Effect of xylitol on the functional properties of low-fat process cheese

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ABSTRACT

Process cheese (PC) is a dairy food prepared by blending natural cheese, salt, emulsifying salts, and other dairy and nondairy ingredients, and heating with continuous agitation to produce a homogeneous product. Fat is a critical component of PC and plays an important role in its functional characteristics. The health concerns associated with fat consumption have led to an increase in the demand for low-fat dairy products. Reducing the fat content of PC results in poor functional properties such as increased hardness and reduced melt characteristics. The objective of the current study was to evaluate the effect of xylitol on the functional properties of low-fat PC. Three different low-fat PC formulations were prepared with 0% (control), 2%, and 4% xylitol. All 3 PC formulations were formulated to contain 5% fat, and each treatment was manufactured in triplicate. Rheological characteristics including elastic modulus, viscous modulus, and temperature at $\tan\delta = 1$ (melt temperature) were determined using dynamic stress rheometry (DSR). The DSR was carried out at a frequency of 1.5 Hz and stress levels of 400 Pa, using a temperature sweep from 20 to 90°C. The hardness of the samples was determined by using texture profile analysis (TPA). Compositional analysis indicated that all treatments had similar fat, protein, and moisture contents. Elastic and viscous moduli results obtained with DSR showed a significant difference between 0% xylitol (control) and xylitol-containing treatments in the temperature range of 30 to 80°C. The melt temperature was not significantly different between the 3 treatments. However, TPA demonstrated that the addition of xylitol significantly decreased the hardness of low-fat PC. Based on TPA and DSR data obtained in this study, we determined that xylitol addition improved the functional properties of low-fat PC.

Key words: process cheese, low fat, xylitol

INTRODUCTION

Process cheese (PC) is a dairy food prepared by blending natural cheese, sodium chloride, emulsifying salts, and other dairy and nondairy ingredients, and then heating with continuous agitation to produce a pasteurized product that is homogeneous and has an extended shelf life (Meyer, 1973; Thomas, 1973; Kapoor and Metzger, 2008). Process cheese or process cheese products utilize nearly one-third of all natural cheese produced in the United States. Process cheese is one of the leading varieties of cheese in the world and is used as an ingredient in various food preparations (Sorensen, 2001; Kapoor and Metzger, 2008). Process cheese is manufactured in a variety of forms such as slices, loaves, shreds, and spreads.

In the United States, the Code of Federal Regulations (CFR) legally defines 3 categories of PC based on the requirements for minimum fat content, maximum moisture content, and minimum pH, as well as the quantity and number of optional ingredients that can be used (FDA, 2008a; 21CFR133.169 to 133.180). A full-fat PC must contain a minimum of 30% butter fat. This substantial quantity of fat plays an important role in its melting characteristics (Subramanian et al., 2006). Even though fat plays a critical role in the overall acceptability of food products, consumer desire low-fat products due to the association of excess fat intake with heart disease and obesity. Cheese is one of the major contributors of dietary fat in America. Hence, efforts have been made to reduce the fat content in natural and process cheeses (Drake et al., 1999).

According to the CFR, the fat content in a reduced-fat PC should be at least 25% less (FDA, 2008b; 21CFR130.10) than that of its conventional counterpart (that contains a minimum of 30% fat). To achieve the claim of a low-fat PC, the fat content in low-fat PC must be less than 6 g/100 g of PC (FDA, 2008c; 21CFR101.62). Consequently, to meet the low-fat requirement, an 80% reduction in fat relative to full-fat PC is required.

Manufacture of reduced- or low-fat PC is a challenge to the dairy industry because acceptance of the PC largely depends on its functional properties, in which fat content is a critical component. In natural cheese,

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the fat and moisture are entrapped in a 3-dimensional protein network (Prentice, 1987), which gives structure to the cheese. However, in the manufacture of PC, the use of emulsifying salt, heat, and vigorous mixing result in a stabilized emulsion of fat within the protein matrix (Lee et al., 2003; Price, 2007). This phenomenon gives a unique microstructure to PC, which consists of a protein network containing an evenly dispersed fat phase that gives PC its functional characteristics (Kapoor and Metzger, 2008; Johnson et al., 2009). Within the protein matrix, fat plays an important role in cheese texture by providing lubrication (Raval and Mistry, 1999). Consequently, when the fat content of PC is reduced, an increase in the protein network and a decrease in lubrication provided by fat occur, which results in a firm, rubbery texture and poor melting characteristics (McMahon et al., 1996; Zhong, 2003).

