EFFECT OF SOY FLOUR ON FAT ABSORPTION BY CAKE DONUTS

by

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INTRODUCTION

Soy flour is utilized in cake donuts for its functional properties rather than for its nutritional quality. In cake donuts, soy flour primarily functions to decrease fat absorption (Wolf 1970) and (Eley 1968). The mechanism by which soy flour functions to decrease fat absorption is unclear. In the past protein solubility has been reported as the major factor affecting functionality (Sipos, et al 1974), (Johnson 1970), and (Dubois 1980). Several of the processing steps in the manufacture of soy flour affect protein solubility. Solvent removal with heat has the most significant effect on protein denaturation as measured by protein solubility in water (Belter, and Smith 1952). Protein dispersibility index (PDI) is one of several methods used to determine protein solubility. This method expresses the percent of protein (N X 6.25) in the flour that remains in the supernate after centrifugation (AOCS Method Ba 10-65). This study was undertaken to gain a better understanding of how soy flour functions to decrease fat absorption by cake donuts.

LITERATURE REVIEW

Defatted soy flour is milled from cleaned, dehulled soybeans that have been solvent extracted. Processing alternatives provide for the manufacture of soy flour with varying degrees of heat treatment and varying granulations. In the production of defatted soy flour, the oil is removed by hexane. Residual hexane is removed by heat and/or vacuum. Heat, particularly moist heat, during the subsequent toasting operation influences the dispersibility of the protein. As the amount of heat treatment increases, the amount of water soluble protein decreases (Kellor 1971). Toasting, ie., heating at 99 to 116^{o}C, can be controlled to produce soy flour with comparatively low protein solubility with PDI of 8 to 45 (Cowan 1973).

Defatted soy flours have a minimum protein content of 50%. Carbohydrate content is about 30%. Protein, carbohydrates, and ash are the major constituents of defatted flour; the remainder consists of residual lipids and a number of minor components such as saponins, isoflavones, and compounds responsible for the typical flavors of raw soybean flour. About one-half of the flour carbohydrates are the oligosaccharides sucrose, stachyose, and raffinose, while the other half consists of polysaccharides, which are insoluble in water or alcohols (Aspinal, et al 1967). Raw soy flours contain many enzymes such as lipoxygenase, lipase, amylases, and proteases which are inactivated during heat treatment. Soybeans also contain an antinutritional factor which retards the action of the trypsin enzyme. Heating destroys the antitrypsin factor, decreases the intensity of the raw flavor, and modifies color (Dubois and Hoover 1981).

Soy flour products are generally marketed as functional and/or nutritional substitutes for proteins from animal sources. It is believed that proteins are the principal functional component of soy protein products, although carbohydrates could contribute to the functional properties of flours (Hutton and Campbell 1981).

The amount of frying fat absorbed by donuts is important to the quality of the donut. Economically and nutritionally, the less fat absorbed the better. However, a donut must contain a certain amount of fat to be palatable. Donuts containing 25 - 30% fat were found to be more palatable than those containing 18 - 20% fat (Thiessen 1939). Donuts containing too little fat may have a pasty mouthfeel. Donuts containing too much fat have a greasy mouthfeel and the flavor of the frying fat becomes prominent (Pyler 1972).

Formulation of the donut mix will affect fat absorption. A rich formula containing large quantities of milk and egg will absorb more fat than a lean formula (Denton, et al 1920) and (Dubois 1979). The balance between structure building components and the tenderizing ingredients control the absorption and also the symmetry, crust character, volume, tenderness, and eating quality of cake donuts (Wheeler and Endres 1967). Paton, et al (1981) measured the force associated with the resistance to movement of a probe inserted in cake batter as a function of baking time. The cohesive or resistive forces appeared to result from the opposing action of toughening (flour), and tenderizing (sugar and shortening) ingredients.

A fifty percent decrease in fat absorption is possible with the addition of ten percent soy flour based on flour weight. The optimum soy flour replacement level is six percent based on flour weight (French 1977). In addition to its effects on fat absorption, soy flour used in the range of 3 -3.5% of the formula provides good crust color, improved shape, higher moisture absorption and a longer shelf-life (Hoover 1975).

Economic factors are the major incentive for food use of soy flour. Usually, for every pound of soy flour added to the formula an additional pound or a pound and a half of water may be added; therefore, yield is also increased (Spios, et al 1974). The increase in water absorption may be due to both the fiber and insoluble protein fractions of the soy flour competing for water. (Urbanski, et al 1982). During mixing, the additional hydrophillic sites compete for free water and increase batter viscosity. Kuntz, et al (1978) found no significant relationship between water uptake and protein content in soymilk. Hydration of the insoluble carbohydrate fraction was determined to be responsible for water uptake.

