Oil Uptake Properties of Fried Batters from Rice Flour

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Batters were prepared, using rice flour as the main component, and analyzed for their oil uptake properties during frying. Rice flour resisted oil absorption better but was less effective as a thickening agent than wheat flour. Of the rice components, increased amylose in the amylopectin/amylose ratio of the starch decreased the batter oil uptake, whereas increased protein content had the opposite effect. Various additives were introduced and investigated for their ability to develop viscosity and other desirable characteristics for the batter. As additives to the rice flour batters, phosphorylated starch and gelatinized rice flour enhanced both the thickening and oil-reducing capacities of the batter. Compared with values for batters from wheat flour, the percent batter oil uptake in the fried crust for the modified rice flour batters was decreased by up to 62%, and the percent total oil uptake for the whole coated drumstick was reduced by up to 59%.

Keywords: *Rice flour batters; oil uptake; batter viscosity; batter pickup; moisture retention; phosphorylated starch; gelatinized starch*

INTRODUCTION

Recently, rice products have become popular as food ingredients because of the recognition that foods from plant sources, compared with those from animal sources, are equally, if not more, nutritious and beneficial to human health (Anon., 1998; National Committee of the American Heart Association, 1988). Rice ingredients, in particular, are readily available, and its components, such as protein and starch, are known to be highly hypoallergenic, easily digestible, and desirable for use in baby foods. Therefore, rice flour has been frequently used in foods including batters to coat foods for frying purposes.

Batters can enhance food sensory quality, but they also absorb oil during frying. The oil uptake in fried batters has become a concern, because it could lead to substantially increased consumption of oil. As excessive oil consumption is known to cause obesity and many other health problems, pressure has increased from governmental and consumer groups to restrict the sources of oil and fat in foods (Roberts, 1989). Oil uptake in fried batters is inevitably a target for studies for oil reduction purposes.

The mechanism of oil uptake in fried batters is poorly understood, and very little is reported in the literature concerning the criteria for oil reduction in batters. Nevertheless, batter materials and their interactions during frying are believed to play an important role in determining the batter oil uptake. For instance, because of their unique thermal gelation properties, methylcellulose and hydroxypropyl methyl cellulose have been used as oil barriers to reduce oil uptake in fried batters (Meyers and Conklin, 1990; Balasubramaniam et al., 1997). Findings have been reported that oil uptake increased with increased removal of water from the sample during frying (Gamble et al., 1987). Although a batter's viscosity is recognized as one of the most important factors in determining its performance during frying, few studies are available about its effect on the oil uptake of fried batters (Cunningham and Tiede, 1981).

In this research, we investigated the oil absorption properties of batters with rice flour as the main component. Particularly, experiments were conducted to clarify the effects of additives on batter viscosity and oil uptake. Batters were subjected to frying treatment both as free (noncoating) batters and in the coating of chicken drumsticks. Conditions for batters to acquire desirable oil uptake and other batter characteristics would then be determined.

MATERIALS AND METHODS

Materials. Long grain rice flour, RL-100, and gelatinized rice flour, Rice Gel L-100, were obtained from Rivland (Houston, TX). Waxy rice flour, Sweet Rice flour, was from California Natural Products (Lathrop, CA), and rice starch, Neutral DR, was from A&B Ingredients (Fairfield, NJ). Wheat flour, Pillsbury's Best all purpose flour, and frying oil, Wesson vegetable oil, were purchased from local supermarkets. Phosphorylated starch esters, with the incorporation of phosphorus at 0.44 and 1.60%, were prepared according to the method of Neukom (1959). Essentially, dry and ungelatinized starch was heated with a mixture of mono- and disodium phosphate salts at 155 °C for 4 h, and the amount of phosphorus incorporated into the starch molecule was controlled by the amount of the phosphate salts used. Propylene glycol alginate, Kelcoloid O, was a gift from Kelco (Chicago, IL). All other chemicals used were of reagent grade.