Most of the fat in PC is derived from the natural cheese used in its manufacture (Johnson et al., 2009). Hence, utilization of fat-free or nonfat natural cheese lowers the fat content in PC. However, lower fat or nonfat natural cheese is associated with many functional and organoleptic defects, which tend to be carried over into the PC (Muir et al., 1997; Gwartney et al., 2002). The fat in PC can be replaced by adding water, protein, or other additives such as gums and stabilizers (Caric and Kalab, 1993; Lee et al., 2003). The acceptability of low-fat PC can be improved by using fat replacers that partially or fully replace fat and simulate the properties of fat (Jones, 1996; Drake et al., 1999).

Fat replacers are classified according to the substances from which they are derived. Carbohydrate-based fat replacers include pectin, gums, starch, dextrin, vegetable fibers, and carrageenan. Protein-based fat replacers include modified whey protein and soy protein. Lipid-based fat replacers include mono- and diglycerides, olestra, salatrim, and carpenin (Napier, 1997).

Several different fat replacers have been shown to produce reduced-fat PC with improved functional characteristics (Davison and Schwimmer, 1993; Mehnert and Prince, 1996; Drake et al., 1999; Swenson et al., 2000). A study on the physical and sensory properties of reduced-fat PC spread made using hydrocolloid fat mimetics concluded that the texture of 40% reduced-fat PC was comparable to that of full-fat PC (Brummel and Lee, 1990). Drake et al. (1999) reported that 50% reduced-fat PC containing lecithin had improved functional properties (elasticity, firmness, and cohesiveness) relative to a 50% reduced-fat control that contained no lecithin. Hassan et al. (2007) reported that 35% reduced-fat PC produced with reduced-fat Cheddar made from exopolysaccharide (EPS)-producing starter cultures had a softer texture compared with a 35% re-

duced-fat PC control that contained no Cheddar made from EPS-producing starter cultures. All of these studies indicate that the functional properties of PC with up to 50% reduced fat can be improved with the use of fat replacers. However, no study has been conducted to evaluate the functional properties of low-fat ($\leq 6\%$ fat) PC.

Xylitol is a carbohydrate-based, hydrocolloid fat mimetic substance that has not yet been evaluated as a fat replacer in reduced- or low-fat PC. Xylitol is a Food and Drug Administration-approved sugar alcohol that can be used in foods as an ingredient. Xylitol is an intermediate product of carbohydrate metabolism obtained from xylan-containing plant materials (Sandrou and Arvanitoyannis, 2000). Xylitol has also attracted the interest of food scientists for use as a sugar replacer because of its sweetening power and low caloric property. Xylitol is highly hygroscopic in nature and absorbs water in foods (Tomasik, 2003; Mushtaq et al., 2010). The hygroscopic nature of xylitol results in formation of a gel-type texture that provides lubricity, which may improve the texture of low-fat PC. Previous studies on low-fat cookies with added xylitol (Zoulias and Pkinis, 2000) have shown improved functional properties. Because the use of xylitol has not been evaluated in low-fat PC, the objective of the current study was to determine the effect of xylitol on the functional properties of low-fat PC.