Fat absorption by the donut has been reported to be controlled by the water content of the batter. Increased water gives less absorption than normal and decreased water gives more absorption (Dubois 1979). Wheeler and Stingley (1963) concluded from their studies on fat absorption by cake donuts that major variations in the amount of water added to the mix will affect fat absorption. Their data, however, appears to contradict their conclusions. Their data shows that variations in batter moisture have no effect on fat absorption. They also discuss an inverse relationship between moisture content of the finished donut and fat absorption. This may be misleading. If the percent moisture present in the fried donut is calculated without subtracting the absorbed fat, then as the percentage of fat increases and the quantity of solids not fat remains constant, percent moisture decreases. Therefore, any relationship between moisture content and fat absorption may be biased by variations in quantity of fat absorbed.

During frying, the volume and the amount of surface area exposed to the frying fat will affect fat absorption. Denton (1920) reports 12 percent fat absorption for donuts fried as rings and 3 percent absorption for the equivalent weight of batter fried as balls. Surface area and volume are influenced by several uncontrollable factors including batter flow and expansion during frying.

Lawhon, et al (1975) reported that donuts made with various levels of high nitrogen solubility soy flour had less fat absorption and more moisture retention than donuts made with low nitrogen solubility soy flour. Donuts fortified with soy flour also showed lower fat absorption than donuts fortified with equivalent quantities of protein from cottonseed or peanut flours.

Soy flour has been reported to decrease loaf volume in bread supplemented with five percent soy flour based on the weight of the flour (Finney, et al 1963). Decreased loaf volume has been reported to be the result of less gas retention rather than less gas production (Hyder, 1971). Scanning electron micrographs of bread supplemented with soy protein indicated that the soy protein caused small pores, ruptured cell structure, and thick cell walls in bread (Fleming and Sosulski 1978).

The proteins most sensitive to heat denaturation are albumins, globulins, and globins. The extent of thermal damage to proteins is a function of time temperature, moisture content, reducing substances and pH. Variations in any of these can cause the destruction of amino acids, formation of amino acid complexs, and inter and intramolecular cross-linking of proteins (Hegarty 1982). Mild heat treatment of proteins creates a browning change due to the Maillard reaction. This damage may be exclusive to lysine. However, lysine was found to be nutritionally available after a normal solvent removal and toasting process in which the temperature reached 95 to 100^{o}C for 45 to 60 minutes (Stott, J.A. and H. Smith 1966). Taira, et al (1965) report similar results. They found that cystine was the only amino acid destroyed under heating conditions commonly used in the processing of soybean products. Cystine represents less than two percent of the protein present in soy flour (Longnecker, et al 1964).

Materials and Methods

Materials

Flour. A blend of commercially available hard and soft wheat flours, (Pillsbury Co., Minneapolis, Minnesota).

Sugar. Granulated sucrose, (C and H Sugar Co., San Francisco, California).

Non Fat Dry Milk. Spray dried NFDM, (Mid America Dairymen Inc., Springfield Missouri).

Powdered Egg Yolks. Pasteurized dried egg yolks, (Monark Egg Corp., Kansas City, Missouri).

Vegetable Oil. Partially hydrogenated soybean oil, (Shurfine Central Corp., Northlake, Illinois).

Baking soda. "Arm & Hammer" brand, (Arm & Hammer Division of Church & Dwight Co., Inc., Piscataway, New Jersey).

Sodium Acid Pyrophosphates. "Donut Pyro" (Stauffer Chemical Co., Westport Connecticut). "B.P. 28", (Monsanto Co., St. Louis, Missouri).

Salt. "Morton" brand, (Division of Morton Thiokol, Inc. Chicago, Illinois).

Ground Nutmeg. (McCormick & Co., Inc. Baltimore, Maryland).

Frying Shortening. "Richtex", brand (Humko Products, Division of Kraft, Inc., Memphis, Tennessee).

Defatted Soy Flours. (Archer Daniel Midland Co., Decatur, Illinois, and Farmland Soy Processing Co., St. Joseph, Missouri). The PDI values (AOCS Method Ba 10-65) and laboratory analysis of the soy flours are shown in Table 1. Soy flours as received were placed in plastic lined sealed cans and stored at 40^{o}F until used. Processing techniques were not divulged by the suppliers.

Table 1. Laboratory Analysis of Soy Flours[a].

