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Soy addition improves the texture of microwavable par-baked pocket-type flat doughs

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Abstract Microwavable baked goods are used frequently by the food industry to enrobe meat, vegetable, and sweet items for convenient meal delivery but suffer from poor texture upon microwave re-heating. Par-baking the dough prior to the reheating stage provides an opportunity to supply fresh baked goods with a simple baking stage at retail locations. Nonetheless, reheating conditions significantly affect texture of reheated par-baked products, resulting in shrinkage, porosity reduction, and crust softening. Appropriate formula modifications have been shown to reduce microwave-induced toughness of reheated bread by virtue of water-binding agents and lipids. The objective of this study was, therefore, to assess the effect of soy addition on the water state of microwavable par-baked doughs. Four dough formulations were developed by substituting wheat flour with increasing amounts of a soy blend. Addition of soy at 20 and 26% levels improved textural properties of microwaved products, resulting in a softer and less chewy texture. Thermogravimetric analysis (TG) showed increased water binding in soy formulations 20 and 26% with a broadening of the main peak (attributed to water loss) that shifted from 40 to 80 °C. Differential scanning calorimetry (DSC) depicted a transition in the −25/−10 °C range, attributed to soy lipids melting, which broadened at high soy addition. This change in water dynamics was confirmed by proton nuclear magnetic resonance (^{1}H NMR) relaxation tests, T_1 and T_2, having lower values in soy products, and therefore, depicting a more solid-like matrix. Soy addition above 20% significantly improved the texture of microwave reheated par-baked flat doughs.

Keywords Par-baked · Hardness · Chewiness · Soy · State of water

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Introduction

Microwavable frozen baked goods are used frequently by the food industry to enrobe meat, vegetable, and sweet items for convenient meal delivery [1]. Doughs, however, suffer from poor texture upon microwave heating. Microwaved doughs' exterior remains tough while the interior is hard and chewy [2]. These and other deleterious textural properties have been discussed elsewhere [3–7].

Par-baking the dough prior to reheating improves bread quality resulting in sensory and textural properties similar to those of the bread obtained by a conventional method [8]. Par-baking is a method of bread manufacturing involving two stages of baking with an intermediate freezing step and provides an opportunity to supply fresh baked bread with a simple baking stage at retail locations [9].

Nonetheless, reheating conditions significantly affect texture of reheated par-baked products, resulting in shrinkage, porosity reduction, crust softening, and viscous crumb [10]. Par-baked frozen products are subject to crumb hardening when thawed and reheated as a consequence of the ice crystallization occurring during the frozen storage [11].

Appropriate formula modifications have been shown to reduce microwave-induced toughness of reheated bread. Miller and Hoseney [12] reported that microwave-heated products that contained excess water, by virtue of water-binding agents, were significantly less tough than a control. Similarly, previous studies in our laboratory showed that soy addition improved the texture of microwave baked pocket-type flat doughs by reducing their toughness [13]. Study of water mobility by thermal analysis (TG, DSC) and nuclear magnetic resonance relaxation studies (^{1}H NMR T_1, T_2) showed that such textural improvement was possibly due to enhanced plasticization of the starch–gluten network in soy-containing products [13–15]. Soy proteins enhanced water association with the polymers in microwavable pocket-type flat doughs, as shown by thermogravimetric analysis (TG) [13]. Furthermore, the higher lipid content of soy depicted by differential scanning calorimetry (DSC) prevented amylose leaching from starch granules during microwave baking [13]. The study of water mobility provides insights on the hydration of polymers, particularly starch and gluten, which affects texture of baked products. Moisture content and distribution can be determined by TG [14, 16]. State of water and starch gelatinization can be analyzed by DSC [14, 17]. ^{1}H NMR T_1, T_2 further investigate water mobility [15, 18].

The objective of this study was therefore to assess the effect of soy addition on the state of water of microwavable par-baked pocket-type flat doughs.

Experimental

Dough production

Four dough formulations were developed with a soy blend HealthyHearth™ Baking Blend, consisting of 2/3 soy flour (Baker's Soy Flour, ADM Protein Specialties Division, Decatur, IL) and 1/3 soy milk powder (Devansoy Farms, Carrol, IA) as shown in Table 1. Soy blend contained 50% proteins, 28% carbohydrates, 9% fat, 5.5% moisture, 5% fiber, and 2.5% ash. Dough formulations contained the following amount of soy blend: 0% (Form 1), 10% (Form 2), 20% (Form 3), and 26% (Form 4). Increasing the soy blend incorporated in doughs required higher amount of water in formulations to completely hydrate the ingredients while other ingredients were kept constant (Table 1).