Frying of Noncoating Batters. A batter base was prepared containing, in addition to common ingredients of 1.0% sodium bicarbonate, 3.0% sodium chloride, and 0.72% pyrophosphate, 95.28% rice flour or a mixture of rice flour and various additives. For most of the experiments, such as in the investigation of rice flour versus wheat flour, 70 g of the batter base was mixed with 80.5 g of deionized water for 5 min at room temperature. After equilibrating for another 5 min, the batter slurry was analyzed for viscosity and subjected to deep-

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Table 1. Comparison of Oil Uptake for Fried Batters from Rice Flours with Different Amylopetin/Amylose Ratios[a]

rice flour	protein (%)	fat (%)	fiber (%)	carbo-hydrate (%)	starch ratio[b]	oil uptake (%)
waxy	9.0	1.5	1.0	79	98:2	34.3[c]
long grain	8.2	1.0	0.7	80	80:20	27.6[d]

[a] Data were provided by the flour manufacturers except for the oil uptakes, which were analyzed as described under Materials and Methods. Superscripts of different letters in the same column indicate significant differences at $P < 0.05$. [b] The ratio of amylopectin and amylose in the starch.

Table 2. Effect of Phosphorylated Starch on Batter Properties during Frying

batter	oil uptake[d] (%)	moisture[d] (%)	viscosity[d] (RVU)
control[a]	46.3[d]	1.5[i]	85[fg]
replaced with			
5% rice starch	45.0[d]	2.2[i]	81[g]
10% rice starch	44.7[d]	2.0[i]	65[g]
15% rice starch	44.9[d]	2.3[i]	61[g]
replaced with			
5% p-starch A[b]	38.9[e]	4.5[h]	118[f]
10% p-starch A	34.7[f]	6.0[h]	258[e]
15% p-starch A	32.0[f]	9.5[g]	285[e]
replaced with			
5% p-starch B[c]	27.1[g]	14.7[f]	325[d]
10% p-starch B	21.5[h]	19.5[e]	350[d]
15% p-starch B	19.1[h]	22.7[d]	350[d]

[a] Batter base consisting of equal ratio of rice and wheat flours (see Materials and Methods). [b] Modified rice starch with 0.44% phosphorus. [c] Modified rice starch with 1.64% phosphorus. [d] Different letters in the same column indicate significant differences at $P < 0.05$.

fry treatment. In one experiment (Table 1), the batter base was prepared by mixing rice flour from waxy or long grain rice. In another experiment investigating the oil-reducing properties of phosphorylated starches (Table 2), the batter base, which consisted of an equal ratio of rice and wheat flours, was partially replaced by rice starch phosphorylated esters.

A 6 qt Dazey deep-fryer (Dazey Co., New Century, KS) with a strainer was used for the frying experiment. The heating was controlled by a temperature probe, Therm-O-Watch L6-1000SS (Instruments for Research and Industry, Cheltenham, PA). The oil bath, filled to a depth of 4.5 cm with 4.1 L of the Wesson vegetable oil, was heated at 177 °C for 2 h before use. Spoonfuls of the batter slurry were introduced into the oil bath using a tablespoon and fried with occasional stirring for 6 min using a metal spatula. The fried batters were removed from the oil bath and ground in a food processor before analysis for moisture content and oil uptake.

Coating and Frying of Chicken Drumsticks. Batters of rice flour and/or wheat flour bases with or without additives were prepared as described in the noncoating experiment. Chicken drumsticks were weighed before and after dipping and coating with the batter. Wet pickup was calculated as the percent ratio of the weight of batter coating divided by the total weight of batter-coated drumstick. The frying was conducted with the oil bath at 177 °C for 10−12 min until temperature at the bone reached 170 °F as measured by a thermometer probe. After frying, the batter-coated drumstick was weighed, and the batter crust was peeled off and saved for oil analysis. Any remaining batter was removed by washing with water. The drumstick was then dried thoroughly with a paper towel and reweighed. The difference between the battered drumstick and the washed drumstick was the batter weight. Dry pickup was the batter weight per 100 g of the battered and fried drumstick.

