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Effects of sugar, protein and water content on wheat starch gelatinization due to microwave heating

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Abstract Understanding the interactions between sugar, starch, protein and water, which are the main components of a baked product, will advance the development of high quality, microwaveable products. This paper presents a mathematical model describing the quantitative relationships between water, sugar and protein on the gelatinization of wheat starch following 20 s of microwave heat as determined by differential scanning calorimetry. Addition of sugar decreased the degree of gelatinization of starch due to microwave heating significantly. Water and protein were not found to be as significant as sugar in delaying gelatinization. The effects of sugar and protein on the gelatinization of starch were pronounced in water-limited systems. The model could be used to describe systems containing 33–67% water, 0–33% sucrose and 0–5.8% protein, with a coefficient of determination of 0.91.

Key words Starch · Gelatinization · Microwave heating · Differential scanning calorimetry

Introduction

The gelatinization of starch is an important phenomenon in baked products, as the degree of gelatinization affects their final texture. Sugars have been shown to delay gelatinization and to increase the gelatinization temperature of starch [1–4]. The mechanisms by which sugars delay starch gelatinization have been shown to result from the reduction of the water activity of the system due to the action of sugars, and the stabilization of amorphous regions of the starch granule by the interaction of sugar with starch chains [4]. Proteins also affect the gelatinization of starch by forming complexes with starch molecules on the granule surface, and preventing the escape of exudates from the granules, thereby increasing the gelatinization temperature of starch [3]. The hydrophilic nature of proteins is another factor that explains the effect of proteins on gelatinization. In starch-water systems containing less than 30% water, no gelatinization of starch was found to occur [5, 6]. Rice starch gelatinization was shown to attain a maximum value at a water/starch ratio of 1.5:1, and remained constant at higher water/starch ratios [6].

Although many acceptable products are produced by microwave heating, less satisfactory results have been obtained for starch-based products. This is reportedly due to the fast heating in microwave ovens [7]. Other contributing factors may arise from the differences in heat and mass-transfer mechanisms, or specific interactions of a product's components, when heated by microwaves [7].

In order to develop high quality, microwaveable, baked products it is necessary to understand the functions and interactions of the various ingredients and their impact on starch gelatinization. Studies reporting on the influence of sugar, protein and water on starch gelatinization due to microwave heating are lacking in the literature. The objective of this study was, therefore, to determine the interactions of starch with varying levels of water, protein and sugar due to microwave heating. A second objective was to determine the quantitative relationships between starch, sugar, protein and water under microwave heating conditions, as this would be most helpful in predicting the level of starch gelatinization when wheat starch is microwave-heated in the presence of sugar, protein or water.

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Materials and methods

Materials. Water, gluten and sucrose concentrations were selected to include concentrations typically used in cake systems.

Wheat starch (Midsol 50) and protein (vital wheat gluten), both from Midwest Grain Products (Atchinson, USA), were mixed with sucrose and water in various combinations to obtain suspensions with moisture contents of 33–67%, sugar contents of 0–33% and protein contents of 0–5.8%. Samples (8 ml) of each suspension were placed in 10-ml Pyrex containers and heated for 20 s in a microwave oven (Carousel Convection, Sharp, Japan). Small samples were used to achieve uniform microwave heating and to minimize the effect of other heating mechanisms. The efficiency of the microwave oven, which was determined by using the IMPI 2-l methods was 67% [8].

Differential scanning calorimetry measurement. Differential scanning calorimetry (DSC) measurements were made of the microwave-heated samples and unheated control samples using a Dupont 910 (Delaware, USA) differential scanning calorimeter. Each sample (20±0.1 mg), after being cooled to 10 °C, was weighed into aluminum pans, which were then hermetically sealed and heated from 10 °C to 100 °C at a rate of 10 °C/min. An empty pan was used as a reference. The endothermic peak area and onset gelatinization temperature were recorded for each sample. The lack of a gelatinization endotherm meant that the sample was completely gelatinized in the microwave oven. Gelatinization enthalpy for each sample was calculated from the endothermic peak area. No increase in gelatinization enthalpy occurred in the control samples that were not processed in the microwave oven after the water/starch ratio exceeded 2:1 (w/w), thus the gelatinization enthalpy of this ratio was equated to 100%. The percentage gelatinization of all other treated samples was calculated proportionally against the water-starch (ratio 2:1) sample. The degree of gelatinization was calculated as follows:

$$\text{Gelatinization degree (\%)} = \left(1 - \frac{\Delta H_p}{\Delta H_s}\right) 100$$

where ΔH_p is the enthalpy of the processed sample and ΔH_s is the enthalpy of the starch-water suspension with a ratio of 1:2.

Computer modeling and statistical analysis. Multiple regression was used to determine the changes in the degree of gelatinization of starch with sucrose, protein and water systems [9]. To obtain the best model, only significant terms were included in the equation. If a linear effect was not significant but its quadratic term or interaction was significant, the linear effect was included in the model. Three-dimensional plots relating water, sucrose and protein contents with the degree of starch gelatinization were obtained from the model determined by using SAS/GRAPH [10]. In the study, three replicates per treatment were used.

