increase the food safety and shelf life of different chilled products.

Up to now however, it is not clear if poly(TBAMS) homopolymer is still active after compounding with standard polymers to produce multilayer foils and which concentration of poly(TBAMS) is necessary to decrease microbial growth.

The aim of the study is to investigate the influence of different processing steps of poly(TBAMS) on the activity and the effect of novel antimicrobial packaging materials containing different concentrations of poly(TBAMS) homopolymer on the growth of typical spoilage and pathogenic bacteria present on meat under cool temperature conditions.

2. Materials and methods

2.1. Polymer discs production

Poly(TBAMS) was synthesized per Brodkorb et al. (2015). Polymer discs were processed from different LLDPE based polymers [Dowlex 2344 (Dow plastics, Midland, USA), Dowlex SC 2108G (Dow plastics, Midland, USA), Plexar PX 3236 (LyondellBasell, Wesseling, Germany) mixed with 10% poly(TBAMS) in a coextruder. Further polymer discs were coextruded out of a LLDPE based polymer (Dowlex 2344, Dow plastics, Midland, USA) mixed with different concentrations of poly (TBAMS) (1.5, 3, 5, 10, 12, 15%). The resulting compounds from the coextrusion process were pressed to polymer discs (3.5 cm in diameter, 2 g) by a fully hydraulic injection moulding machine. Test discs of different base polymers were produced as reference materials. Parts of the resulting compounds consisting of the Dowlex 2344 LLDPE and 10% poly(TBAMS) were used for the multilayer foil production and fibre spinning.

2.2. Foils production

In total, three multilayer blown foils and one flat foil containing poly(TBAMS) were produced. The multilayer polymer foils, consisting out of five layers with different barriers (Table 1), were co-extruded at a pilot plant scale (Germany). The inner layer of the blown foils was the one containing poly(TBAMS) and LLDPE and was in contact with the bacteria suspension respectively meat in the experiments. Two of the foils contained 10% poly(TBAMS) as inner liner, with different thicknesses of 10 µm (Foil 2) and 5 µm (Foil 3). The third foil was produced with an inner layer of 70% LLDPE/10% poly(TBAMS) compound and 30% LLDPE antiblocking agent (thickness: 15 µm). The inner layer of the reference foil consists of 100% LDPE (3026 K). Table 1 gives an overview of the polymers used for the multilayer foils. All multilayer blown foils were produced as rolls with a width of 21 cm. Foils were of even thickness and transparent.

Furthermore, a flat foil with a coated thin film containing poly

Table 1
Summary of the produced multilayer foils with different layers and layer thickness.

	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5
Foil 1 (reference)	80% Copolymer PP (PPR3221[c])/20% Homopolymer PP (MR2002[c]) 15 µm	Bonding agent LLDPE (PX3226[a]) 5 µm	EVOH (EV3201) 5 µm	Bonding agent LLDPE (PX3226[a]) 5 µm	100% of LDPE (3026 K[a]) 10 µm
Foil 2					100% of LLDPE/10% poly(TBAMS) compound 10 µm
Foil 3					100% of LLDPE/10% poly(TBAMS) compound 5 µm
Foil 4					70% of LLDPE/10% poly(TBAMS) compound/ 30% LLDPE antiblocking agent (Dowlex2035[b]) 15 µm

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