Batter Analysis. Batter analysis was conducted in triplicate. Batter viscosity was determined using an RVA-3D analyzer (Foss Food Technology Co., Eden Prairie, MN) by introducing 28 g of the batter into the sample cup and the

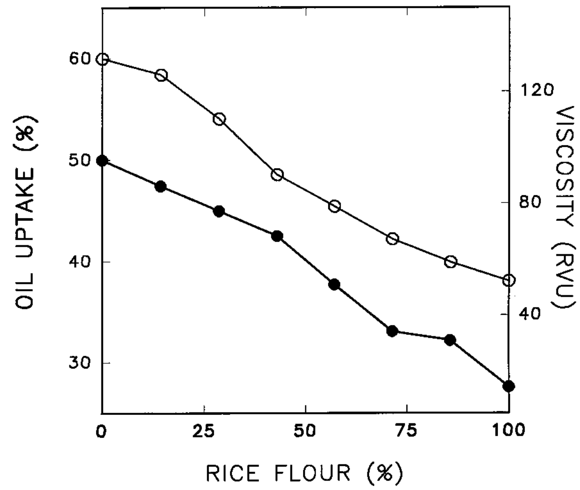

Figure 1. Effect of rice flour in batter containing a mixture of rice and wheat flours on oil uptake and viscosity during frying: (●) oil uptake; (○) viscosity.

viscosity in RVU units was read after spinning, first at 960 rpm for 10 s and then at 160 rpm for the remaining time, at the end of a total time of 4 min. Moisture content of the fried batter was measured using a Mettler LP 16 infrared dryer moisture analyzer (Mettler Co., Hightstown, NJ) by spreading the ground batter (~1 g) on the sample pan at 160° C for 15 min. Oil uptake was analyzed according to the Soxhlet extraction method (AOAC, 1984). The ground fried batter (3 g) was placed in a thimble and extracted with 100 mL of petroleum ether at boiling temperature for 4 h. The petroleum ether was removed with a Rotovap (Buchi, Westbury, NJ), and the flask with the oil residue was equilibrated to room temperature in a desiccator for 30 min and then weighed to obtain the oil uptake.

Statistical Analysis. The samples were analyzed in triplicate. Data were assessed by the one-way ANOVA and mean comparisons by the least significant difference (LSD) test with $P < 0.05$ using SAS software version 6.12 (SAS Institute Inc., Cary, NC).

RESULTS AND DISCUSSION

Rice Flour versus Wheat Flour. Figure 1 shows the oil uptake of free fried batters (not coating foods) from a mixture of rice and wheat flours as a function of the ratio of these two components. Oil retention ranged from 27.6% for the pure rice flour batter to 49.3% for the pure wheat flour batter. Rice flour has better oil resistance than wheat flour and may be desirable for low-fat batter applications. However, as the rice flour content was increased, the fried batter became more brittle, less fluffy, and harder to chew. Also, batter slurries high in rice flour were low in viscosity. Although adequate viscosity is required for batters to coat foods, the lack of it is also responsible for the generally lower quality in texture for the fried batters with high ratios of rice flour.

The effect of batter viscosity on oil uptake varies, depending on frying conditions including time, temperature, and batter material. Normally, as will be explained in later sections, increased viscosity often resulted in decreased oil uptake for the fried batters. In the present case, a dominant factor appeared to be that wheat flour, because of the presence of the hydrophobic wheat gluten, had greater affinity for oil than rice flour. The leavening effect of gluten in wheat flour and the lack of it in rice flour also made the wheat batter more porous, which could enhance its moisture release

