Wheat Starch Effects on the Textural Characteristics of Puffed Brown Rice Cakes

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ABSTRACT

A process was described for creating puffed wheat starch based or hybrid starch and rice snack foods processed in a rice cake puffing machine. Puffed cakes consisting of wheat starch and whole grain brown rice, created by mixing wheat starch beads with brown rice before processing and puffing for 10 sec (cooking time) at 210°C, exhibited greater flexibility and fracture strength than traditional rice cakes. The density of puffed wheat starch cakes decreased with increasing moisture content independent of particle size for particles 0.8–5 mm in diameter. The addition of sucrose and shortening promoted the formation of lower density puffed cakes at lower moistures, while salt had little effect.

Rice cakes and corn cakes are an increasingly popular line of snack foods made by puffing whole rice, dehusked corn, and rice and corn mixtures in specially designed puffing (or popping) machines. The market for rice cake type snacks has increased from ≈$157 million in 1992 to over $250 million in 1995 (Woods 1997) due, in part, to a shift in American dietary attitudes toward healthier, lower fat snacks. Rice cakes are a good source of rice bran fiber, which has been shown to lower cholesterol levels (Kahlon 1990). Growth in rice and corn cake sales has paralleled an increased marketing presence by several large food companies.

Puffed rice cakes are traditionally made by heating whole grain rice (with a typical moisture content of 16–20%, w/w) in a confined mold at temperatures of 190–250°C. During heating, steam pressure builds within the mold. Upon opening the mold, pressure is released rapidly, causing flash vaporization of the superheated water and steam. This process causes the grains to melt and fuse during their expansion into puffed cakes. Under such harsh processing conditions, sugars, proteins, and other potentially interesting additives tend to burn, losing volatile flavor components and damaging nutrients. Thus, in commercial production, most flavor additives are introduced by spray-coating the cakes after puffing.

Little has been written on the effect of processing conditions on the properties of puffed rice and corn cakes, with the exception of a comprehensive series of articles by Hsieh et al (1989; 1990a,b; 1992). They describe 1) the optimal tempering and heating conditions for puffing long grain brown rice (Hsieh et al 1989), 2) the structural characteristics of cakes derived from a mixture of long and medium grain rice cakes (Hsieh et al 1992), 3) the effect of moisture sorption on textural characteristics of rice cakes (Hsieh et al 1990a), and 4) a method for using dent corn grits in a puffing machine (Hsieh et al 1990b). The patent literature generally discusses the types of machines used (Touba 1972, Hayashi 1987, Wu 1989, Menzin 1996) or the preparation of grains for optimal popping (Yamaguchi 1988).

Two drawbacks of traditional rice cakes have limited their market growth: 1) flavor-coated rice cakes generally provide only a subtle addition of flavor, and 2) cakes tend to crumble during packaging, transportation, and storage. For example, marketing of rice cakes to airlines is limited because messy foods are not tolerated (*personal communication*, R. Bates, Lundberg Family Farms, Richvale, CA).

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In a previous article on flavor components in rice cakes (Buttery et al 1999), we briefly introduced a technique to create more uniformly flavored rice cakes by mixing flavored starch beads with rice during puffing. Starch beads with a similar size, shape, and density to rice, yet containing a model flavor compound such as maltol or vanilla, were mixed with whole grain brown rice at a 1:4 ratio before puffing. During puffing, these hybrid cakes maintained flavor within the cake. Furthermore, the starch component appeared to change the structural integrity of the cake. The focus of this article is to explore whether the addition of wheat starch or starch and flavor mixtures has a significant effect on the density and structural properties of puffed rice cake snacks. Additionally, starch beads could act as a carrier of other components into the cake such as salt, sugar, or shortening. For example, the present industrial method of adding salt to cakes in either the tempering step or in the final flavor spray tends to corrode metal parts during production. There may be clear processing advantages to encapsulating salt, sugar, or shortening within a starch bead.

The objectives of this study are to determine whether 1) wheat starch beads form an adequate foam structure during puffing, 2) wheat starch beads can be mixed with rice particles to alter structural properties of the cakes, and 3) other additives such as salt, sugar, and shortening affect the puffing of the wheat cakes.

