J. Dairy Sci. 98:1–10
http://dx.doi.org/10.3168/jds.2015-9739

Prediction of process cheese instrumental texture and melting characteristics using dielectric spectroscopy and chemometrics

J. K. Amamcharla*[1] and L. E. Metzger†
*Department of Animal Sciences and Industry, Food Science Institute, Kansas State University, Manhattan 66506
†Dairy Science Department, South Dakota State University, Brookings 57007-0647

ABSTRACT

This study evaluated the potentiality of dielectric spectroscopy as a tool to predict the functional properties of process cheese. Dielectric properties of process cheese were collected over the frequency range 0.2 to 3.2 GHz at 25°C. Dielectric spectra of process cheese were collected using a high-temperature, open-ended dielectric probe connected to a vector network analyzer. The present study was conducted using 2 sets of commercial process cheese formulations and a set of specially formulated process cheese. For the all the process cheese samples analyzed, a decrease in dielectric constant and dielectric loss factor was observed as the incident frequency increased. Partial least square regression (PLSR) and multilayer perceptron neural network models were developed using the dielectric spectra of process cheese to predict the hardness (gf), melting point (°C), and modified Schreiber melt diameter (mm) of process cheese. The prediction models were validated using the full cross-validation method. The ratio of prediction error to deviation was greater than 2 for melt diameter and hardness, indicating a good practical utility of the PLSR prediction models. The predictability of multilayer perceptron neural network was less than the PLSR models and could be due to the small number of training samples in the data sets. Dielectric spectroscopy coupled with PLSR could be a useful tool for the nondestructive measurement of functional properties of process cheese.
Key words: dielectric spectroscopy, process cheese, functional properties

INTRODUCTION

Process cheese (**PC**) is very popular in the American diet because of its versatility as a food ingredient or consumer product (Fagan et al., 2005). It is manufactured by blending natural cheeses with different degrees of maturity, emulsifying agents, sodium chloride, acidifying agents, water, and many other optional ingredients. Generally, the blend of ingredients is then heated under constant shear until a homogeneous mixture is obtained. The finished product, PC, has an extended shelf life (Kapoor and Metzger, 2008). The various ingredients used in PC play a role in the functional properties of PC, including its melting and texture characteristics (Kapoor and Metzger, 2008). Additionally, the melting and textural properties of PC influence consumer acceptability (Konstance and Holsinger, 1992).

Several techniques are available to measure the textural and melting characteristics of PC. Texture profile analysis (**TPA**) is a widely used instrumental technique to determine texture parameters, including hardness, fracturability, adhesiveness, springiness, cohesiveness, and gumminess. Meltability is a complex functional property (Wang and Sun, 2002) and is dependent on the thermal phase change characteristics of solid cheese and the rheological characteristics of melted cheese (Everard et al., 2005). Several empirical and instrumental techniques have been developed to characterize the melting properties of PC. Some of the recent developments are discussed by Kapoor and Metzger (2008), Gunasekaran and Ak (2002), and Gunasekaran et al. (2002). A rheological-based method available for melt analysis called dynamic stress rheometry (**DSR**) was developed by Sutheerawattananonda and Bastian (1998). Recently, a rapid visco analyzer was used to measure the melting properties of process cheese spread or product (Prow and Metzger, 2005). Even though several techniques are available in the literature to measure the melting characteristics of PC, most of these methods are destructive and require dedicated instruments to carry out the test. Hence, a rapid and nondestructive method is needed for simultaneous determination of melt and unmelt characteristics of PC in an industrial setting.

The melted and unmelted functional properties of PC primarily depend on the type of ingredients used in the formulation (natural cheese, emulsifying salt, and so on) as well as the processing conditions. The type,

Received April 22, 2015.
Accepted May 23, 2015.
[1]Corresponding author: Jayendra@ksu.edu

quantity, and age of natural cheese in a PC formulation affect the dielectric properties as well as the functional properties of PC. As the intact CN and mineral content of PC is a significant contributor to its functionality as well as dielectric properties (Kubiš et al., 2001), we hypothesized that dielectric spectroscopy can provide a rapid and noninvasive method of determining the texture and melting characteristics of PC.