Results and discussion

A mathematical equation was developed to depict variations in the degree of starch gelatinization during microwave heating in response to different levels of sucrose, water and protein (Table 1). Quadratic and linear terms were included in this equation as well as their interactions. The coefficient of determination of the equation was determined as 0.91. The significant terms and coefficients of the model of best-fit are tabulated in Table 1. According to this equation, sugar was the most significant ($p = 0.0001$) main term affecting starch gelatinization. Water and protein were not found to be as significant as sugar. However, these terms were still included in the model since their interactions were found to be significant.

Comparison of the gelatinization endotherms of microwave-heated starch suspensions with and without the addition of sucrose (Figs. 1 and 2, respectively) revealed that the addition of sucrose at a concentration of 33% shifted the onset gelatinization temperatures from 65 °C to 78 °C. This showed that the addition of sugar delayed gelatinization during microwave heating. Likewise, the addition of protein at a concentration of 5.8% to the water-starch suspensions increased the gelatinization temperature (Fig. 3).

In the absence of sugar, there was no significant effect of water or protein on starch gelatinization (Fig. 4). The lack of curvature in the three-dimensional graph resulted from the greater significance of the linear terms in relation to the quadratic terms and interaction terms in the model equation. Figure 5 shows the effects of sugar and water on starch gelatinization in the presence of protein. In protein containing starch systems the addition of sugar reduced the degree of gelatinization, and had a much greater effect on gelatinization as compared to the effects of protein alone (Fig. 4).

Table 1 Equation of best fit relating gelatinization degree with water-sucrose-protein systems. *S* Sugar/starch ratio, *P* protein/starch ratio, *W* water/starch ratio, *L* linear, *Q* quadratic

Degree of gelatinization[a] (%)			
i	Independent variables x_i	Constants a_i	$p > \|F\|$
1	1	78.527	0.0001
2	S_L	−223.512	0.0001
3	P_L	− 54.918	0.4464
4	W_L	8.858	0.1008
5	S_Q	82.353	0.0001
6	$S_L \times P_L$	−441.882	0.0001
7	$S_L \times W_L$	226.269	0.0001
8	$S_Q \times W_L$	− 81.211	0.0002
9	$S_L \times W_Q$	− 52.796	0.0001
10	$P_L \times W_Q$	− 14.170	0.0034
11	$S_Q \times W_Q$	18.439	0.0005
12	$S_L \times P_L \times W_L$	181.330	0.0001

[a] $\sum_{i=1}^{i=12} a_i x_i$

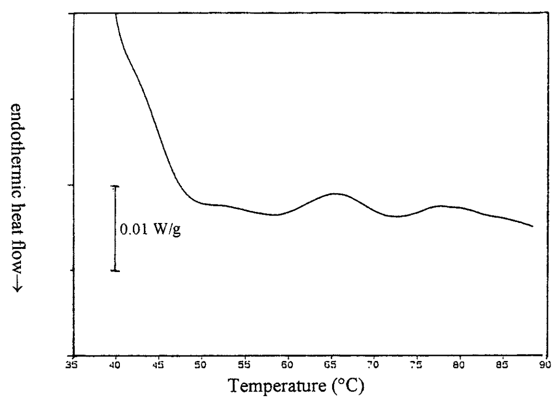

Fig. 1 Differential scanning calorimetry (DSC) endotherms of wheat starch suspensions heated in a microwave oven in the absence of protein and sugar

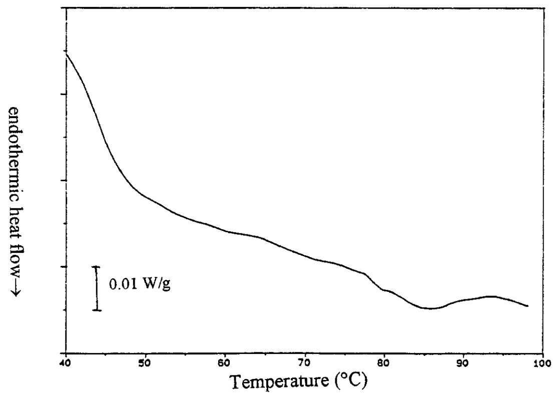

Fig. 2 DSC endotherms of wheat starch suspensions heated in a microwave oven in the presence of sugar

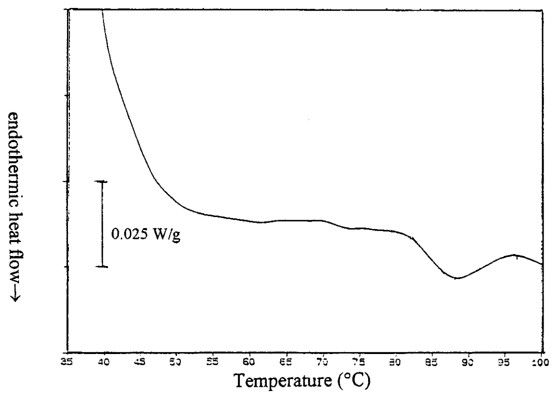

Fig. 3 DSC endotherms of wheat starch suspensions heated in a microwave oven in the presence of protein