Flour Sample	PDI[b]	Protein[c] (%)	Ash (%)	Moisture (%)	Fat (%)	Fiber (%)
1	95	53.6	6.4	7.0	1.07	5.0
2	80	55.4	6.7	6.3	0.46	4.1
3	69	55.0	6.7	6.0	0.89	3.9
4	30	55.1	6.4	6.2	0.63	3.9

[a] Dry matter basis

[b] Protein Dispersibility Index

[c] Protein calculated as nitrogen X 6.25

Methods

Donut Mix Preparation. The following formula was used to prepare 300 lbs of donut mix:

Ingredient	Bakers %	True %
Hard Wheat Flour	50.0	30.5
Soft Wheat Flour	50.0	30.5
Sugar	40.0	24.6
Non Fat Dry Milk	5.0	3.1
Vegetable Oil	10.0	6.0
Powdered Egg Yolks	2.0	1.2
Salt	1.67	1.0
Soda	1.40	0.86
B.P. 28	0.39	0.24
Donut Pyro	1.55	0.95
Ground Nutmeg	0.8	0.5

All ingredients were blended together in a Wenger ribbon mixer (300 lb capacity) for 30 minutes. The sides of the mixer and blades were scraped down at 10 minute intervals during mixing. The mix was packaged in six plastic lined paper sacks, and stored at $-22^{o} \pm 1^{o}$C. until 24 hours before use.

Batter Weight. The Belshaw type "K" donut cutter is a volumetric device. Production of similar batter weights between treatments requires a constant viscosity. Apparent viscosity was measured with the Brookfield Viscometer model RVT, with helipath stand. The #7 spindle was used, the RPM was set at 2.5 and the batter temperature was $23^{o} \pm 1^{o}$C. The procedure used for measuring apparent viscosity is described below.

> The prepared batter was placed in a 600 ml. beaker and leveled off across the top. Using the helipath stand, the spindle was lowered into the batter to the depth indicated on the spindle. After 4 min. had elapsed, the viscometer was turned on. The scale

reading that represented the highest resistance was recorded. Because shear thinning occurs, only the first three scale readings as the pointer came into view were recorded. This procedure was repeated after 9 min. and 14 min. floor time. An average of the nine scale readings for each batter was calculated. Apparent viscosity, in centipoise, was calculated by multiplying the average scale reading by a factor provided by the manufacturer. In this case, a factor of 1.6×10^4 was used.

To determine the reproducibility of this procedure, apparent viscosity was measured on four identical batches. Summary statistics are shown in Appendix A. Water absorption level was adjusted to maintain an apparent viscosity of $7.1 \times 10^5 \pm 5 \times 10^4$ centipoise. One percent change in water absorption resulted in a $4.9 \times 10^4 \pm 1.6 \times 10^4$ centipoise change in apparent viscosity for batters prepared without soy flour.

<u>Batter Preparation</u>. A Hobart mixer, Model 50N, equipped with a cake paddle and a 5 qt. bowl, was used. The donut mix and soy flour were dry blended for 10 minutes on first speed. The bowl was scraped once after 5 minutes of mixing. Water was added and incorporated for 1 1/2 minutes on first speed. Water temperature was adjusted to achieve a final batter temperature of $23 \pm 1^{\circ}C$. The bowl was scraped down and returned to the mixer for two additional minutes on second speed. Mixed batter was placed in the donut cutter (equipped with a standard plunger assembly), and ten minutes floor time was allowed before frying.

Frying. Donuts were fried in a Belshaw, Model 61, Mini Fryer. Six donuts were deposited into the frying fat (191°C) at 2 second intervals. After 50 seconds, the donuts were individually turned in the same sequence as deposited, and fried an additional 50 seconds on the second side. After frying, donuts were drained on a metal rack for 45 minutes with the first side fried facing up. While frying six donuts, the fat temperature would drop to 186°C. After the temperature of the frying fat returned to 191°C, an additional six donuts from the same batch were fried. To observe the diffusion of fat into the donut, two batches with and without soy flour were fried in dyed frying fat (lipid crimson, "Gurr" brand, High Wycombe, Bucks, England).

Sample Preparation. Six donuts were randomly selected from each batch of twelve by use of a random digit table (Snedecor and Cochran 1980). The six donuts were considered a sample and weighed. Samples were prepared for analysis by hand crumbling and lyophilizing. Lyophilized samples were ground in a coffee mill (Moulinex, Varco Inc.). To prevent sample heating and loss of fat during grinding, the samples were ground with dry ice. Dry ice to sample ratio was approximately 1:1 by weight. The remaining donuts from each batch were placed in plastic zip-loc bags and stored at -22°C ±1°C.