Table 1 Dough formulations used in this study

Ingredient/%	Form 1	Form 2	Form 3	Form 4
Wheat flour	61	50	39	30
HealthyHearth™ Baking Blend	0	10	20	26
Water	36	37	38	41
Yeast	1	1	1	1
Salt	2	2	2	2

Wheat flour (13% proteins, 1.7% fat; Magnifico Special) was purchased from Conagra Mills (Omaha, NE) while instant active dry yeast (Red Star) was purchased from Universal Foods Corporation (Milwaukee, WI). Consequently, soy addition resulted in the following compositions: Form 1 (7.9% proteins, 1.0% fat), Form 2 (8.6% proteins, 1.8% fat), Form 3 (15% proteins, 2.5% fat), Form 4 (17% proteins, 2.9% fat).

The following process was used to make the doughs: ingredients were scaled and then mixed in a high speed mixer for approximately 1 min (cuisine mixer, Kitchen aid, K5SS, St. Joseph, MI). Dough was then allowed to rest for 10 min (hydration), rolled in a sheeter (Atlas model 150 mm deluxe, Italy), par-baked at 145 °C for 11 min in a convection oven (Frigidaire, Model GLDSM 986, Martinez, GE) and cooled on wire racks.

Par-baked doughs were analyzed before and after microwave reheating (60 s at high power in a convection microwave oven, Sharp Carousel II, Tokyo, Japan) and conventional reheating (2 min at 182 °C in a toaster oven, Hamilton Beach Toastation, Washington, NC). All samples were analyzed at room temperature. Reheated doughs were allowed to cool down to room temperature prior to TG, DSC, and NMR analyses.

Thermal analysis

Thermal transitions indicative of the state of components in a system were determined using a differential scanning calorimeter (DSC). About 10 mg of dough were placed in large-volume, stainless steel sample pans and lids fitted with o-rings (PerkinElmer, Boston, MA). Sample and reference pans were placed inside the DSC equipped with a refrigerated cooling system (Q 100, TA Instruments, New Castle, DE). Samples were equilibrated at −50 °C and heated to 100 °C at 5 °C/min. Transitions observed in the thermograms were analyzed using the Universal Analysis TM software (TA Instruments, New Castle, DE). Enthalpies of transitions were estimated by integration of peaks and were expressed in J/g.

Moisture content and distribution were determined by thermogravimetric analysis (TG). Samples were placed in a TGA Instrument (Q 5000 TA, New Castle, DE) equilibrated at 25 °C and heated to 150 °C at 5 °C/min. Transitions were analyzed using the Universal Analysis Software, Version 4.2 (TA Instruments, New Castle, DE).

Nuclear magnetic resonance

Nuclear magnetic resonance ^{1}H T_1 and T_2 experiments were performed at room temperature (25 °C) using a Bruker NMR DMX 300 MHz: Saturation Recovery [19] and the CPMG sequences [20], respectively (Table 2). For

Table 2 Physicochemical characterization of wheat dough (Form 1) after conventional and microwave baking

Parameter	Conventional	Microwave	p value
Hardness/N	39 ± 2[a]	47 ± 3[b]	0.037
Chewiness/N	979 ± 358[a]	1760 ± 248[b]	0.012
Springiness/mm	3.0 ± 1.1[a]	3.5 ± 1.0[a]	0.574
Cohesiveness/ratio	0.50 ± 0.16[a]	0.67 ± 0.07[a]	0.230
Moisture content/g water/ 100 g sample	17.6 ± 0.9[a]	19.3 ± 0.4[a]	0.077
^{1}H T_1/ms	618 ± 54[a]	702 ± 8[a]	0.055
^{1}H T_2/ms	1.9 ± 0.1[a]	26 ± 1[b]	<0.001

Different letters refer to statistical difference between samples (α 0.05)

the T_1 experiments, one major ^{1}H peak was observed and, therefore, this peak intensity was used for the fit using Eq. 1. For the T_2 experiments, however, three different peaks were observed (chemical shift ~2, 4, and 5 ppm) as documented previously [18] and the intensity of the peak occurring at ~5 ppm was used to fit Eq. 2 since these protons most likely represented the water signal.

$$T_1 \text{ INTENSITY fit: } I(t) = I(0) + P * \exp\left(\frac{-t}{T_1}\right) \quad (1)$$

$$T_2 \text{ INTENSITY fit: } I(t) = P * \exp\left(\frac{-t}{T_2}\right) \quad (2)$$

Texture profile analysis

The mechanical properties hardness, chewiness, cohesiveness, and springiness were obtained using an Instron table Micro System performing a TPA test [21].

