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# Investigating the influence of ultrasound pre-treatment on drying kinetics and moisture migration measurement in *Lactobacillus sakei* cultured and uncultured beef jerky

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## ABSTRACT

Low Frequency-Nuclear Magnetic Resonance (LF-NMR) was employed to elucidate changes in water distribution in cultured (*Lactobacillus sakei*) and uncultured beef jerky samples subjected to ultrasound pre-treatment. Ultrasound pre-treatment at frequencies of 25, 33 and 45 kHz for 30 min, followed by marination (18 h) was carried out for both cultured and uncultured jerky samples. Among the various kinetic models assessed, the Wang and Singh model provided the closest fit to the drying experimental data, with high $R^2$ ($\geq$0.994), low RMSE ($\leq$0.023) and low AICc ($<-$74.535) values for both cultured and uncultured samples. Distributed exponential analysis of $T_2$ transversal relaxation times measured by LF-NMR curves revealed the presence of three distinct peaks attributed to; bound water, water present within the dense myofibrillar protein matrix and free-water at a relaxation time range of 0–10 ms ($T_{2b}$), 10–100 ms ($T_{21}$) and >100 ms ($T_{22}$), respectively. Results presented in this study demonstrates that the ultrasound effect on drying behaviour was frequency dependent and that LF-NMR can be employed to evaluate moisture mobility and drying degree of beef jerky.

## 1. Introduction

Beef jerky is a nutrient dense ready-to-eat meat snack, possessing characteristics of a typical intermediate moisture content product with a relatively long shelf-life. Commercially, beef jerky is prepared using a hurdle-technology approach which involves employment of interventions, such as; reducing water activity ($a_w$) and addition of preservatives (e.g. organic acids, spices and curing salts). The development of whole-muscle and/or restructured jerky from a range of meats by employing various curing ingredients (e.g. organic acids, spices, sugars, NaCl and nitrate/nitrite salts), curing methods and drying conditions have been widely reported (Choi et al., 2008; Jang et al., 2015; Kucerova, Hubackova, Rohlik, & Banout, 2015). In recent years, the application of starter culture (e.g. lactic acid bacteria) to improve flavour and quality of jerky products, while preventing the growth of spoilage bacteria, has been reported (Biscola et al., 2013; O'Connor, Ross, Hill, & Cotter, 2015; Zhao et al., 2016).

The application of ultrasound has been reported to enhance mass transfer rates during brining/curing of meat, primarily by disrupting the continuity of cellular membranes due to various physical and chemical effects of ultrasound (Ozuna, Cárcel, García-Pérez, Peña, & Mulet, 2015). Ultrasound, in combination with vacuum has been shown to enhance the drying rate of beef and chicken meat (Başlar, Kılıçlı, Toker, Sağdıç, & Arici, 2014). Ultrasound pre-treatment is widely reported to accelerate drying of a range of food products (Awad, Moharram, Shaltout, Asker, & Youssef, 2012), which can affect texture and water activity of products. Additionally, ultrasound treatment has shown promise in improving meat tenderisation, depending on the ultrasonic intensities, frequencies and processing times employed.

Moisture content is the main factor influencing the quality, safety and shelf life of meat-based jerky. Conventionally, the moisture content of commercial forms of jerky is determined by oven drying methods and sensory assessments. However, these methods are tedious, time-consuming, expensive and require trained and skilled personnel. Thus, there is a great scientific and industrial interest to develop a rapid, non-destructive and online method for determination of moisture content and drying degree in order to ensure consistent jerky quality. Low-field nuclear magnetic

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resonance (LF-NMR) is a sensitive, fast and non-invasive technique which has been widely adopted as an analytical technique for the characterization of water mobility and distribution within food matrices (Agudelo-Laverde, Schebor, Buera, 2014; Troutman, Mastikhin, Balcom, Eads, Ziegler, 2001; Haiduc and van Duynhoven, 2005). The state and distribution of water in food matrices, including meat, can be determined by LF-NMR and can provide useful information about interactions between water and myofibrillar meat proteins, as it is governed by exchange of water protons and exchangeable protons in proteins (Bertram, Engelsen, Busk, Karlsson, & Andersen, 2004). LF-NMR has been successfully employed to study the effectiveness of various processing techniques, including; brining, cooking, freezing and thawing on water distribution and mobility (Bertram, Kohler, Böcker, Ofstad, & Andersen, 2006; Damez & Clerjon, 2013; Li et al., 2012; Ojha, Keenan, Bright, Kerry, & Tiwari, 2016; Sánchez-Alonso, Moreno, & Careche, 2014). This technique has also been suggested as an alternative method for the conventional determination of drying degree upon the quality of chicken jerky (Li et al., 2014).

The objective of this study was to investigate the use of ultrasound as a pre-treatment prior to hot air convective drying of cultured and uncultured beef jerky. Modelling approaches were used to assess the influence of ultrasound frequency on the drying kinetics of beef jerky samples. Another objective of this study was to demonstrate a feasibility of using LF-NMR to determine water mobility and distribution of water during drying of cultured and uncultured beef jerky samples. Correlation analysis of transverse relaxation times and the moisture contents of dried beef jerky at different drying intervals were also determined to evaluate the drying degree of cultured and uncultured beef jerky samples.

