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Temperature sensitive smart packaging for monitoring the shelf life of fresh beef

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ABSTRACT

We successfully developed temperature-sensitive packaging using a eutectic mixture of soybean oil and tetradecane (S + T) as a thermo-regulating material (TRM). The eutectic mixture was vacuum impregnated inside expanded graphite (EG/S + T) to increase the thermal conductivity of the TRM. A thermal insulation coating (EG/RH/S + T) was prepared and applied inside the walls of the expanded polypropylene (EPP) boxes using EG/S + T and a rice byproduct, i.e., rice husk (RH), to enhance the thermal buffering. The developed eutectic mixture (S + T), EG/S + T, and thermal insulation coating (EG/RH/S + T) were characterized using scanning electron microscopy (SEM), thermogravimetric analysis, Fourier transform infrared (FTIR) spectroscopy, and differential scanning calorimetry (DSC). The SEM analysis indicated that the S + T TRM was sufficiently absorbed into the EG porous network. The FTIR results revealed that the S + T TRM and EG did not undergo chemical reactions however, physical interactions were observed. The DSC results revealed that the S + T TRM melts at −0.31 °C with a latent heat of 71.06 J/g, and it solidifies at −2.01 °C with a latent heat of 74.89 J/g. The thermal insulation coating melts at −0.94 °C with a latent heat of 19.49 J/g, and it solidifies at −3.93 °C with a latent heat of 19.35 J/g. Temperature sensitive package further studied with fresh beef to determine weather is could provide temperature maintain or not up to-8 days. Meat sample place inside the small PET container and cover with cling film. PET tray transfer to temperature sensitive package. The quality of the fresh beef was determined based on its pH, color, texture, total volatile basic nitrogen, and total plate count. EPP boxes with EG/RH/S + T coatings and a G-Pack show excellent temperature control during 3 h of storage at ambient temperature. All the quality parameters for fresh beef are within the acceptable range when using the temperature-sensitive packaging. The developed temperature-sensitive packaging is useful to control the temperature of fresh beef from the store to preparation and consumption.

1. Introduction

Fresh beef is very popular in South Korea, but its limited shelf life is a concern. South Korea became the ninth largest meat importing country and the fourth largest beef importing country in the world in 2003. Among Asian countries, South Korea has become the second largest market for imported meat after Japan, with imports accounting for two-thirds of the volume of beef consumed in 2003 (Ryan and Cheetham, 2017). Because of the high quantity of imported beef, temperature fluctuations during transport are a major concern and can affect the freshness and quality of beef (Lee and Yoon, 2001). The shelf life of beef is the time that passes before it becomes unacceptable for consumption and distribution because of the growth of spoilage bacteria. Beef with >7 log CFU/g bacteria is unacceptable for international trade (Chai et al., 2017). In addition, temperature control is lacking from the store to preparation and final consumption.

Food companies spend millions of dollars to ensure the integrity and wholesomeness of their refrigerated products, yet many are faced with the necessity of recalling products that have been contaminated along points of the cold chain. Controlling the storage temperature is vital for maintaining the quality and safety of refrigerated foods throughout the food continuum (gate to plate) (Gaikwad et al., 2016; Wallace et al., 2011). Therefore, it is important that good chill/storage procedures are in place to ensure that such foods achieve their shelf lives and are safe for consumption by the end user. Low temperatures and active packaging enhance the safety and quality of high-value food

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products (Singh et al., 2016a,b, 2018a,b; Gaikwad et al., 2017; Choi et al., 2016; Ahn et al., 2016).

Temperatures can be maintained using small freezers, large cold storage enclosures, and refrigerated warehouses and trucks (Singh et al., 2017a,b,c). However, during the transportation electricity failure and some time at the consumer door product is unattended for 3–4 h or more. In that case unattained product for 2–3 h can spoil the product. A temperature-regulating material would solve this problem; its phase-change ability would release the latent heat and maintain the temperature without refrigeration for up to 3–4 h.

In rice processing, the main residue is the husk. Rice husks (RHs) are not of commercial interest and cause serious pollution problems. RHs have been used for centuries as thermal insulation in construction. Several studies have examined the use of RHs as reinforcement in composite wood, in thermal power plants, and in rural buildings as thermal insulation (da Rosa et al., 2015). In our study, we utilize RHs to create a thermal insulation coating.

We developed a new eutectic mixture: a mixture of paraffin and vegetable oil. The newly developed class of organic-based thermoregulating materials (TRMs), here termed bio-based TRMs, is significantly less flammable than paraffins alone. They show good thermal stability for thousands of melting and freezing cycles with no risk of oxidation because they are fully hydrogenated. They are also capable of absorbing, storing, and releasing large amounts of latent heat, similar to conventional paraffins. Despite many desirable characteristics, their low thermal conductivity is a major drawback. Vacuum-impregnated expanded graphite (EG) is selected to improve the thermal conductivity. The vacuum impregnation process assures the high heat storage of TRM because of the capillary forces and surface tension during the incorporation process.