Moisture. Before fat extraction, moisture content was determined by a modified vacuum-oven procedure (AACC Method 44-40).

Fat Determination. Percent fat by both acid hydrolysis (AACC Method 30-10), and petroleum ether extract (AACC Method 30-26) were determined on a series of samples during a preliminary portion of the study. Later samples were analyzed by petroleum ether extract only.

Frying Fat Quality. Free fatty acid level (AOCS Method 5a-40) of the frying fat was maintained at 0.40% $\pm$0.01%. The viscosity of the frying fat was maintained at 10 $\pm$1 centipoise at 100 $^{\circ}$C with the Brookfield viscometer model LVT (equipped with spindle #1 and set at 30 RPM). A separate supply of conditioned shortening was obtained by frying a series of donuts in a batch of shortening until the free fatty acid level increased to 0.43%. Conditioned fat was stored in a covered container until use. Before frying each batch, frying fat quality was adjusted. Shortening was removed from the fryer and replaced with fresh of conditioned shortening as needed.

Soy Flour Fractionation. Fractions of soy flours separated by the Protein Dispersibility Index (PDI) procedure (AOCS Method Ba 10-65) were lyophilized. The percent solids and laboratory analysis of the protein present in each fraction are shown in Table II.

Fat Absorption Calculations. Weight of fat present in the quantity of batter needed to produce one donut was subtracted from the total fat present in the fried donut. The difference was the amount of fat absorbed per donut. This quantity was then divided by the total solids not fat in the donut to yield grams of fat absorbed per gram donut solids not fat (gFA/gDSNF).

Donut Volume. Frozen donut samples were removed from the freezer the day before measuring volume. Two donuts from twenty

Table II. Analysis of Soy Flour Fractions.

PDI	Fraction	Yield (%)	Protein (% d.b.)
95	Soluble	69	63.8
	Insoluble	31	31.5
80	Soluble	65	63.0
	Insoluble	35	43.2
69	Soluble	55	58.2
	Insoluble	45	53.3
30	Soluble	37	37.5
	Insoluble	63	66.5

batches were randomly selected from donuts prepared with 95, 80, and 69 PDI soy flours. Donut samples were analyzed for volume by a modified procedure described by Shogren and Finney (1984). Density of the rapeseed was standardized by weighing repeated volumes in a 100-ml graduated cylinder. Volume was calculated by dividing the weight of the rapeseed displaced by the density of the rapeseed.

RESULTS AND DISCUSSION

Fat Determination. It is a recognized fact that the determination of fat in baked products by petroleum ether extraction gives results lower than those for the combined fat of the ingredients entering the product. Because some lipids are bound to proteins and carbohydrates, complete extraction is prevented. Therefore, disintegration of the sample with acid allows for more complete extraction of fat (Hertwig 1923). Twenty six samples were analyzed for fat by both petroleum ether extraction and acid hydrolysis (Appendix B). Percent fat (dry basis) was analyzed and correlated by least squares analysis. The resulting equation had a slope of .983, an intercept of 1.8 and a correlation coefficient greater than .99. Because the equipment needed for acid hydrolysis was not readily accessible, fat extraction by petroleum ether was used for the remainder of the study. All results are reported as grams of fat by ether extract.

Batter Weights. Donuts of equal weights should have similar surface area and volume if flow properties and expansion during frying are the same. The Belshaw cutter did not permit precise control of batter weights. If it is assumed that the only two mass transfer events that occur during frying are the loss of moisture and the uptake of fat, the weight of the batter used, can be calculated from the finished weight of the donut. A flow diagram is shown in Appendix C. Analysis of variance showed no significant difference (5% level) between calculated batter weights for all batches. Summary statistics are shown in Appendix D.

Batter Fat. Measurement of fat content in batters containing the 95 PDI soluble fraction (3.85% level of protein addition) and the 30 PDI soluble fraction (3.56% level of protein addition) by ether extraction resulted in fat values considerably below the average batter fat. Analysis of the samples for fat by acid hydrolysis revealed no difference in fat content compared to other batters. Therefore, it appears that above a certain level of protein addition the PDI soluble protein binds fat to a greater extent than intact soy protein or PDI insoluble protein. Percent fat contained in the batters was calculated from an average of all batters excluding the two mentioned above.

Batter Preparation. Preliminary work estimated the variance in the grams fat absorbed per gram solids not fat in the donuts to determine the experimental design. Replicates produced on three different days failed to show significant difference (5% level) between days. Summary statistics are shown in Appendix E.