MATERIALS AND METHODS

Prepuffing Preparation

Long-grain California brown rice, which was used to make standard puffed rice cakes and hybrid wheat starch and rice cakes, was obtained from Lundberg Family Farms, Inc. (Richvale, CA). The as-received rice had a moisture content of 10.5–12% (w/w) as measured using a halogen moisture analyzer (HR73, Mettler Toledo, Hightstown, NJ).

Agglomerated wheat starch particles or beads were produced using Midsol 50 wheat starch from Midwest Grains (Atchison, KS); other minor components such as salt (Morton Salt, Chicago, IL) and shortening (Crisco brand, Proctor and Gamble, Cincinnati, OH) were obtained from standard retail sources. Starch was used at moisture levels obtained at room humidities, which corresponded to 10.2–11.8% moisture. Wheat starch beads were formed by pregelatinizing starch (10%, w/w, starch in water) at 94°C for ≈10 min. The 10% starch gel (330 g) was added to wheat starch powder (600 g) and paddle-mixed for 10 min (model A-200, Hobart, Troy, OH) to form a relatively dry, pelletized powder. In some runs, flavor components (salt 1–4%, sucrose 5%, shortening 2%) were also added at this time. The powdery mixtures were extruded into long strands using the mixer's pasta extruder attachment with 6-mm diameter holes. After drying in a dry oven at 30°C, starch strands were cut using a rotating cutter forming rods with a range of lengths that were subsequently sieved through a set of standard mesh screens (Table I). The work required to shake particles through the screens tended to round their edges, forming beads.

Moisture levels of wheat starch beads and rice were tempered to appropriate levels (14–22%) by adding water, tumbling at 20 rpm for 2 hr in a ball mill apparatus (Norton Akron, OH) without any milling balls present, and allowing samples to equilibrate for 24 hr in a closed container.

Puffing Operation

Rice, wheat starch beads, or rice and starch bead mixes (at relative ratios) were puffed by introducing 15 g of sample into the mold of a rice-popping machine (Airin Co., Okazaki, Japan) and heating for 10 sec. Platen surface temperatures within the mold were set at ≈210°C based on conditions from preliminary data (not shown) and on temperatures used by Hsieh et al (1989). As shown in Fig. 1, the mold consists of two heated platens. The upper platen (1) is plunged into the cavity defined by the outer ring (3) toward the lower platen (2). When sealed, the tolerances between the upper platen and the outer ring are only thousandths of an inch, creating a near-hermetic seal, while the gap between the two heated platens is 1.2 cm. During cooking, steam pressure is generated within the gap. Pulling the platens apart suddenly releases this pressure, creating a foamed cake by flash vaporization. The time, temperature, and gap width used in this study were chosen based on industrial parameters used for brown rice cakes but not necessarily optimized for starch or starch and rice mixtures. Each puffed cake was ≈10 cm in diameter with thicknesses ranging from 0.9 to 2.2 cm, depending on processing conditions.

Puffed Cake Properties

Density measurements were determined on five replicate samples by band-saw cutting a 1 × 1 cm square from the center of each cake. The dimensions of these squares were measured using a micrometer (in triplicate for each dimension), and weighing each square. Linear regression analysis of data followed the principles outlined by Guttman et al (1982).

Mechanical measurements of compressive and flexural structural properties were run at room temperature on a universal testing machine (Instron model 4500, Canton, MA). The flexural test was a three-point bend measurement in which a strip 3.2 cm wide cut from the center of a puffed cake was suspended between two straight edges 5 cm apart. A rod with a diameter of 0.8 cm was attached cross-wise to the head of the Instron universal testing machine and moved through the top of the suspended sample (and thus the surface of the puffed cake) at a speed of 0.5 cm/min. Measurements were terminated at full failure, giving an indication of the flexural breaking strength of the puffed cakes.

A compression test was established to describe differences in the internal foam structure between samples. A slice 0.9 cm wide and 5 cm long was cut from the center of puffed cakes. This slice was laid flat on a platen, exposing an internal foam surface to the compressive probe. The 0.8 cm flathead cylindrical rod attached to the head of the Instron universal testing machine was moved into the sample at 0.1 cm/min. The test was run until the rod had penetrated 0.2 cm into the sample. This meant that for some of the more ductile samples, full structural failure was not always achieved. Modulus and maximum force at the breaking point were determined using the software supplied with the Instron universal testing machine. Statistical significance of both types of mechanical tests were determined from 10 replicate samplings, from which *t*-test 95% confidence levels were calculated.