MATERIALS AND METHODS

Process Cheese Formulations

Three different PC formulations were developed that contained 0% xylitol (control), 2% xylitol, and 4% xylitol. The ingredients used in each formulation are shown in Table 1. The ingredients used were trisodium citrate (KIC Chemical Inc., New Paltz, NY), salt (Cargill, Minneapolis, MN), fat-free Cheddar (Valley Queen Cheese Factory, Milbank, SD), aged Cheddar (Cabot Extra Sharp Cheddar, Cabot, VT), 88% lactic acid (Fisher Scientific, Pittsburgh, PA), sorbic acid (Hawkins Inc., Minneapolis, MN), lactose (Fisher Scientific, Pittsburgh, PA), xylitol (Danisco USA Inc., Thomson, IL) and water. The same blend of fat-free and aged Cheddar cheeses was used for all the treatments and replicates. The primary carbohydrate in PC is lactose and a typical PC formulation will have approximately 4% lactose. In PC, lactose is used as filler and has a minimal effect on the functionality (Kapoor and Metzger, 2008). Consequently, to balance the composition of each formulation, addition of xylitol was compensated by a reduction in lactose: the 0% xylitol

Table 1. Formulation of process cheeses made with addition of 0, 2, or 4% xylitol

Ingredient	Xylitol		
	0% (Control)	2%	4%
Aged Cheddar cheese (%)	12.00	12.00	12.00
Trisodium citrate (%)	3.00	3.00	3.00
Salt (%)	0.70	0.70	0.70
Water (%)	17.24	17.24	17.24
Lactic acid (%)	0.40	0.40	0.40
Sorbic acid (%)	0.20	0.20	0.20
Fat-free cheese (%)	62.46	62.46	62.46
Lactose (%)	4.00	2.00	0.00
Xylitol (%)	0.00	2.00	4.00

(control) formulation had 4% lactose, the 2% xylitol treatment had 2% lactose, and the 4% xylitol treatment had no lactose. The sweetness of xylitol is similar to that of sucrose and, at the 2% and 4% addition levels used in this study, it did not affect the flavor of the PC. An Excel-based software program called Tech Wizard (Metzger, 2003) developed by Owl Software (Lancaster, PA) was used for developing all 3 formulations, which contained 55% moisture, 5% fat, and 27% protein.

Process Cheese Manufacture

The 3 PC treatments were manufactured in triplicate in 4.5-kg batches using a twin-screw process cooker blender (Blentech Corp., Rohnert Park, CA). During manufacture, all the ingredients were added to the Blentech twin-screw cooker and mixed at 50 rpm for 30 min at 20°C to achieve a homogeneous paste. Subsequently, the temperature of the preblend was increased to 80°C over approximately 5 min and held for an additional 5 min. Auger speed throughout the heating and holding stages was 140 rpm. Process cheese was packaged into 1-kg loaves and stored at 4°C until analysis was completed.

Chemical Analysis

Samples were analyzed for fat using the Mojonnier method (Atherton and Newlander, 1977), moisture con-

tent using a forced-draft oven (model OV-490A-2; Blue M, Blue Island, IL), and pH using a Corning pH/ion meter model 450 (Corning Glass Works, Medfield, MA) fitted with a Thermo Orion combination pH probe (Thermo Electron Corp., Louisville, CO). All of the analyses on each sample were performed in duplicate.

Analysis of Functional Properties

Texture Profile Analysis. Hardness of the samples was determined by texture profile analysis (TPA). Process cheese samples were cut into cylinders 20 mm in diameter and 20 mm high using a cork borer and cheese slicer. Cheese cylinders were wrapped in Reynolds food service film (Nogg Chemical and Paper, Omaha, NE) to prevent moisture loss and tempered at 20°C for at least 1 h before testing. The TPA was performed using a TA.XT2 Texture Analyzer (Texture Technologies Corp., Scarsdale, NY/Stable Microsystems, Godalming, UK) as described by Drake et al. (1999). Test conditions were as follows: uniaxial 2 bite compression with 50-mm-diameter cylindrical flat probe (TA-25). Three replicates of each sample were analyzed with a cross-head speed of 0.8 mm/s, and the peak force (cheese hardness) was recorded at 80% compression.