Water Absorption. To determine if the variation in water absorption level would predict fat absorption by the donut as suggested by the work of Wheeler and Stingley (1963), grams of moisture in the batter required due to the addition of soy flour were correlated with grams fat absorbed per gram of donut solids not fat. Even though water absorption level was not a truly independent variable within this study, the variations in batter moisture did not appear to explain variations in fat absorption.

Also no significant relationship was found between grams of moisture per donut and grams of fat absorbed per gram donut solids not fat. Correlation coefficient for the regression was 0.00. This contradicts work by Stingley and Wheeler (1963) which suggests an inverse relationship between moisture content of the finished donut and fat absorption.

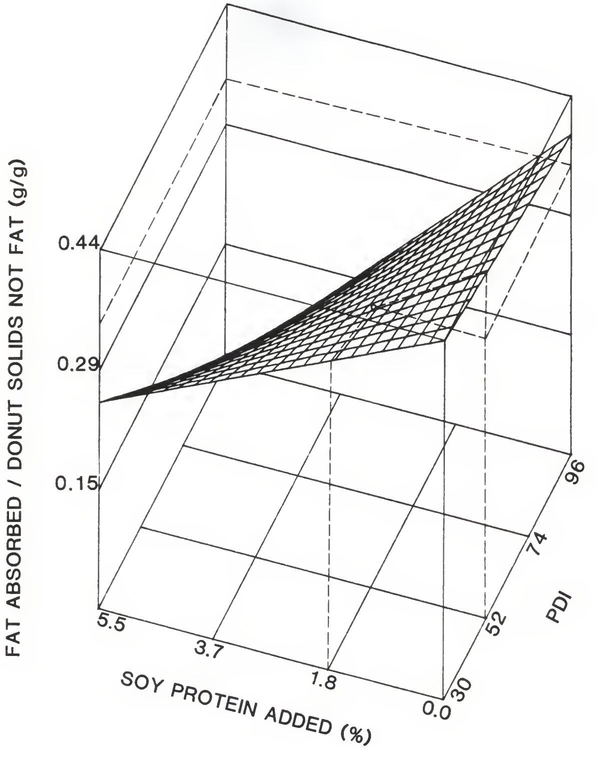
Moisture Loss During Frying. Because fat absorption influences fried donut moisture, when the moisture is expressed as a percent, moisture loss was calculated in grams. Grams of moisture per fried donut was subtracted from grams moisture in the batter to yield moisture loss. To determine if fat absorption was simply a mass transfer event between the loss of water and the uptake of fat during frying, the relationship between grams of fat absorbed per gram donut solids not fat and moisture loss within this study was analyzed. Significant (5% level) differences existed between treatments in the amount of moisture lost during frying. The correlation coefficient between moisture loss and fat absorption was -0.60. Although there were variations in moisture loss during frying, fat absorption is not dependent upon the diffusion of moisture from the donut or the retention of mositure.

Soy Flour Fractionation. Fractionation of the soy flours by the PDI procedure resulted in PDI soluble and insoluble fractions. A replacement level of 6% intact soy flour was chosen because it represents the upper limit of the range of soy flour used in cake donuts (French 1977). 6% soy flour based on weight of mix is about 10% based on the weight of flour. The fractionationrecombination technique used did not alter the ability of the soy flour to reduce fat absorption. Analysis of variance showed no significant difference (5% level) in grams fat absorbed per gram solids not fat between the intact soy fours at the 6% (5.64% d.b.) replacement level and the recombined fractions at the level present in the intact soy flours (Appendix F).

Effect of Soy Flour. A preliminary study with 30, 69, and 80 PDI soy flours at the 2, 6, and 10% replacement levels based on the weight of the mix showed a decrease in grams of fat absorbed with an increase in quantity of soy flour added (Appendix G). As PDI level of the soy flour decreased, fat absorption increased. The PDI level and the quantity of soy flour affect fat absorption by cake donuts. The multiple correlation coefficient for the linear relationship between PDI, quantity of protein added, and fat absorption was 0.96. This indicates that 93% of the variability in fat absorption can be accounted for by PDI, quantity of protein added and the interaction bewteen PDI and quantity of protein added. An empirical linear regression model was developed to express the predicted fat absorption by cake donuts as a function of PDI and quantity of protein added (Appendix H). SAS/graph was used to generate a three dimensional graph showing this relationship (Figure 1).