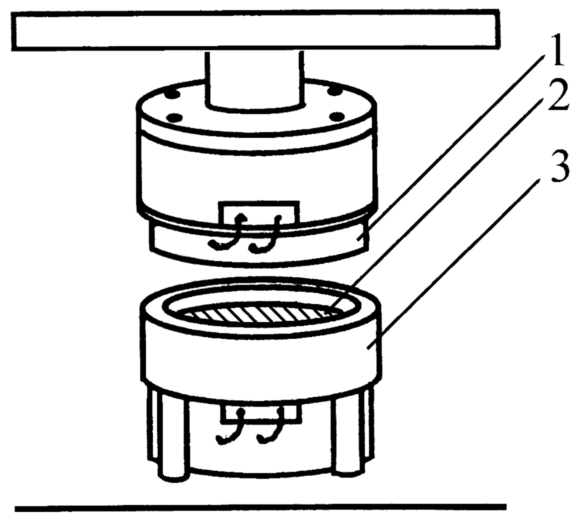

Fig. 1. Schematic view of the main assembly of a rice-popping machine (Airin Co., Okazaki, Japan). During processing, the heated upper platen (1) is inserted into the outer mold ring (3) to close the gap between the upper and lower platen (2).

TABLE I
Size Classification of Wheat Starch Beads Obtained by Standard Sieving

Sample Description	Retained on Sieve Mesh	Size Range (mm)
Large aggregates (discarded)	2	>5.0
Large beads	6	3.35–5.0
Medium beads	10	2.0–3.35
Small beads	20	0.833–2.0
Fines (discarded)	<20	<0.833

TABLE II
Effect of Moisture on Cake Density for Different Bead Sizes: Fitting Parameters[a]

Sample Description	Fitting Parameter *a* (slope)	Fitting Parameter *b* (intercept)	*R*
Large beads	–0.0067 ± 0.0010	0.183 ± 0.35	0.979
Medium beads	–0.0061 ± 0.0023	0.175 ± 0.82	0.951
Small beads	–0.0071 ± 0.0016	0.197 ± 0.44	0.972
Large, 1% salt	–0.0059 ± 0.0024	0.171 ± 0.62	0.960
2% salt	–0.0071 ± 0.0040	0.189 ± 0.74	0.935
3% salt	–0.0091 ± 0.0029	0.264 ± 0.48	0.958
4% salt	–0.0057 ± 0.0034	0.1057 ± 0.68	0.950

[a] Data in Fig. 2 were fit by the linear regression model: $y = ax + b$. R is an indication of the goodness of fit for the linear model ($R = 1$ is ideal). Confidence levels reflect 95% certainty. There is no significant difference between slopes or intercepts.

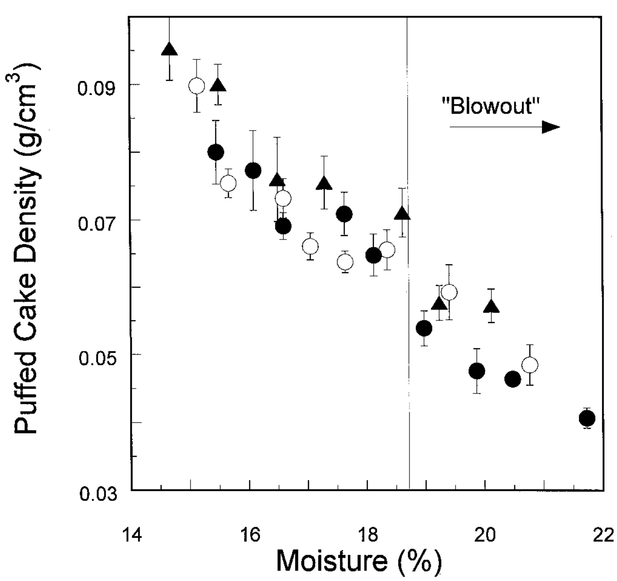

Fig. 2. Effect of moisture content and bead size on density of large (●), medium (○), or small (▲) wheat starch puffed cakes (containing no rice). Cakes formed at concentrations >18.7% moisture are likely to lose material due to excessive puffing.

Micrographs of the foams were obtained by slicing samples with a razor knife, mounting cut slices on a hard surface, and photographing the foam structure using a universal research light microscope (Zeiss, Berlin, Germany).