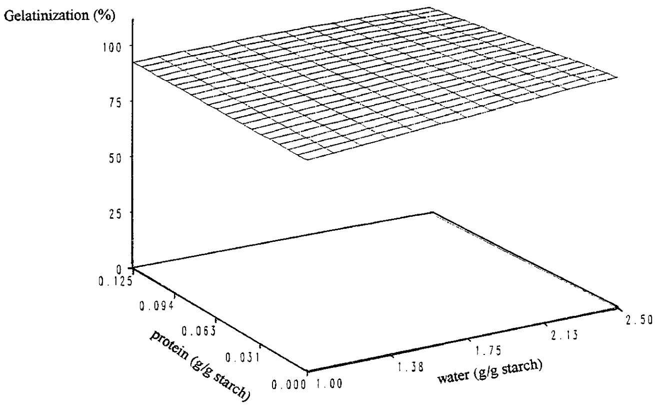

Fig. 4 Variation of degree of gelatinization with protein and water contents in the absence of sugar

The effects of protein and sugar on the gelatinization of starch at different moisture levels are shown in Figs. 6 and 7. Sugar was more efficient than protein in reducing the degree of gelatinization. When protein was used at concentrations of 1–5% there were no significant differences in their impact on starch gelatinization. Similarly, no significant differences were observed between the effects of sugar at concentrations ranging from 10% to 30% in this study. This may have been due to the fact that at these concentrations, sugars and proteins absorb microwave energy to the same extent. The effects of the various concentrations of sugar-protein combinations could be distinguished more easily in water-limited systems (Figs. 6, 7). This was contrary to results showing the efficiency of salt and sucrose in delaying the gelatinization of corn starch even at high water concentrations (water/starch ratio 2.5:1.0) [11]. The differences between the results of the latter and the present study may have been due to the differences in heat transfer mechanisms between microwave and convection heating, and also differences in the thermal be-

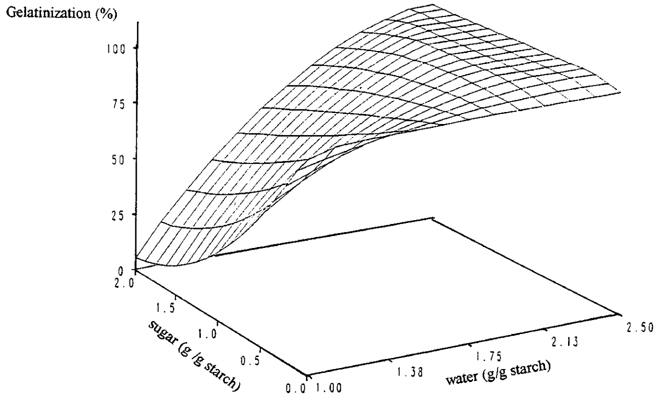

Fig. 5 Variation of degree of gelatinization with sugar and water contents in mixtures with a protein/starch ratio of 0.1:1.0

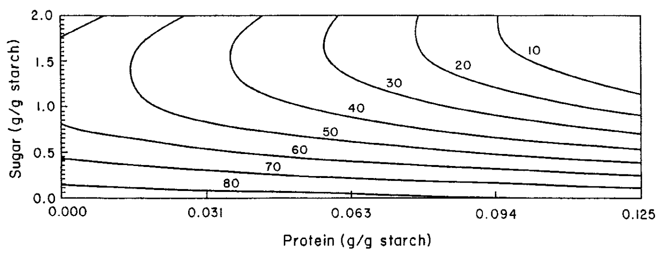

Fig. 6 Contour plot showing the effects of protein and sugar on the degree of gelatinization of mixtures with a water/starch ratio of 1.0:1.0

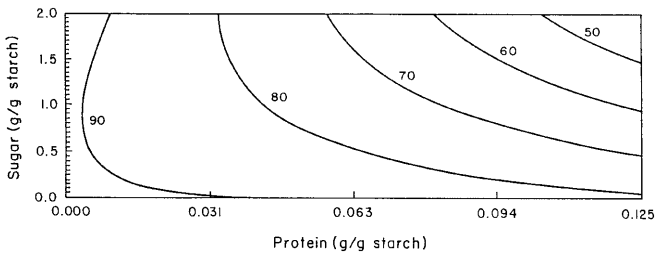

Fig. 7 Contour plot showing the effects of protein and sugar on the degree of gelatinization of mixtures with a water/starch ratio of 1.5:1.0

havior of corn and wheat starches. It is known that an increase in the concentration of water leads to an increase in microwave absorption [12] and to an increase in gelatinization [6]. In the present study the mixture may have been heated very fast at higher water concentrations, such that the effects of the protein and sugar components on starch gelatinization were inconsequential.

The equation determined from this study can empirically estimate the extent of wheat starch gelatinization due to microwave heating in the presence of sucrose concentrations up to 33% and protein concentrations up to 5.8%. This equation provides a useful tool for determining the degree of starch gelatinization in the presence or absence of protein and sugar when products with different moisture levels are heated in microwave ovens. The validity of this model can be tested by using different types of starch and other cake ingredients, such as emulsifiers and shortenings.

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