Effect of Soy Flour Fractions. Because fat absorption was affected by the PDI level, it appeared that protein solubility of the soy flour might affect fat absorption. To determine the effect of protein solubility, soy flour fractions separated by

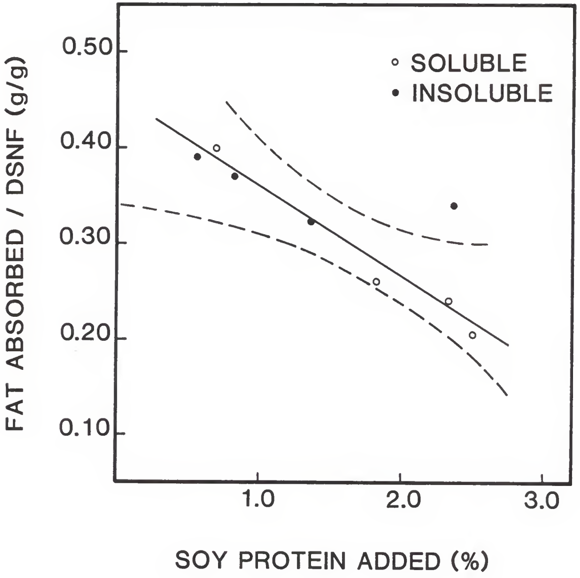
Figure 1. Response Surface Graph of the Linear Relationship between the quantity of soy protein added, protein dispersibility index, and grams fat absorbed per gram donut solids not fat.


FAT ABSORBED / DONUT SOLIDS NOT FAT (g/g)
0.44
0.29
0.15
5.5
3.7
1.8
0.0
SOY PROTEIN ADDED (%)
30
52
74
96
PDI

the PDI procedure were added to the donut mix at the level present in the intact soy flour at the 6% replacement level (Appendix I). It appears that whether or not the soy protein is soluble by the PDI procedure, the relationship between grams of fat absorbed per gram donut solids not fat and quantity of protein added (Figure 2) is not affected. The regression line has a correlation coefficient of 0.85. The 95% confidence interval is plotted by the dashed lines. One point, corresponding to the 30 PDI insoluble fraction, lies outside the confidence interval. It appears that during processing, the 30 PDI flour received sufficient heat treatment to significantly alter the solubility as well as functionality of the protein. Excluding the 30 PDI data from the analysis, resulted in a correlation coefficient of 0.98 for the relationship between fat absorption and quantity of protein added. The high correlation indicates that PDI solubility of the soy protein may not affect the relationship between fat absorption and quantity of soy protein added.

Effect of Protein Solubility. To further test the hypothesis, fat absorption by donuts prepared from batters containing equivalent quantities of protein of different solubilities on a dry solids basis were compared. 80 PDI soluble and insoluble fractions from the PDI procedure were compared as well as 30 PDI fractions. Results are shown in Table III. No siginificant difference was found in fat absorption between donuts containing 2.36% 80 PDI soluble protein and donuts with the same quantity of 80 PDI insoluble protein. However, the 30 PDI fractions were

Figure 2. Relationship Between Grams of Fat Absorbed per Gram of Donut Solids Not Fat and Quantity of Soy Protein Added. Standard deviation among means ranged from 0.005 to 0.012 g Fat Absorbed / g Donut Solids Not Fat.



FAT ABSORBED / DSNF (g/g)
0.50
0.40
0.30
0.20
0.10
1.0
2.0
3.0
SOY PROTEIN ADDED (%)
○ SOLUBLE
● INSOLUBLE

Table III. Effect of PDI Solubility of Protein on Fat Absorption.

PDI	Fraction	Protein Level[a] (% d.b.)	gFA/gDSNF[bc]
80	Soluble	2.31	0.24
	Insoluble	2.31	0.25
30	Soluble	2.36	0.26
	Insoluble	2.36	0.34

[a] Protein = N x 6.25

[b] Grams fat absorbed per gram donut solids not fat.

[c] Standard deviation = 0.012 gFA/gDSNF.

significantly (5% level) different. The 30 PDI soluble fraction at the 2.31% protein level was as effective as the 80 PDI fractions in decreasing fat absorption. It appears that the quantity of protein present is the major factor affecting the ability of soy flour to decrease fat absorption by cake donuts. Whether or not the protein has been PDI insolubilized by mild heat treatment does not affect the ability of soy flour to decrease fat absorption. This indicates that changes in the soy protein conformation due to the unfolding of the protein during heat treatment may not affect the functionality of the soy protein to decrease fat absorption. Severe heat treatment, as in the processing of the 30 PDI soy flour, diminishes the ability of the PDI insoluble protein to reduce fat absorption, however the PDI soluble fraction retains its functionality.