RESULTS AND DISCUSSION

Effect of Size and Moisture Content on Puffing of Wheat Starch Particles

In preliminary work, it was determined that wheat starch powder alone could not be processed in a rice puffing machine to form suitable puffed cakes. Over a range of moisture levels from 12–24%, wheat starch powder forms dry, compressed cakes after cooking for 10 sec at 210°C. Yet, under the same conditions, rice forms low-density puffed cakes. This observation, supported by results from Hsieh et al (1990b) for puffing corn grit particles, suggests that particle size is an important parameter to explore.

Figure 2 shows the effect of moisture level for several different bead sizes on the density of puffed wheat starch cakes. Density decreases with increasing moisture content. The density behavior is not significantly different for particles of different sizes over the range studied (Table II). The goodness-of-fit parameter (R) for the three fitted curves ranges from 0.95 to ≈0.98; all three fitted curves have slopes that are indistinguishable. There is no a priori reason for assuming a linear model to describe this relationship, although a linear model helps to distinguish the effect of different conditions.

Within the range studied, the size of the beads has no significant effect on the cake density. As shown in Fig. 2, the density for the large (3.35–5.0 mm), medium (2.0–3.35 mm), and small (0.833–2.0) beads follows the same near-linear decrease with increasing moisture. This result is somewhat unexpected and in contrast to the results for rice grits (Hsieh et al 1990b) in which there was a significant size effect. Considering that starch powders (granules) and wheat flour do not form low-density puffed cakes, it was speculated that small beads would be relatively more difficult to puff because they would not retain enough moisture during the initial heating process. If such a drying process does occur, it does not affect the smallest beads studied (0.833–2.0 mm). The data in Fig. 2 implies that, for commercial application, there is a wide degree of flexibility in choosing particle size.

The general trend in Fig. 2 is in contrast to the result of Hsieh et al (1989) for the puffing of long grain brown rice. They showed that density increases with increasing moisture content >14%, w/w. (Actually they showed that specific volume, the inverse of density, decreases with moisture.) Such a difference between rice grains and starch beads is most likely due to the differences in the physical properties of the two materials, as well as to differences in structure of the particles. Rice starch, which constitutes ≈75% of brown rice, is clustered in relatively small granules (2–10 μm) within the endosperm of the grain. The other components within the grain such as protein and lipids may act to plasticize the starch and promote puffing. In contrast, the wheat starch beads lack such a complex structure, consisting of a population of relatively large starch granules. One could imagine that the diffusivity of steam through a partially gelatinized wheat starch bead would be much different than through a complex rice grain.

There were also differences in the moisture tempering conditions between the two studies. Whereas Hsieh et al (1989) tempered brown rice for only a matter of hours before puffing, in this study