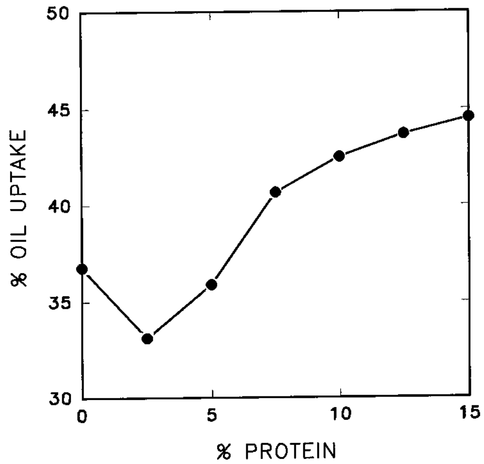

Figure 2. Effect of protein content on oil uptake of batter containing rice starch during frying.

and oil uptake during frying. As a result, increased viscosity was actually accompanied by increased oil uptake.

Effect of Components in Rice Flour. Rice flour consists of starch (80−82%) and protein (7−9%) as the main components. The high content of starch makes it an important factor in determining the oil uptake characteristics of rice flour batters. The two main components of starch are amylopectin and amylose. The amylopectin-to-amylose ratios of rice starch range from 80:20 for regular long grain rice to 98:2 for waxy rice. Table 1 shows the oil uptake for batters from flours of regular long grain rice and waxy rice. Both flours have comparable levels of protein, fat, fiber, and total carbohydrate. However, batters from the long grain rice flour with the lower amylopectin/amylose ratio retained substantially less oil than batters from the waxy rice flour. Good film-forming has been reported to be a desirable characteristic for lowering oil absorption in batters (Balasubramaniam et al., 1997). Amylose is known to have good film-forming properties (Nisperos-Carriedo, 1994), which may account for the lower oil uptake for batters from the long grain rice flour.

Because protein molecules consist of both hydrophilic and hydrophobic groups, proteins can be good emulsifiers. The presence of protein in batters tends to enhance oil uptake during frying. Figure 2 shows the effect of rice protein on the oil uptake properties of rice starch batters. The fried batter of pure rice starch had a 36.8% oil uptake, substantially higher than the 27.6% for the batter of rice flour. When rice starch was replaced by increasing amounts of rice protein, oil uptake of the batter decreased slightly initially and then steadily increased. Similar increases in oil uptake because of increased protein in batters from wheat flour have also been reported (Olewnik and Kulp, 1990).

Effect of Phosphorylated Starch. Table 2 shows the effect of phosphorylated starch esters on batter properties during frying. The batter with an equal ratio of rice and wheat flours was used as the control. Replacing the batter with up to 15% rice starch barely affected the fried batter's oil uptake or moisture retention; rice starch is one of the major components of the control batter, and so partial replacement of the batter with rice starch should not significantly alter the composition and characteristics of the batter. Phosphorylated starches, however, are known to have physical and functional properties different from those of non-

Table 3. Composition of Batters for the Coating of Drumsticks

batter[a]	rice flour (g)	wheat flour (g)	additive (g)	water (g)	total solid (%)
A	95.28			99.0	50.3
B	47.64	47.64		114.0	46.7
C		95.28		130.0	43.5
D	45.26	45.26	4.76[b]	153.0	39.5
E	42.88	42.88	9.52[b]	204.0	32.9
F	94.38		0.95[b]	115.0	46.5
G	92.42		2.86[b]	115.0	46.5
H	88.60		6.68[c]	115.0	46.5
I	95.28		1.15[d]	115.0	47.0

[a] In addition to the composition for the batters shown in the table, each batter also contained (per 100 g of total weight), sodium chloride (3 g), sodium bicarbonate (1 g), and sodium pyrophosphate (0.72 g). [b] Modified rice starch with 1.64% phosphorus. [c] Gelatinized long grain rice flour. [d] Propylene glycol alginate.

phosphorylated or intact starch, such as better thickening and film-forming properties (Kerr and Cleveland 1962; Solarek, 1986). The replacement of starch batter with phosphorylated starch appeared to result in lower oil uptake for the fried batter. With the modified starch containing 0.44% phosphorus, oil uptake was reduced to 34% at 15% replacement of the starch batter, as compared with the 46% oil uptake for the control. When the modified starch with 1.64% phosphorus was used, the oil uptake was reduced to 19% at 15% replacement.