The determination of the dielectric properties of a substance over a wide range of frequencies is called dielectric spectroscopy (Nelson, 2005). Dielectric spectroscopy has been widely used in industrial (Marland et al., 2001), agriculture (Starr et al., 2000; Wang et al., 2003), and food (Berbert et al., 2001; Guo et al., 2007; Bohigas et al., 2008) sectors. According to Kent et al., (2001), dielectric spectroscopy is a nondestructive, noninvasive, and nonhazardous technique.

Dielectric spectroscopy studies the interaction of microwaves with a material. Dielectric properties consist of dielectric constant (ε') and dielectric loss factor (ε''). The ε' is the measure of a material's ability to store electromagnetic energy, whereas ε'' is a measure of material's ability to dissipate incident energy. Major food components, such as carbohydrates, fat, moisture, protein, and salt, influence the dielectric properties of foods (Datta et al., 2005). Moreover, physical changes due to processing (moisture loss, protein denaturation) also affect the dielectric properties of food material (Shukla and Anantheswaran, 2001). The objective of the present study was to develop and evaluate neural network and partial least square regression (**PLSR**) models for prediction of melt and unmelt properties of PC using dielectric spectroscopy.

MATERIALS AND METHODS

PC Samples

The study was carried out on 3 different data sets. The PC samples in data sets 1 and 2 were procured from a commercial manufacturer, whereas data set 3 was carefully formulated and manufactured in a pilot-scale cheese cooker to achieve a wide range of functional properties.

Data Sets 1 and 2. Slice-on-slice PC samples (data set 1; n = 24) and "Supermelt" PC samples (data set 2; n = 25) were obtained from a commercial manufacturer (Bongards' Creameries, Chanhassen, MN). All the PC samples were selected from different batches and consisted of a similar chemical composition in terms of fat, protein, moisture, salt, and emulsifying agent. However, the functional properties of the product were expected to be different because of variations in the characteristics of different batches of natural cheese used as an ingredient in the PC. The PC samples were stored refrigerated until analyzed.

Data Set 3. A 3 × 2 × 2 factorial design was used to manufacture PC with a wide range of functional properties. Intact casein content (**ICC**), cooking temperature, and cooking mixer speed were selected as the independent variables. Three levels of ICC (14, 15.5, and 17 g/100 g of PC), 2 levels of cooking temperature (76.7 and 87.78°C), and 2 levels of cooking mixer speed (100 and 350 rpm) were incorporated into the experimental design. A carefully formulated blend of 1-wk-, 1-mo-, 3-mo, and 1-yr-aged natural Cheddar cheeses were used to achieve the desired level of ICC in the finished PC.

All the natural cheeses were analyzed for fat, protein, moisture, ICC, and salt as described in the composition analysis section below. The rest of the ingredients, including salt, water, fat, and lactose, were kept constant in all the experimental samples. Each formulation was cooked in duplicate following a standard procedure. Briefly, a preblend of all the ingredients (natural cheese, butter, salt, water, sorbic acid, sodium citrate, nonfat dry milk, enzyme modified cheese paste, and dry color) was prepared (4.5 kg) in the Blentech twin-screw cooker blender (Blentech Corporation, Santa Rosa, CA) by mixing at a predetermined speed (100 or 350 rpm) for 3 min at room temperature. The temperature of the preblend was then increased to either 76.7 or 87.8°C over a 3-min interval by indirect steam heating. The PC samples were packed immediately to prevent any moisture loss and stored at 4°C until further analysis.

Composition Analysis

Representative samples of PC were obtained by drawing approximately 50 g from the package, which were then shredded and analyzed for chemical composition. The moisture content of the PC samples was analyzed using the vacuum oven method as described by Bradley and Vanderwarn (2001). Fat content of the PC was determined using the Mojonnier method (Atherton and Newlander, 1977). Salt content was measured using a Corning Chloride Analyzer 926 (Ciba Corning Diagnostics, Medfield, MA), and pH was measured with a Corning pH/ion meter model 450 (Corning Glass Works, Medfield, MA) with a glass electrode. Total protein in the PC was determined by measuring total N in the PC using the Dumas combustion method (Elementar, Analysensysteme GmbH, Hanau, Germany) with a multiplication factor of 6.38.

Functional Properties Measurement

The modified Schreiber melt test (Muthukumarappan et al., 1999) was performed on all the PC samples.