Dynamic Rheological Analysis. Dynamic rheological analysis was done using a rheometer (ATS Rheosystems, Rheologica Instruments Inc., Borden-town, NJ). Samples were cut into cylinders 28 mm in diameter and 2 mm high using a cork borer and cheese slicer. The samples were wrapped in Reynolds food service film (Nogg Chemical and Paper) and stored at 4°C. To maintain the initial sample temperature at 20°C, samples were tempered at 20°C for at least 1 h and tested with the rheometer using the parallel plate method. Fine sandpaper (400 grit, 3M, St. Paul, MN) was glued to the upper plate to prevent sample slippage. The sample was placed on the bottom plate and the top plate was brought in contact with the sample. The gap was set at 2.0 mm. Initially, stress sweep and frequency sweep tests were done to determine the linear region that was required to conduct the temperature sweep. The dynamic rheology test was conducted using a temperature sweep at a frequency of 1.5 Hz and

Table 2. Mean squares (*P*-values in parentheses) of chemical properties of process cheese

Factor	df	pH	Moisture	Fat	Protein
Replicate	2	0.00100 (0.45)	0.09400 (0.56)	0.00003 (0.99)	0.04500 (0.58)
Treatment	2	0.00300 (0.13)	1.28700 (0.03)	0.00243 (0.68)	0.06600 (0.47)
Error	4	0.00100	0.14000	0.00596	0.07300

Table 3. Mean composition of process cheeses made with addition of 0, 2, or 4% xylitol

Chemical attribute	Xylitol		
	0% (Control)	2%	4%
pH	5.12 ^a	5.18 ^a	5.17 ^a
Moisture (%)	54.64 ^a	54.32 ^{ab}	53.38 ^b
Fat (%)	5.08 ^a	5.02 ^a	5.06 ^a
Protein (%)	27.26 ^a	27.28 ^a	27.53 ^a

^{a,b}Means within a row not sharing a common superscript are significantly different ($P < 0.05$).

at constant stress of 450 Pa while increasing the temperature at the rate of 1°C/min from 20 to 90°C. The exposed cheese surface was coated with vegetable oil (ConAgra Foods Inc., Omaha, NE) to minimize drying during measurement. All measurements were performed in triplicate. Data were collected and analyzed as described by Sutheerawattananonda and Bastian (1998). Elastic modulus (G'), viscous modulus (G''), tangent angle ($\tan \delta$), and melt temperature were determined. The melt temperature was defined as the lowest temperature during the temperature gradient experiment, where $\tan \delta$ equaled 1 ($G' = G''$).

Statistical Analysis

Statistical analysis was performed to study the effect of xylitol on the functional properties of low-fat PC. An ANOVA was performed to obtain the mean squares (MS) and P -values using the GLM procedure available in SAS (SAS OnlineDoc, Version 8, SAS Institute Inc., Cary, NC). When a significant treatment effect ($P < 0.05$) was detected, differences among treatment means were tested using the Tukey multiple comparison test.

RESULTS AND DISCUSSION

Composition

The ANOVA with MS and P -values for pH, moisture, fat, and protein of the PC is shown in Table 2. The

Table 4. Mean squares (P -values in parentheses) for texture profile analysis (TPA) hardness and dynamic stress rheometer (DSR) melt temperature of the process cheese

Factor	df	TPA hardness	DSR melt temperature
Replicate	2	652,486.000 (0.3100)	38.370 (0.4300)
Treatment	2	35,345,914.000 (0.0001)	29.150 (0.5200)
Error	22	522,589.250	43.936

Table 5. Mean functionality of process cheese made with addition of 0, 2, or 4% xylitol determined by texture profile analyzer (TPA) and dynamic stress rheometry (DSR)

Functional property	Xylitol		
	0% (Control)	2%	4%
TPA hardness (g)	11,757.7 ^a	9,167.1 ^b	7,864.6 ^c
DSR melt temperature (°C)	71.8 ^a	68.8 ^a	68.6 ^a

^{a-c}Means within a row not sharing a common superscript are significantly different ($P < 0.05$).

replicate factor was not significant ($P > 0.05$) for any parameter. Additionally, we observed no significant differences ($P > 0.05$) in pH, fat, or protein for the treatment factor. However, we did observe a significant ($P < 0.05$) difference in moisture.