Effect of Non-Protein Material in Soy Flour. Laboratory analysis of the flours and their fractions for protein provided data for calculation of the quantity (g) of non-protein soy flour contained in the donuts. No siginificant relationship was found between the grams of non-protein material in soy flour added and grams of fat absorbed per gram donut solids not fat. Correlation coefficient for the relationship was 0.33. Because protein was not isolated from the soy flour fractions, this does not prove that the non-protein portion of the soy flour does not correlate with fat absorption. Within this study, the quantity of non-protein soy flour present in the donut correlates poorly with fat absorption.

Effect of Quantity of Soy Protein Added. The model comparison method (Draper and Smith 1981) revealed that at or below the 3% level of soy protein (equivalent to 6% soy flour) added the relationship between fat absorption and quantity of protein added for soy flours with a PDI of 69 or more can be adequately explained by one line as shown in Figure 3. Because there was no significant difference in fat absorption by cake donuts containing either 69, 80 or 95 PDI soy flours at the level of replacement normally found in cake donuts, the decrease in fat absorption apparently is a function of the quantity of protein added. Only at levels approximating 10% did the effect of PDI on fat absorption become apparent.

Effect of Donut Volume. From observations made on the fried donut, it appeared that fat absorption decreased by two methods - a reduction in the surface area exposed to the frying fat and a slower rate of diffusion of fat into the donut (Figure 4). Because volume and surface area of the donut have been reported to affect fat absorption (Denton 1920), we sought to determine if the reduction in fat absorption could be explained by the decrease in volume due to the addition of soy flour. Analysis of variance revealed that variations in volume could only explain 79% of the decrease in fat absorption, where as 93% of the variation in fat absorption could be explained by the quantity of soy protein added. This suggests that the reduction in fat absorption might be more complex than merely the reduction in the amount of surface area exposed to the frying fat.

The mechanism by which soy protein functions to decrease fat

Figure 3. Effect of Quantity of Protein Added (%d.b.) on Grams of Fat Absorbed per Gram of Donut Solids Not Fat by Cake Donuts. Intact soy flours, PDI soluble and insoluble fractions below 3.25% protein replacement level are included in the graph. Standard deviation among means of replicates ranged from 0.005 to 0.012 gFA/gDSNF.

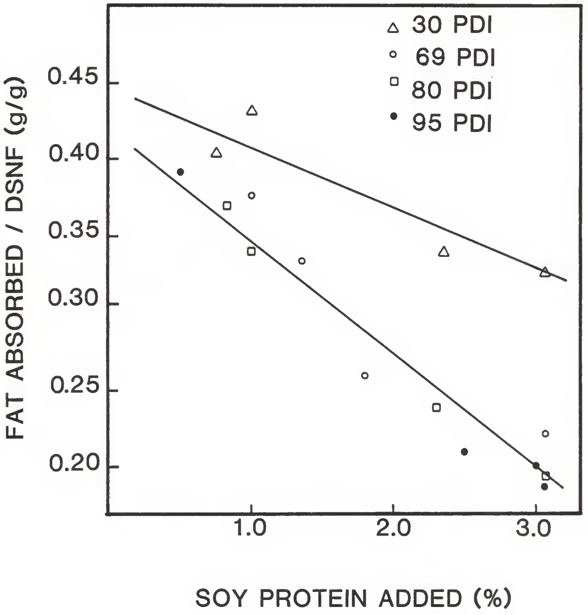

30 PDI
69 PDI
80 PDI
95 PDI
0.45
0.40
0.35
0.30
0.25
0.20
1.0
2.0
3.0
FAT ABSORBED / DSNF (g/g)
SOY PROTEIN ADDED (%)

Figure 4. Photograph of the cross-section of cake donuts containing 0%, and 6% replacement level of 80 PDI soy flour.


6% SOY FLOUR
0% SOY FLOUR
CONTROL

absorption is not siginficantly influenced by either water absorption level of the batter, moisture loss during frying, or PDI solubility of the protein which received mild heat treatment. As in bread, soy protein may be responsible for a ruptured cell structure and thick cell walls in cake donuts. Ruptured cell structure may be the result of the interaction between gluten and soy protein. Gluten has elastic and extensible properties that soy protein does not have. During frying, heat denatures protein. The soy protein may denature before the gluten. As the gluten continues to expand, air cells may rupture where gluten and soy proteins interact. Lower volume may be the result of greater gas diffusion from the donut due to a ruptured cell structure. Lower fat absorption by cake donuts supplemented with soy flour may be the result of lower volume and thicker cell walls. Lower volume would decrease the amount of surface area exposed to the frying fat. Thick cell walls may slow the diffusion rate of fat into the donut.