Statistical analysis

Tests were performed in triplicate with the exception of ^{1}H NMR, which was performed in duplicate. Means were calculated with SPSS statistical software (Version 16.0, SPSS Inc., Chicago, Illinois). SPSS was used to perform one-way analysis of variance ANOVA and least significant difference test (LSD) to identify differences of evaluated parameters among formulations (soy effect; 95% confidence level, $p < 0.05$).

Results and discussion

Comparison of conventional and microwave reheating of wheat doughs

Microwave reheating of the par-baked wheat dough resulted in a firmer and chewier texture, as expected for crumb of microwaved goods [7] and of reheated par-baked products [11, 12] (Table 2). Chewiness of the microwaved product was twice as high as of the conventionally reheated product (1760 N vs. 979 N, Table 2). No significant changes in cohesiveness and springiness were observed, thus indicating that par-baking prevented the microwave-induced development of tough and rubbery texture as observed for untreated samples [13].

Although moisture content was not significantly affected by the reheating mode (Table 2), difference in water distribution was observed. TG derivative weight loss showed a lower temperature for water evaporation (water easier to remove) in the microwaved product compared to conventionally reheated sample (weight loss peak shifted from ~100 to 40 °C, Fig. 1a). Such results indicate less plasticization of the gluten–starch network in the microwave baked product. DSC thermograms did not significantly differ (Fig. 1b) among reheating modes. One endothermic transition in the range from −25 to −15 °C was observed for both heating modes (Fig. 1a) and was attributed to polar lipids melting [22]. Aktas and Kaya [22] observed a crystallization peak in the same temperature range during a cooling ramp from 70 to −40 °C of beef body fat, margarine, and butterfat samples and attributed it to polar lipids. Furthermore, Aktas and Kaya [22] observed a melting peak in the same temperature range during heating ramp of the same samples from −40 to 70 °C.

NMR T_1 and T_2 confirmed the lower plasticization of the microwaved product by showing a dramatic increase of transverse relaxation time (T_2): 26 versus 1.9 ms (Table 2). Longer transverse relaxation times (T_2) indicated higher water mobility in the microwaved product. TG and NMR findings depicted easily removed water that is highly mobile. Highly mobile water was associated to harder and chewier texture of the reheated product as discussed previously [5]. Merabet related the microwave-induced toughening of bread to the decreased water “binding” to polymers measured by broad-band dielectric spectroscopy (relaxation frequency).

Effect of soy addition on microwave reheated par-baked doughs

Addition of soy improved textural properties of microwaved par-baked products. These improvements were significant at 20 and 26% soy addition and consisted of a softer and less chewy texture (p value 0.001 for hardness and p value <0.001 for chewiness, Table 3). Addition of soy prevented the deleterious effects of microwave reheating and resulted in a product with textural properties similar to the conventionally reheated wheat dough (Form 1): hardness <40 N, chewiness <1000 N (Table 3). Nonetheless, a significant increase of springiness was

Fig. 1 Comparison of microwave baked versus conventionally baked wheat doughs by TG (**a**) and DSC (**b**)