Mean compositional analysis for each treatment is shown in Table 3. The pH of all treatments was lower than the pH range of typical full-fat PC, which ranges from 5.4 to 5.8 (Kapoor and Metzger, 2008). However, in preliminary research, we determined that it was possible to have a lower pH in low-fat PC. This may be a result of the elevated protein content of low-fat PC.

A significant ($P < 0.05$) difference was found between the moisture content of the 0% xylitol (control) and the 4% xylitol treatment. However, moisture contents did not differ between the 0% xylitol (control) and 2% xylitol treatment or between the 2% and 4% xylitol treatments. The significantly higher moisture content of the 0% xylitol (control) treatment compared with 4% xylitol PC should improve the functional properties of the 0% xylitol (control) because additional moisture has been shown to improve the functional characteristics of reduced- or low-fat PC (Drake et al., 1999; Johnson et al., 2009). Consequently, any observed improvement in the functional properties of the 4% xylitol treatment would need to compensate for the lower moisture content in this treatment.

Functional Properties

The ANOVA with MS and P -values for TPA hardness and melt temperature of the PC from each treatment are shown in Table 4. The replicate factor was not significant ($P > 0.05$) for either parameter and the treatment factor was not significant ($P > 0.05$) for dynamic stress rheometer (DSR) melt temperature. However, the treatment factor was significant ($P < 0.05$) for TPA hardness.

Mean values for TPA hardness and melt temperature of the PC from each treatment are shown in Table 4. The 4% xylitol PC had significantly ($P < 0.05$) less

Table 6. Mean squares (*P*-values in parentheses) for elastic (*G'*) and viscous (*G''*) moduli determined by dynamic stress rheometry (DSR) of process cheese treatments at 20, 70, and 90°C

Factor	df	<i>G'</i>				<i>G''</i>			
		20°C	70°C	90°C		20°C	70°C	90°C	
Replicate	2	235,920,715 (0.2100)	42,273,985 (0.0200)	161,562 (0.0640)		22,776,633 (0.2750)	9,917,563 (0.0860)	258,590 (0.0770)	
Treatment	2	7,837,317,781 (0.0010)	47,371,128 (0.0140)	158,886 (0.0670)		873,544,411 (0.0001)	20,916,192 (0.0090)	292,414 (0.0570)	
Error	22	141,793,929	9,131,341	52,006		16,644,726	3,609,892	89,401	

Table 7. Mean elastic (*G'*, Pa) modulus of process cheese made with addition of 0, 2, or 4% xylitol during heating from 20 to 90°C

Temperature (°C)	Xylitol		
	0% (Control)	2%	4%
20	123,114 ^a	81,109 ^b	66,208 ^c
30	101,430 ^a	67,482 ^b	57,559 ^b
40	65,027 ^a	43,698 ^b	36,922 ^b
50	36,259 ^a	23,389 ^b	19,229 ^b
60	16,069 ^a	9,312 ^b	9,469 ^{ab}
70	7,473 ^a	3,496 ^b	3,503 ^{ab}
80	1,931 ^a	1,100 ^b	643 ^{ab}
90	530 ^a	409 ^a	264 ^a

^{a-c}Means within a row not sharing a common superscript are significantly different (*P* < 0.05).

hardness than the 2% and 0% xylitol PC, and the 2% xylitol had significantly (*P* < 0.05) less hardness than the 0% xylitol PC (Table 5). The reduction in TPA hardness was substantial and was 22 and 33%, respectively, for the 2 and 4% xylitol treatments compared with the 0% xylitol (control). A similar improvement in the texture of low-fat cookies containing xylitol was reported by Zoulis and Piknis (2000). The lower TPA values substantiate the proposed lubrication effect of xylitol within the protein matrix of PC. Rheological studies conducted by Drake et al. (1999) reported a similar reduction in the TPA hardness of 50% reduced-fat PC containing lecithin as a fat replacer. A small but not significant (*P* > 0.05) difference occurred in the melt temperature values as the xylitol content increased. These results indicate that xylitol addition had no effect on the melt temperature of low-fat PC. Similar to this study, Hassan et al. (2007) reported that in 35% reduced-fat PC produced from reduced-fat Cheddar cheese made with EPS-producing starter cultures did not affect the melt temperature of reduced-fat PC.