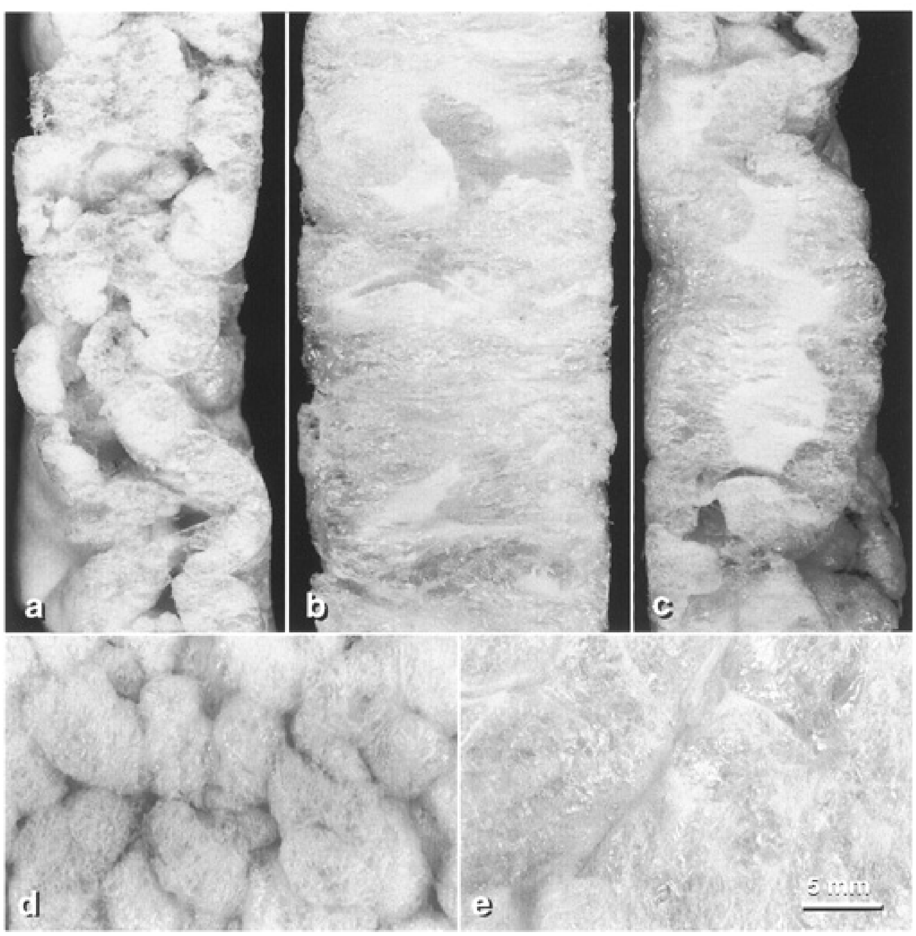

Fig. 3. Light micrographs of puffed cakes produced from long grain brown rice (**a**), wheat starch particles (**b**), and a 1:4 mixture of wheat starch particles and rice (**c**). Top surfaces of pure brown rice cake (**d**) and pure wheat starch cakes (**e**) demonstrate the relative uniformity of the pure starch foam.

the starch beads were tempered until their moisture content reached a constant level (>24 hr). Water is a significant plasticizer of starch, resulting in greater starch-chain mobility. With increases in moisture content from 14 to 20%, the effective glass transition temperature of wheat starch drops from ≈80 to 25°C (Zeleznak and Hoseney 1987). Interestingly, the trend in Fig. 2 correlates to a lowering of the glass transition temperature.

The density values quoted in this article are slightly lower than those noted by Hsieh et al (1989, 1990a, 1992) for rice cakes. This is due, in part, to differences in the cakes, and to differences in the two measuring techniques used. Hsieh et al employed a sand displacement method, whereby density is determined by adding sand of a known density to a preweighed container holding the rice cake. The amount of added sand displacing the free volume is inversely related to the volume of the cake. In this study, density was determined by cutting the cakes into squares of a known size, measuring the thickness of the cake, and weighing the pieces. This method is feasible because, unlike rice cakes, the outer surface of the starch foams are flat and relatively smooth. Measurement of density by determining the overall size and weight invariably gives a lower density value than the sand method because it accounts for all of the pores, regardless of whether they are accessible to sand. In the sand technique, some exterior and even interior pores may or may not be filled with sand, depending on pore size and accessibility. To compare methods, the density of traditional brown rice cakes was measured using both methods. By the direct method, the densities from a series of brown rice cakes were 0.030–0.065 g/cm^3, while the sand method gave results of 0.09–0.14 g/cm^3, values similar to those reported by Hsieh et al (1989, 1990a, 1992). For the wheat starch cakes, the measurement used here was more statistically consistent than the sand method.

The densities of wheat starch cakes are still higher than those obtained from brown rice cakes formed at the same moisture levels (using either method). For example, at 17% moisture content, wheat starch cakes have a density of 0.065– 0.074 g/cm^3, compared with 0.030–0.055 g/cm^3 for pure rice cakes. One explanation is that rice cakes tend to entrap air between rice grains, leaving distinct gaps between grains, as shown in Fig. 3a and d. In contrast, wheat starch beads tend to fuse together more completely, losing their individual structure (Fig. 3b and e). Air is not entrapped between grains.

At >18.5% (w/w) moisture, the cakes start to blow out of the mold (i.e., the puffing action is so active that puffed material is lost out the edges during release). Although blowout does not affect the accuracy of the density measurements, it represents a practical limitation. Significant loss of material due to blowout would not be tolerated during industrial production.