Therefore, EG/S + T (S + T is a eutectic mixture of soybean oil and tetradecane) and a rice byproduct i.e., RH thermal insulation coating (EG/RH/S + T) were prepared and applied to the inside wall of the expanded polypropylene (EPP) boxes to enhance the thermal buffering (Fig. 1). This study analyzed the characteristics of the developed microstructure, chemical bonding, heat capacity, thermal resistance, and thermal conductivity of the thermally enhanced TRM and TRM coating using scanning electron microscopy (SEM), Fourier transform infrared (FTIR) spectroscopy, differential scanning calorimetry (DSC), and thermogravimetric analysis (TGA). The developed EPP packaging with a TRM coating was examined to prevent temperature variations in fresh beef and maintain product freshness throughout the entire distribution chain.

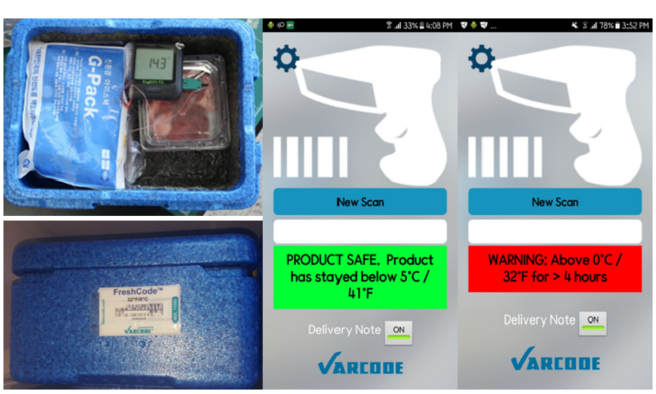

Fig. 1. Temperature-sensitive packaging for fresh beef.

2. Materials and methods

2.1. Material

In the experiment, we used a paraffin + vegetable TRM, which has a latent heat capacity of 74.85 J/g and melting point of −0.31 °C. EG was prepared using graphite ES 350 F5 in a microwave for 30 s.

2.2. Preparation

Vacuum impregnation was used to enhance the thermal conductivity of the prepared TRM. EG (100 g) was vacuum dried overnight. The EG was transferred to which was connected to a water trompe device to vacate air from the porous structure of EG. The prepared TRM (200 g) was added to a separatory funnel, and the valve between the conical flask and separatory funnel was opened to allow TRM to cover EG. A 60-min vacuum process was preformed; the atmospheric pressure forced the TRM inside the hollow structure of EG. Excess TRM was removed by filtration, and the remaining sample was dried in an oven at 60 °C for 24 h.

2.3. Thermal insulation coating

As presented in Table 1, different amounts of RH/EG + TRM were slowly added to a 7-mL ethanol solution and magnetically stirred. Different amounts of polyurethane and hardener were added to the ethyl acetate solutions while stirring vigorously using an automatic stirrer for 30 min to produce the coating solution, followed by further stirring for 30 min. Then, each mixture was coated inside the walls of the EPP boxes.

2.4. Characterization techniques

The surface morphology of the thermally improved EG-TRM and EG-TRM coating was observed using SEM at room temperature. SEM (Leica S 360, Leica Microsystems Cambridge Ltd., UK) was performed at an acceleration voltage of 10–15 kV. DSC analysis of the materials was performed on a PerkinElmer DSC 7 by applying various heating–cooling cycles from −60 to 60 °C in a nitrogen atmosphere with a refrigerating cooling accessory (IntraCooler 2, PerkinElmer, USA). A scan rate of 10 °C/min was applied to observe the thermal properties. The thermal properties of the material were analyzed using a thermal-gravimetric analyzer (TGA-4000, PerkinElmer Co., Netherlands). During testing, 4–10 mg of a clean, dry sample was heated from 10 to 800 °C at a rate of 20 °C/min. Nitrogen was used as the purge gas at a flow rate of 20 mL/min. For TGA, the material was scanned from 10 to 800 °C at a rate of 20 °C/min (ASTM E1131), again using nitrogen as the purge gas at a flow rate of 20 mL/min. The thermal stability of the samples was characterized by measuring the weight (mass) loss with increasing temperature. FTIR was used to document the changes in the chemical structure of the samples. The spectra were acquired using an FTIR spectrometer (PerkinElmer, USA) in the range of 400–4000 cm^{-1} with a resolution of 1 cm^{-1}.

Table 1
Composition of thermal insulation coating.

Coating %	Graphite-TRM(4:6) (g)	Rice bran (g)	Binder (g)	Hardener (g)	Total amount (g)
20%	1	1	5	3	10
30%	1.5	1.5	4.5	2.5	10

*TRM- Temperature regulating material.