## 2. Materials and methods

### 2.1. Sample preparation and ultrasonic pre-treatment

Beef used in this study was *Musculus Semitendinosus* which was obtained from a local supplier (Dublin Meat Company, Blanchardstown, Co. Dublin, Ireland). Meat was stored at 4 °C, sliced to 0.2 cm in thickness using a meat slicer and were further cut by knife into slices of uniform dimensions (Length = 10 cm, Width = 4 cm). The beef slices were cured using two different curing solutions: (I) Cultured, containing 70% water, *L. sakei* DSM 15831 culture, 1.5% salt, 1.0% sugar, 0.05% sodium nitrite and (II) Uncultured, containing 70% water, 1.5% salt, 1.0% sugar, 0.05% sodium nitrite (based on raw meat weight; v/w). The ingredients were thoroughly mixed, and samples from both cultured and uncultured treatment groups were subjected to ultrasonic (US) pre-treatments at frequencies of 25 kHz (Model: Elma IT H5), 33 kHz (Model: Jencons-PLS S1000) and 45 kHz (Model: Elma IT H5) for 30 min at comparable output power of circa 65 W along with a control (no US pre-treatment). US pre-treatments were performed in ultrasonic bath systems maintained at a temperature of 30 °C. All samples were subsequently cured for 18 h at 4 °C.

### 2.2. Drying of beef jerky

Cultured and uncultured cured beef jerky slices were dried using a hot air drying oven (Gallendkamp Plus II, Weiss Technik, UK) at a temperature of 60 °C for 4 h and using an air velocity which was maintained at 0.3 m/s. Beef jerky samples were placed in trays and were transferred to the hot air drying oven. Two slices from each treatment were withdrawn after every 30 min for 4 h and subsequently weight using precise weighing balance (Sartorius, Germany), after weight determination slices were placed back to the oven.

### 2.3. Mathematical modelling

Moisture content, on a dry basis, is the weight of moisture present in the product per unit weight of dry matter in the product. For drying experiments, where weight losses were recorded, the instantaneous moisture contents at any given time can be obtained from Eq. (1):

$$M = \frac{(M_o + 1)W_o}{W_t} - 1 \tag{1}$$

where $W_o$ is the initial weight (g) of jerky sample after a curing period of 18 h, $W_t$ is the weight (g) of sample at time t (min) and $M_o$ is the initial moisture content (g water/g dry solids), respectively. The initial moisture content was determined using the hot air oven method as per AOAC. The data obtained experimentally for control and ultrasound pre-treated beef jerky slices from both uncultured and cultured groups were plotted as a dimensionless variable moisture ratio (MR) *versus* time as calculated from Eq. (2):

$$Moisture\ ratio\ (MR) = \frac{(M_t - M_e\ )}{(M_o - M_e)} \tag{2}$$

where $M_t$ is the moisture content at any time t, $M_e$ the equilibrium moisture content and $M_o$ is the initial moisture content and all expressed as g water/g dry solids. The value of the equilibrium moisture content (Me) is relatively small compared to $M_t$ or $M_0$. Thus, Eq. (1) can be simplified as $MR = Mt/Mo$ (Ju et al., 2016; Xie et al., 2017). Moisture diffusivity ($D_f$) for beef jerky samples were calculated by using Eq. (3) by analogy to the analytical solution to the Fick's second law of diffusion assuming negligible shrinkage, constant temperature, and constant moisture diffusivity (Zielinska & Michalska, 2016).

$$MR = \frac{8}{\pi^2} exp\left[-\frac{\pi^2 D_f\ t}{4L^2}\right] \tag{3}$$

where, $D_f$ is the effective moisture diffusivity ($m^2$/min), L is the thickness of the sliced beef (m).

Six empirical models were employed to describe drying kinetics were Henderson and Pabis, Wang and Singh, Page, Lewis (Newton), Weibull and Peleg (Table 1). The regression coefficient ($R^2$), Root mean square error (RMSE) and AICc values were calculated using Eq. (4)–(6), respectively. $R^2$, RMSE and AICc values were used as the primary criteria for measuring best model fit.

$$R^2 = \frac{\sum_{i=1}^{N}\left(MR_i - MR_{pred,\ i}\right) \times \sum_{i=1}^{N}\left(MR_i - MR_{exp,\ i}\right)}{\sqrt{\left[\sum_{i=1}^{N}\left(MR_i - MR_{pred,\ i}\right)^2\right] \times \left[\sum_{i=1}^{N}\left(MR_i - MR_{exp,\ i}\right)^2\right]}} \tag{4}$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(MR_{exp,\ i} - MR_{pred,\ i}\right)^2} \tag{5}$$

$$AICc = 2n - 2log_e\left(\mathscr{L}\left(\widehat{\theta}\middle|y\right)\right) + \frac{2n(n+1)}{N-n-1} \tag{6}$$

where, $MR_{exp,i}$ is moisture content observed experimentally and $MR_{pre,i}$ is predicted moisture content; *SSE* is the sum of squared error, $2log_e(\mathscr{L}(\widehat{\theta}|y))$ is the log-likelihood at its maximum point of the model estimated, *N* and *n* represent the number of observations and parameters assessed, respectively.