Effect of Salt, Sucrose, and Shortening on Puffing

The effect of additives such as salt, sucrose, and shortening to puffed wheat starch cakes is shown in Fig. 4. Although bead size is not a significant consideration, large beads were selected for the remainder of this study because they are produced most abundantly by our processing and sieving procedure. Salt had little effect on the densities of cakes puffed at a given moisture (Fig. 4A, Table II). This result is not completely surprising considering that salt did not alter the puffing of corn grits (Hsieh et al 1990b) in a rice puffing machine, although it has been shown to improve the expansion of corn meal during extrusion (Hsieh et al 1990c) and popcorn during microwave popping (Lin and Anantheswaran 1988). The fact that salt does not affect cake density suggests that wheat starch beads could potentially be used as a vehicle for carrying salt into a rice cake without resorting to corrosive spraying or tempering techniques that are presently used in the industry

In contrast, sucrose and shortening (Fig. 4B and C, respectively) decreased the density obtained at a given moisture level. Sucrose generally raises the gelatinization temperature of wheat starch by as much as 30°C (Bean et al 1978, Spies and Hoseney 1982).

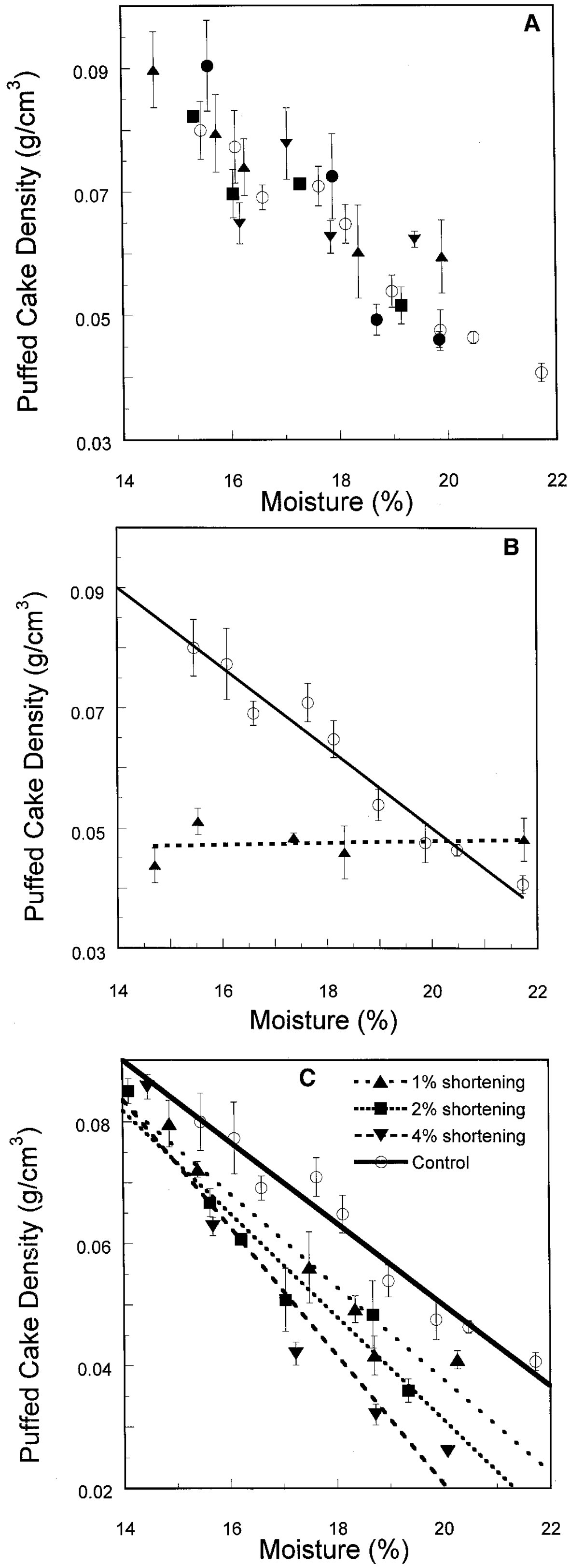

Fig. 4. Effect of added salt, sucrose, and vegetable shortening on density of puffed starch cakes processed at different moisture levels. **A,** Salt added to large beads at concentrations of 1 (▲), 2 (■), 3 (●), and 4% (▼) compared with control beads (○). **B,** Control beads (○) compared with beads made with 5% sucrose (▲). **C,** Control beads (○) compared with beads with shortening added at 1 (▲), 2 (■), and 4% (▼).

