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Case study

Utilization of pectin-enriched materials from apple pomace as a fat replacer in a model food system

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ABSTRACT

Water soluble pectin-enriched materials (PEMs) from apple pomace, were evaluated as a fat replacer in a model food system. When PEM solutions were subjected to steady-shear measurements, shear-thinning behavior was observed. The flow behaviors could be described by the Cross model ($R^2 = 0.99$), and temperature effects were investigated by the Arrhenius equation. The addition of PEMs significantly increased the pasting parameters of wheat flour as measured by a starch pasting rheometer. Gelatinization temperature and enthalpy increased with increasing PEM concentrations. When PEMs were incorporated into cookie formulations in place of shortening (semisolid fat generally used in baked foods) up to 30% by the weight of shortening, the cookie spread diameter was reduced while an increase in the moisture content was observed. Moreover, replacement of shortening with PEMs contributed to a more tender texture and lighter surface color.

1. Introduction

Apple pomace is the primary waste product of apple juice manufacturing, and approximately 3.0–4.2 $\times$ 10^6 Mton/year are generated annually worldwide (Djilas et al., 2009). Since disposal can pose serious economical and environmental problems, numerous attempts have been made to utilize this waste such as a source of dietary fibers (Sudha et al., 2007), polyphenols (Lu and Yeap Foo, 2000), animal feed (Joshi et al., 2000; Joshi and Sandhu, 1996), and biofuels (Sandhu and Joshi, 1997). It was also suggested that pectin production can be the most reasonable way for utilizing apple pomace (Schieber et al., 2001). Pectin extraction is generally performed under acidic conditions at elevated temperatures (Arthey and Ashurst, 2001), but enzymatic (Contreras-Esquivel, 2006; Fissore et al., 2009; Ptichkina et al., 2008) and chemical (Iglesias and Lozano, 2004; Koubala et al., 2008a,b) approaches combined with thermo/mechanical treatments have also been applied.

Pectin has become highly valued since it is a dietary fiber. Accumulating evidence suggests that it can reduce cholesterol (Brown et al., 1999), delay gastric emptying (Schwartz et al., 1988), and induce apoptosis of colon cancer cells (Olano-Martin et al., 2003). When used in food products, pectin functions as a gelling and thickening agent to modify texture and rheology. However, due to the strong gelling and thickening characteristics, there are considerable difficulties in incorporating high levels of pectin into foods (Theuwissen and Mensink, 2008). Therefore, the development of foods with higher levels of pectin acceptable to consumers is being pursued.

There have been previous studies which reported the possible use of the pectin-enriched materials from plant sources. Fissore et al. (2009) produced pectin-enriched products from butternut with the assistance of cell wall hydrolytic enzymes for thickeners in the food industry. Pectin was also used as a fat replacer in low-fat frankfurters (Candogan and Kolsarici, 2003; Pappa et al., 2000) and cheeses (Lobato-Calleros et al., 2001, 1999), but fat replacement with pectin has not yet been extended to other types of food.

The goals of this study were to isolate water soluble pectin-enriched fractions from apple pomace, investigate their physicochemical/rheological properties, and evaluate their performance as a fat replacer in cookie formulations.

2. Methods

2.1. Preparation of pectin-enriched materials (PEMs) from apple pomace

PEMs from apple pomace were prepared according to the water-based extraction method of Min et al. (2009). Apple pomace, which was obtained from the First Fruits Company (Seoul, Korea), was dried and finely ground to pass through a 50 mesh

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sieve. The apple pomace powder (5 g) was mixed with distilled water and agitated for 1 h. After filtration with miracloth (Merck KGaA, Darmstadt, Germany), the residue was homogenized for 3 min with an ultrasonic homogenizer (VCX-750, Sonics & Materials, Inc., Newtown, CT, USA) and autoclaved at 121 °C for 10 min, followed by cooling at room temperature. The slurries were treated with Viscozyme® L (Novozymes, Bagsvaerd, Denmark) containing 1.2×10^{-3} units of fungal β-glucanase (FBG) at 40 °C for 1 h. After boiling for 5 min and filtering with miracloth, the filtrate was freeze-dried and stored in a plastic bag. This product contained 37.3% galacturonic acid with a degree of esterification of 61.7% as determined by the methods of Filisetti-Cozzi and Carpita (1991) and Klavons and Bennett (1986), respectively.

2.2. Physicochemical characterization of pectin-enriched materials (PEMs)

2.2.1. Rheological measurements

For rheological measurements, PEM solutions at three different concentrations (10%, 20%, and 30%, w/w) were loaded onto a stress-controlled rheometer (AR1500ex, TA Instruments, USA) with a 40 mm parallel plate. Steady-shear measurements were made to investigate the flow behaviors of the PEM solutions at a range of shear rates from 1 to 500 s^{-1} at 25 °C, which were then characterized by the Cross model as follows;

$$\eta = \eta_\infty + \frac{(\eta_0 - \eta_\infty)}{(1 + (\lambda\dot{\gamma})^n)}$$

where η is apparent viscosity, η_∞ is infinite-shear rate viscosity, η_0 is zero-shear rate viscosity, $\dot{\gamma}$ is shear rate, λ is structural relaxation time constant, and n is dimensionless power-law index for the Cross equation.