Effect of Moisture Retention. Table 2 also shows a general trend of decreased oil uptake with increased moisture retention. Because the samples had the same initial water content, an increase in final moisture retention means a reduction in moisture loss during frying, which normally correlates with oil uptake for the fried batter (Gamble et al., 1987). Apparently, the presence of phosphorylated starch, which has superior pasting and film-forming properties, enhanced the batter's water-holding ability and made it a more effective oil barrier during frying.

Table 2 also shows that viscosity of the batters increased with increased starch phosphate. Depending on the batter material, batter viscosity may or may not lead to decreased oil absorption for the fried batter. Normally, with increased viscosity, batter pickup increased, which enhanced the formation of a hard crust during frying. The crust served as a barrier to prevent water loss and, as a result, contributed to reduced oil absorption. Similar findings and discussion about the effect of crust formation on overall oil retention for the coated fried foods have been reported in the literature (Love and Goodwin, 1974; Makinson et al., 1987). However, when the batter materials have poor film-forming or water-retaining properties, the increase in pickup due to increased viscosity did not provide an effective oil-resisting barrier to the coated foods, actually resulting in an increase in oil absorption such as in the case of wheat flour batters as discussed earlier.

Coating of Chicken Drumsticks. To investigate oil uptake properties of batters in the coating of foods, experiments were carried out using batters to coat chicken drumsticks. The fried batters were then removed from the drumsticks and analyzed. Table 3 shows the composition of the batters. To offset the effects of viscosity on batter properties, the viscosities of batters A−E were adjusted to a comparable level ranging from 82 to 94 RVU. Because rice flour is a poor thickening agent, a higher concentration of its dispersion was required to reach the same viscosity level as those from

Table 4. Performance of Batters as Coatings of Chicken Drumsticks during Frying[a]

batter[b]	viscosity[c] (RVU)	pickup[c,d] (%)		oil uptake[c,e]	
		wet	dry	% batter	% total
A	82^{j}	8^{k}	13^{h}	20.7^{h}	2.69
B	88^{ij}	12^{j}	13^{gh}	27.0^{g}	3.51
C	94^{i}	13^{ij}	15^{f}	37.6^{e}	5.64
D	91^{ij}	16^{gh}	15^{fg}	21.5^{h}	3.38
E	88^{ij}	15^{hI}	9^{I}	30.7^{f}	2.76
F	106^{h}	19^{ef}	12^{h}	19.5^{h}	2.34
G	220^{e}	21^{e}	20^{e}	14.4^{i}	2.88
H	183^{g}	18^{gh}	12^{h}	20.2^{h}	2.40
I	204^{f}	17^{fgh}	16^{f}	25.3^{g}	4.12

[a] Frying conditions were given under Materials and Methods. [b] Composition as shown in Table 3. [c] Different letters in the same column indicate significant differences at $P < 0.05$. [d] Wet pickup is the percent w/w ratio of the batter coating to the total of chicken drumstick and batter coating before frying; dry pickup is the same ratio after frying. [e] Oil uptake (percent batter) is the percent w/w ratio of oil uptake to the fried batter coating; oil uptake (percent total) is the percent ratio of total oil uptake to the fried chicken drumstick and batter coating.

other batter materials, such as wheat flour, with better thickening capacities. Accordingly, the solid content decreased from batter A (rice flour) to batter B (1:1 rice/wheat flours) and then to batter C (wheat flour). Similarly, the decrease in total solid from batters D and E, which consisted of the same batter base (1:1 rice/wheat flours), was due to the presence of an increased phosphorylated starch, a good thickener. The resulting wet pickup values were comparable, ranging from 13 to 16% except for the 8% of batter A, whereas values of dry pickup were also in a narrow range of 12−15% except for the 9% of batter E.