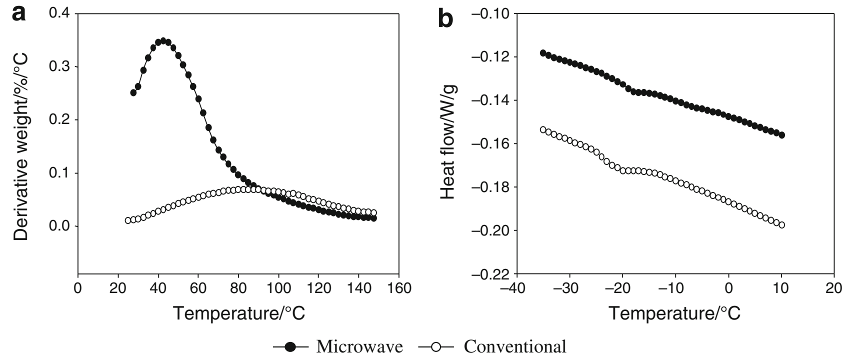


Table 3 Physicochemical characterization of microwave baked doughs

Parameter	Form 1	Form 2	Form 3	Form 4	p value
Hardness/N	47 ± 3[a]	37 ± 5[a]	18 ± 4[b]	16 ± 7[b]	0.001
Chewiness/N	1760 ± 248[a]	1201 ± 197[a]	596 ± 109[b]	524 ± 134[b]	<0.001
Springiness/mm	3.5 ± 1.0[a]	4.2 ± 0.0[b]	4.4 ± 0.1[b]	4.3 ± 0.1[b]	<0.001
Cohesiveness/ratio	0.67 ± 0.07[a]	0.66 ± 0.01[a]	0.67 ± 0.05[a]	0.71 ± .02[a]	0.702
Moisture content/g water/100 g sample	19.3 ± 0.4[a]	15.1 ± 0.6[b]	20.9 ± 1.3[a]	20.1 ± 0.1[a]	<0.001
^{1}H T_1/ms	702 ± 8[a]	606 ± 50[b]	319 ± 8[c]	371 ± 13[c]	<0.001
^{1}H T_2/ms	26 ± 1[a]	15 ± 0[b]	2.4 ± 0.2[c]	2.1 ± 0.3[c]	<0.001

1, 2, 3 and 4 refer to respective formulations in Table 1. Different letters refer to statistical difference between samples (α 0.05)

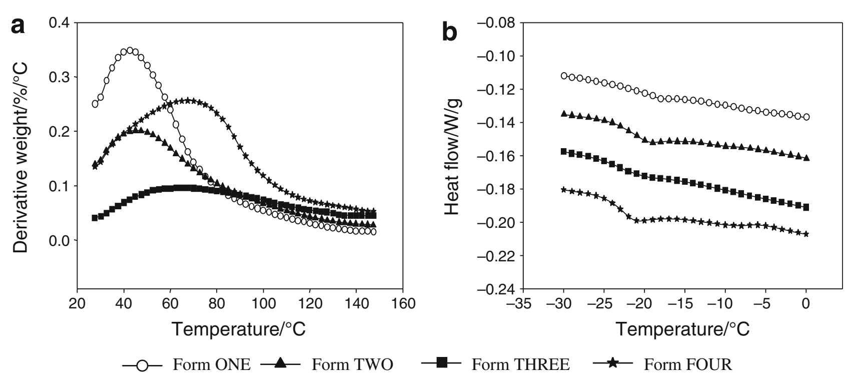
observed in all soy-containing formulations (~4.3 vs. 3.5 mm, p value <0.001, Table 3) depicting a rubbery texture. The increase of springiness occurred at a smaller extent compared to the decrease of hardness and chewiness (threefold reduction from 0 to 26% soy, Table 3).

The lower firmness of soy-containing products was possibly due to the higher water-binding capacity of soy proteins [23] which represented 50% of the soy blend. Although moisture contents of soy formulations and wheat product were similar (Table 1) differences in water distribution were observed.

TG thermograms of soy-containing products showed an increase in the temperature range required to remove water (shift from 40 to 80 °C at high soy addition, 20 and 26% soy, Fig. 2a) suggesting a more mechanically entrapped water population. TG of soy-containing products showed a broadening of the water loss peak along with its shift towards higher temperature, depicting higher heterogeneity and water retention of 20 and 26% soy formulations. Such change in water dynamics was confirmed by ^{1}H NMR with T_1 and T_2 being shorter in soy products (Table 3) depicting a more solid-like ^{1}H population and thus a more viscous matrix.

Reduction of chewiness in soy products was likely due to the higher fat content of these formulations (soy blend contained 9% fat, Table 1). DSC thermograms depicted a transition in the range between −25 and −10 °C in all products (Fig. 2b) which was attributed to lipid melting [22]. Increased soy addition resulted in lower T onset and higher enthalpy of this transition, depicting a different fat

Fig. 2 Comparison of microwave baked formulations (details in Table 1) by TG (**a**) and DSC (**b**)



composition (Fig. 2b). Previous studies investigating thermal properties of soybean oil depicted a first order transition (melting) in the same temperature range and attributed it to soy lipids (mainly consisting of linoleic acid and oleic acid) [24, 25]. Observations on soy lipids were carried out with heating ramps of 20 °C/min [24] and 20 °C/min [25].

Fat (especially polar lipids), as well as emulsifiers, are known to reduce chewiness of baked products by preventing starch swelling upon microwave baking and, therefore, reducing amylose leaching outside the granules. Previous study on low starch-gel systems demonstrated that T_2 was directly proportional to starch content and inversely proportional to fat content [26]. ^{1}H NMR test T_2 confirmed these findings by showing shorter relaxation time (Table 3) in soy products.