Increases in gelatinization temperatures with sucrose have been correlated to increases in the volume of standard baked cakes (Bean et al 1978). Higher gelatinization temperatures imply that it will take longer for the cake to reach its gelatinization temperature within the cooking cycle. As such, starch chains would be relatively less mobile, starch crystalline structures would remain intact longer, and water would be less likely to diffuse through the starch beads during the puffing cycle. Potentially more water (or steam) would be retained within the interior of beads. Upon flash vaporization at the end of the cooking cycle, this greater amount of moisture in the bead interior would mean a greater release of pent-up steam, and more foaming action.

The addition of sucrose beyond compositions of 5% would prove impractical because the cakes burn, leaving a carbonized residue on the heated platens. To obtain evenly cooked cakes, the platens would need to be cleaned constantly, which would be an impractical labor cost. Part of the reasoning behind introducing shortening to the cakes was to explore the possibility of reducing the amount of material that sticks to the cooking surfaces.

More work would be required to determine the role of shortening on the puffing of starch. Different fats affect the gelatinization temperature of wheat starch in different ways, depending on their lipid structure and ability to complex with amylose (Eliasson 1985). The formation of complexes would reduce the mobility of amylose during the melting process and generally raise the gelatinization temperature (Eliasson 1985). Then the argument would be similar to that used for sucrose (i.e., that the shortening helps to retain moisture in the bead until it can flash vaporize into foam).

Mechanical Properties of Puffed Rice and Starch Cakes

Wheat starch cakes have different mechanical properties than puffed rice cakes. Data from an Instron universal testing machine (Figs. 5 and 6) show that pure rice cakes are brittle, fracturing at a relatively low value of compressive displacement. This fracturing often leaves a handful of puffed rice particles, implying that the weakness in the cake is due to relatively low adhesion between rice particles.

The mechanical properties of puffed cakes (Figs. 5 and 6) are changed significantly by mixing wheat starch beads with brown rice before puffing and then cooking for 10 sec. For these tests, a moisture content of 17% (w/w) was used for rice and beads, and a suitable moisture content was used for both rice and starch beads. At low starch compositions (<20% starch), samples exhibit structural failure before the compressive probe traveled 2 mm into the sample (Fig. 5). In contrast, samples with starch compositions >25–30% do not fracture. The stress-strain curves in Fig. 5 for samples with higher starch concentrations are roughly similar to each other. That is, the stress, or compressive force increases smoothly as a function of increasing strain, with stress reaching its maximum at or near the maximum strain (not all of the composition data are shown in Fig. 5). One exception is the curve for pure starch cake (the dotted curve in Fig. 5), which is not smooth but exhibits several minor fracture points. This is because pure starch samples have air pockets larger than the foam structure that tend to collapse during compression. Their fracture does not correspond to full sample failure. Thus, the maximum force reported for pure starch foams may correspond to the crushing of an air pocket and not necessarily to full sample failure. The results for pure starch foams are summarized in Fig. 6A.

While the compression test was used to probe the internal foam structure of the cake, the flexural test was used to explore the breaking properties of a cake as a whole. Figure 6B is a plot of the initial modulus (i.e., the initial slope of the stress strain curve) as a function of rice composition. For pure brown rice cakes and low-wheat starch compositions, the modulus is relatively high, indicating relative stiffness. At starch compositions >20–25%, the modulus is lower and relatively independent of starch composition. Results of the flex test are influenced by the skin structure of the cake and are likely more suitable for assessing behavior during typical handling by a consumer.

Although two different sampling and measuring techniques were used, the data in Fig. 6A and B follow similar trends (albeit inverted with respect to each other). Both data sets show a significant break at a starch bead composition of ≈25%. At low starch compositions, a high flexural modulus (Fig. 6B), corresponds to relatively low fracture strains under compression (Fig. 6A). At higher starch compositions, the samples are not as stiff and do not fracture as easily. Thus,