Oil uptake properties of the fried batters (batters A−E) varied substantially, and the oil absorption reducing characteristics of rice flour and phosphorylated rice starch were obvious. Although oil retention in terms of percent fried batter crust increased substantially from batter A (20.7%) to batter C (37.6%) because of the decrease in rice flour, oil retention also decreased from batter B (27.0%) to batter D (21.5%) because of the presence of phosphorylated starch in batter D. The results confirm earlier findings, shown in Figure 1 and Table 2 for noncoating fried batters, that rice flour was a better oil barrier than wheat flour and the introduction of small amounts of phosphorylated starch as additives enhanced oil resistance for the fried batter. The relatively high oil uptake for batter E was most likely due to the excessive lowering of the solid content in the batter. Low solid content led to low dry pickup of the oil-reducing rice flour, reducing the overall oil-lowering capacity of the batter. Batter E also formed an extremely thin crust, which had poor texture quality, and often yielded erratic and less reliable oil uptake values. On the other hand, percent total oil uptake of the whole fried battered drumstick appeared to be dependent on dry pickup. An increase of 2% dry pickup from batter A to batter C resulted in an increase in percent total oil uptake from 3.51 to 5.64%, whereas a 6% decrease in dry pickup from batter D to batter E resulted in a decrease in percent total oil uptake from 2.76 to 2.34%.

Batter viscosity influences the quantity and quality of pickup, the potential for voids, the handling ease, and the coating texture. The viscosity of batters from wheat flour is normally in the range of 85−100 RVU (1050−1200 cP) (Olewnik and Kulp, 1990). Rice-based batters have been found in our investigation to work best in a higher viscosity range of 100−250 RVU. Batter pickup is recommended by the Food and Drug Administration not to exceed 30% (9 CFR 319.880), and rice-based batters appeared to have the best texture at a range of 12−24% dry pickup. On the basis of these guidelines on viscosity and dry pickup, we proceeded to prepare four batters (batters F−I) using rice flour in the batter base and small amounts of different thickeners to provide the needed viscosity.

Phosphorylated starch ester appeared to be effective as both a thickener and an oil barrier. Batters F and G maintained a viscosity in the desirable range with the addition of the starch phosphate at 0.95−2.86%. Whereas batter G, at the higher end of the desirable viscosity scale, scored the lowest percent of batter oil uptake (14.4%) of the samples listed, batter F, at the lower limit of the desirable viscosity scale, achieved the best percent of total oil uptake (2.34%). Compared with values for the wheat flour batter (batter C), the percent of batter oil uptake for batter G was reduced by 62% and the percent of total oil uptake for batter F was lowered by 59%. For batter H, acceptable viscosity and oil uptake were achieved by the introduction of a relatively high amount of gelatinized rice flour (6.8%). However, propylene glycol alginate, an exceptionally good thickener, was not as effective in lowering the oil uptake values. It appears that the ability to thicken rice flour batter is a top criterion for additives to develop desirable batter properties. However, a good thickening agent may or may not enhance the oil-reducing capacity of rice batters. On the other hand, (long grain) rice-based thickeners in general are effective fat-reducing agents, and their use as additives can be helpful in reducing the oil uptake of rice batters.

Conclusions. Batters from long grain rice flour retain less oil during frying than wheat flour batters. However, long grain rice flour batters form thin slurries and require additives to develop viscosity and other desirable batter properties. The addition of thickeners can normally raise the viscosity of the batter, but not all thickeners can be effective in enhancing its oil-reducing capacity. A good strategy is to use rice-based thickening agents as additives, because these thickeners normally maintain the superior oil-reducing characteristics of the intact long grain rice flour. Particularly, gelatinized long grain rice flour and phosphorylated long grain rice starch esters can be effective in enhancing both the viscosity and the oil-lowering properties of rice flour batters.

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