In addition, the viscosity of the PEM solutions was analyzed as a function of temperature by increasing the temperature from 20 to 80 °C at a constant shear rate of 100 s^{-1}. Arrhenius equation was then applied to investigate the viscosity dependence on temperature (Steffe, 1996).

$$\eta = A \cdot \mathrm{EXP}(E_a/RT)$$

where η is the viscosity of the PEM solutions, A is the pre-exponential factor, E_a is the activation energy, R is the gas constant, and T is the absolute temperature. The activation energy was obtained from the slope of a $\ln(\eta)$ versus $1/T$ plot.

2.2.2. Thermal analysis

Differential scanning calorimetry (DSC 200 *F3 Maia*, NETZSCH, Bavaria, Germany) was used to investigate the effect of PEMs on the thermal properties of wheat flour. Wheat flour (5 mg) was weighed into stainless steel pans, distilled water (25 μL) or PEM solution (1%, 3%, and 5%, w/w) was added, and the pans were hermetically sealed. After 1 h at 25 °C, the samples were heated from 30 to 90 °C at a rate of 5 °C min^{-1}. The DSC instrument was calibrated with indium and distilled water was used as reference.

2.2.3. Pasting property measurement

PEM-induced changes in pasting properties of wheat flour were analyzed with a rheometer equipped with a starch pasting cell (AR1500ex, TA Instruments, USA) which can be operated like a rapid visco-analyzer (RVA). Wheat flour (3 g) was mixed with distilled water (25 mL)/PEM solutions (1%, 3%, and 5%, w/w) in an aluminum canister and subjected to programmed heating/cooling cycles consisting of an initial equilibration at 50 °C for 1 min, heating to 95 °C at 15 °C min^{-1}, holding at 95 °C for 2.5 min, cooling to 50 °C at 15 °C min^{-1}, and holding at 50 °C for 2 min.

2.3. Application of pectin-enriched materials (PEMs) as a fat replacer in cookies

2.3.1. Cookie preparation

According to the approved method by American Association of Cereal Chemists (AACC, 1995), the formulation for the control cookie contained the following ingredients; 225 g pastry flour (CJ Co., Seoul, Korea), 72 g sugar (CJ Co., Seoul, Korea), 22.5 g brown sugar (CJ Co., Seoul, Korea), 100 g shortening (Criso, The J.M. Smucker Co., Orrville, OH, USA), 2.3 g nonfat dry milk, 2.3 g sodium bicarbonate, 3.4 g high-fructose corn syrup, 2.8 g salt, 1.1 g ammonium bicarbonate, and 49.5 g water. For shortening replacement, PEM gels were prepared by dispersing PEM powders in distilled water at a concentration of 30% with agitation. The PEM gels were incorporated into the cookie formulations by replacing shortening (10%, 20%, and 30%) on an equal weight basis.

Shortening was mixed with sugar, brown sugar, nonfat dry milk, salt, and sodium bicarbonate on speed 1 for 3 min by using a KitchenAid mixer (St Joseph, MI, USA) equipped with a paddle beater. Then, the mixture of high-fructose corn syrup and water with ammonium bicarbonate was added and mixed for 1 min on speed 1, followed by scraping down and mixing for an additional minute on speed 2. After flour was added, the mixing was continued for 2 min with scraping down every 30 s. The cookie doughs were flattened with a rolling pin, cut into cylindrical shapes (6 cm diameter and 1 cm thickness) with a cookie cutter, baked at 205 °C for 11 min, cooled at a room temperature, and sealed in a plastic bag until measurements were taken.

2.3.2. Measurement of cookie geometry

According to the approved method by American Association of Cereal Chemists (AACC, 1995), the average diameter of a cookie was measured from the total diameter of six cookies which were placed next to each other and then rotated by 90° four times. Six cookies were then stacked twice in different order and the total height was used to calculate the average height of a cookie.

2.3.3. Textural measurement

A puncture test was applied to investigate the textural properties of cookies by using a texture analyzer (TMS-Pro, Food Technology Co., Virginia, USA) with a 25 N load cell. Based on the method of Lee and Inglett (2006) with slight modifications, cookie samples for puncturing were placed centrally on the platform of the texture analyzer and a cylindrical probe with a diameter of 0.5 cm was then lowered to penetrate through the cookies at a crosshead speed of 100 mm min^{-1}. The plot of force and penetration distance was obtained where the maximum forces and distance to a peak were determined.

2.3.4. Color measurement

A handheld Minota color chromameter (CR-300, Minota Co. Ltd., Osaka, Japan) was used to investigate color changes of cookies in which shortening was replaced with PEMs. The values of L^* (lightness/darkness), a^* (redness/greenness), and b^* (yellowness/blueness) were recorded.

2.4. Statistical analysis

All experiments were carried out in triplicate. Results were statistically analyzed by analysis of variance (ANOVA), followed by Duncan's multiple range test. Statistical significance was indicated at a confidence level of 95%.