Conclusions

In conclusion, soy addition above 20% significantly improved the texture of microwave reheated par-baked flat doughs by means of its high water-binding capacity and polar lipid content. Thermal analyses TG and DSC have been successfully applied to study the effect of soy addition by accurately depicting changes in water status and thermal transitions. Thermal data correlated textural and NMR measurements.

References

1. Räsänen J, Härkonen H, Autio K. Freeze-thaw stability of prefermented frozen lean wheat doughs: effect of flour quality and fermentation time. Cereal Chem. 1995;72:637–42.
2. Shukla TP. Batters and breading for traditional and microwavable foods. Cereal Foods World. 1993;38:95–6.
3. Hegenbert S. Microwave quality: Coming of age. Food Prod Des. 1992;17:29–52.
4. Yin Y, Walker CE. A quality comparison of breads baked by conventional versus nonconventional ovens: a review. J Sci Food Agric. 1995;67:283–91.
5. Merabet M. Water behavior in baked dough-based products and relation to textural changes induced by microwave reheating. In: Berk Z, Leslie RB, Lillford PJ, Mizrahi S, editors. Water science for food, health, agriculture, and environment. Lancaster: Technomic Publishing; 2001. p. 207–22.
6. Keskin SO, Sumnu G, Sahin S. Bread baking in halogen lamp-microwave combination oven. Food Res Int. 2004;37:489–95.
7. Sumnu G. A review on microwave baking of food. Int J Food Sci Technol. 2001;36:117–27.
8. Bárcenas ME, Haros M, Benedito C, Rosell CM. Effect of freezing and frozen storage on the staling of part-baked bread. Food Res Int. 2003;36:863–9.
9. Vulicevic IR, Abdel-Aal E-SM, Mittal GS, Lu X. Quality and storage life of par-baked frozen breads. Lebensm-Wissenschaft und-Technologie. 2004;37:205–13.
10. Mandala IG, Sotirakoglou K. Effect of frozen storage and microwave reheating on some physical attributes of fresh bread containing hydrocolloids. Food Hydrocoll. 2005;19:709–19.
11. Bárcenas ME, Rosell CM. Effect of frozen storage time on the bread crumb and aging of par-baked bread. Food Chem. 2006;95:438–45.
12. Miller RA, Hoseney RC. Method to measure microwave-induced toughness of bread. J Food Sci. 1997;62:1202–4.
13. Serventi L, Sachleben J, Vodovotz Y. Effect of soy addition on microwavable pocket-type flat doughs. Under Review.
14. Vittadini E, Vodovotz Y. Changes in the physicochemical properties of wheat- and soy-containing breads during storage as studied by thermal analyses. J Food Sci. 2003;68:2022–7.
15. Lodi A, Vodovotz Y. Physical properties and water changes during storage in soy bread with and without almond. Food Chem. 2008;110:554–61.
16. Fessas D, Schiraldi AD. Water properties in wheat flour dough I: classical thermogravimetry approach. Food Chem. 2001;72:237–44.
17. Li S, Dickinson LC, Chinachoti P. Mobility of "unfreezable" and "freezable" water in waxy corn starch by ^{2}H and ^{1}H NMR. J Agric Food Chem. 1998;46:62–71.
18. Vodovotz Y, Vittadini E, Sachleben J. Use of ^{1}H cross-relaxation nuclear magnetic resonance spectroscopy to probe the changes in bread and its components during aging. Carbohydr Res. 2002;337:147–53.
19. Derome AE. Modern NMR techniques for chemistry research. 1st ed. Oxford: Pergamon; 1987.
20. Carr HY, Purcell EM. Effects of diffusion on free precession in nuclear magnetic resonance experiments. Physical Rev. 1954;94:630–8.
21. AACC Method 74-09 Measurement of Bread Firmness by Universal Testing Machine; 2008.
22. Aktas N, Kaya M. Detection of beef body fat and margarine in butterfat by differential scanning calorimetry. J Therm Anal Calorim. 2001;66:795–801.
23. Kinsella JE. Functional properties of soy proteins. J Am Oil Chem Soc. 1979;56:242–58.
24. Yang L, Dai H, Yi A, Lin B, Li G. Structure and properties of partially epoxyzed soybean oil. J Therm Anal Calorim. 2008;93:875–9.
25. Lin B, Yang L, Dai H, Hou Q, Zhang L. Thermal analysis of soybean oil based polyols. J Therm Anal Calorim. 2009;95:977–93.
26. Ruan R, Almaer S, Huang VT, Perkins P, Chen P, Fulcher RG. Relationship between firming and water mobility in starch-based food systems during storage. Cereal Chem. 1996;73:328–32.