Table 8. Mean viscous (*G''*, Pa) modulus of process cheese made with addition of 0, 2, or 4% xylitol during heating from 20 to 90°C

Temperature (°C)	Xylitol		
	0% (Control)	2%	4%
20	41,539 ^a	26,968 ^b	22,767 ^b
30	36,181 ^a	23,709 ^b	21,473 ^b
40	26,236 ^a	17,533 ^b	16,241 ^b
50	17,768 ^a	11,744 ^b	11,045 ^b
60	10,608 ^a	6,650 ^b	6,580 ^b
70	5,926 ^a	3,337 ^b	3,237 ^b
80	2,142 ^a	1,541 ^{ab}	1,042 ^b
90	943 ^a	852 ^a	596 ^a

^{a,b}Means within a row not sharing a common superscript are significantly different (*P* < 0.05).

Figure 1. Elastic (G' , Pa) modulus of process cheese, made with addition of 0, 2, or 4% xylitol, during heating from 20 to 90°C at the rate of 1°C/min during dynamic rheological analysis. Color version available in the online PDF.

The ANOVA table with MS and P -values at 20, 70, and 90°C for both elastic (G' , Pa) and viscous (G'' , Pa) moduli of the PC from each treatment are shown in Table 6. The mean values for G' of the PC during heating from 20 to 90°C at 10°C increments for each treatment are shown in Table 7, and those for G'' are shown in Table 8. Figures 1 and 2 graphically show the effects of the 0, 2, and 4% xylitol content on G' and G'' , respectively, on PC during heating from 20 to 90°C.

The G' and G'' of the 2% and 4% xylitol treatments were lower than that of the 0% xylitol (control) be-

tween 20 and 70°C (Figures 1 and 2). These differences were significant ($P < 0.05$) between 20 and 50°C for G' (Table 7) and between 20 and 70°C for G'' (Table 8). The comparison between the 2% and 4% xylitol treatments showed that G' was significantly different at 20°C, but no significant ($P > 0.05$) differences were found at any temperature for G'' . These results clearly demonstrate that xylitol has a substantial effect on the rheological characteristics of low-fat PC.

A study by Subramanian et al. (2006) on the viscoelastic properties of regular and 80% reduced-fat PC

Figure 2. Viscous (G'' , Pa) modulus of process cheese, made with addition of 0, 2, or 4% xylitol, during heating from 20 to 90°C at the rate of 1°C/min during dynamic rheological analysis. Color version available in the online PDF.

(4.76% fat) reported higher dynamic viscosity values for 80% reduced-fat PC. The current study demonstrates that the high dynamic viscous values typically observed in reduced- or low-fat PC can be reduced by 40 to 50% with the addition of 4% xylitol. The improvement in the functional characteristics of xylitol-containing low-fat PC may be a result of lubrication within the protein matrix caused by xylitol. The results also indicate that the lubrication effect of xylitol is more substantial at lower temperatures ($<20^{\circ}\text{C}$) and becomes less critical as the protein matrix collapses during melting ($>70^{\circ}\text{C}$).

CONCLUSIONS

Compositional analysis showed no significant difference between treatments except for the significantly lower moisture content of the 4% xylitol treatment compared with the control (0% xylitol). Even with significantly lower moisture content, addition of 4% xylitol improved the functional characteristics of low-fat PC. Results of TPA showed a significant decrease in hardness with an increase in xylitol content. Melt temperature obtained with DSR did not differ significantly among the treatments. The G' and G'' values indicated only slight differences between 2 and 4% xylitol treatments, but these 2 treatments were significantly different from the 0% xylitol treatment (control) in the heating range of 20 to 80°C . Overall, compositional and functional analyses indicated that xylitol-containing PC samples have improved functional properties. Consequently, xylitol could be used as a fat replacer to improve the functional properties of low-fat PC.

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