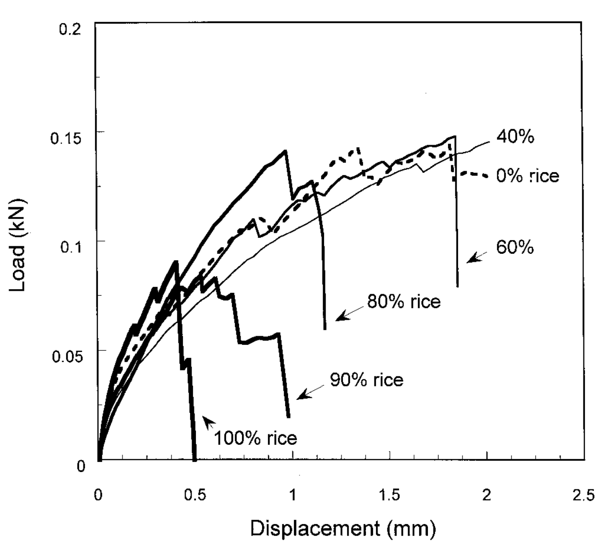

Fig. 5. Series of compressive stress-strain curves derived from rice cakes with varying degrees of added starch. Internal foam structure of each sample was compressed with a small probe over a displacement of 2 mm. For some of the more flexible samples full failure was not achieved.

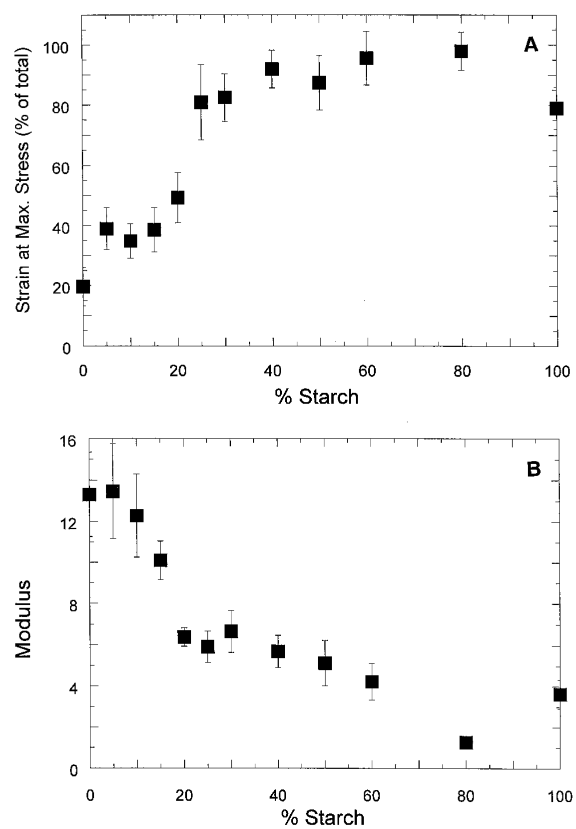

Fig. 6. Effect of added starch on compressive strain at maximum stress (**A**) and flexural modulus (**B**) of puffed rice cakes.

adding starch to rice cakes has increased the flexibility of the cakes. These reductions in cake friability may be indicative of increased shelf life and less loss during packaging and transportation.

The mechanical properties such as increases in compressive strength and flexibility of cereal-based foams have been correlated directly to increases in density (Hutchinson et al 1987, Glenn and Irving 1995). This trend is true here, considering that the pure starch foams are significantly denser than the pure rice cakes. Making such a claim here, though, is complicated by the fact that the mixed wheat starch and rice cakes are not uniform foams but, rather, a hybrid foam mixtures (Fig. 3c). A better interpretation of the trends in Fig. 6 is that the wheat starch acts as a matrix that holds puffed rice particles together. Thus, even if the foam structure within a rice kernel is strong, the cake will fracture easily if there is little binding between kernels. When the starch composition exceeds 25%, there is enough matrix material to provide adhesion between kernels (Fig. 3c). This is supported by visual observations that the fracture of pure rice cakes often leaves only a handful of puffed kernels. Interestingly, at >30% wheat starch, there is relatively little improvement in flexibility.

In conclusion, the mechanical properties of puffed brown rice cakes can be altered by the addition of wheat starch before processing in a rice puffing machine. Wheat starch beads were developed that produce uniform foamed cakes under the same conditions used to puff long grain brown rice. When mixed with rice, these beads appear to form a foamed matrix between rice kernels. The addition of sucrose and vegetable shortening promoted the formation of low-density puffed wheat starch cakes, while the addition of salt or the use of different bead sizes had little effect.

These data are presented to introduce a potential commercial process for producing puffed snack cakes that incorporate wheat with rice. Added wheat starch has the potential to improve shelf-life properties and act as a flavor carrier.

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