Cystine may be responsible for the formation of disulfide bonds between soy protein and wheat gluten. More severe heat treatment as in processing the 30 PDI soy flour may destroy cystine to a greater extent. Donuts made with 30 PDI soy flour, may have a less rigid and/or tough cell structure compared to donuts made with higher PDI soy flours. The resistance to expansion may be less, and the volume may be greater. The diffusion rate of fat into the donut may be greater because of fewer collapsed cells. Therefore, fat absorption by donuts made with 30 PDI soy flour may be greater than that by donuts made with higher PDI soy flour when based on the quantity of protein added.

APPENDIX

Appendix A. Summary Statistics of the Reproducibility of the Procedure Used to Measure Apparent Viscosity

	Floor Time, minutes 5	10	15
Average [a]	6.45×10^5	6.83×10^5	7.16×10^5
Std. Dev.	2.87×10^4	2.76×10^4	1.90×10^4
C.V.(%)	4.5	4.0	2.7

[a] Apparent viscosity in centipoise, average of 4 replications.

Appendix B. Flow Diagram of Steps and Calculations Used to Obtain at Batter Weight

BATTER (g)
↓ lyophilized
BATTER (g) (α)
↓ vacuum oven dried
% Solids (β)
↓ fat extraction
% Fat (d.b.) (γ)

6 DONUTS (g)
↓ lyophilized
6 DONUTS (g) (A)
↓ vacuum oven dried
% Solids X (A) = Donut Solids (g) (B)

(B) ÷ 6 = Avg. Donut wt. (g) (C)
↓ fat extraction
% Fat (d.b.) X (C) = Fat (g) / Donut (D)

100 - (γ) = % Solids Not Fat (δ)

(C) - (D) = Donut Solids Not Fat (g) (E)

$\frac{(E)}{(\delta)}$ = Solids (g) / Donut (ε)

$\frac{(\varepsilon)}{(\beta)}$ = Batter (g) / Donut

APPENDIX C. Fat Content of Various Batters and Fried Donuts Determined by Ether Extraction and Acid Hydrolysis.

Sample Number	Acid Hydrolysis % d.b.	Ether Extraction % d.b.
1	9.9	8.4
2	44.6	43.3
3	10.4	8.4
4	40.3	39.9
5	6.4	4.1
6	27.5	25.1
7	10.9	9.1
8	52.4	50.8
9	10.5	8.7
10	51.7	51.3
11	10.0	8.8
12	32.1	31.4
13	10.5	8.8
14	35.0	33.4
15	8.3	5.9
16	8.3	8.5
17	8.3	8.3
18	8.7	6.3
19	31.2	29.6
20	8.1	6.3
21	31.2	30.0
22	8.6	6.6
23	30.0	28.5
24	8.8	6.4
25	8.3	6.6
26	8.5	6.7

Appendix D. Summary Statistics of the Variation in Batter Weights Between Treatments.

Source	degrees of freedom	Sum of Squares	Mean Squares	F-value
Model	19	13.6193	0.7168	1.05
Error	27	18.3700	0.6803	
Total	46	31.9893		

F-value (5% level) = 2.09 (Snedecor and Cochran 1980).

Appendix E. Summary Statistics of the Daily Variation in Fat Absorption by Cake Donuts.

Source	Degrees of Freedom	Sum of Squares	Mean Squares	F-value
Model	2	0.00047	0.00023	2.13
Error	6	0.00066	0.00011	
C. Total	8	0.00113	0.00034	

F-value (5% level) = 5.15 (Snedecor and Cochran 1980).

Appendix F. Effect of Recombined Soy Flours[a]

PDI	6% (gFA/gDSNF)[b]	Recombined (gFA/gDSNF)
95	0.19	0.20
80	0.19	0.21
69	0.22	0.20
30	0.32	0.32

[a] Standard deviation among means of replicates = 0.012 gFA/gDSNF

[b] Grams of fat absorbed per gram donut solids not fat

Appendix G. Effect of Soy Flours on Fat Absorption by Cake Donuts

PDI[a]	Replacement Level of total mix (%)	Soy Protein[c] Added (%)	gFA/gDSNF[d]
80	2	1.05	0.34
	6	3.16	0.19
	10	5.27	0.12
69	2	1.05	0.38
	6	3.16	0.22
	10	5.39	0.14
30	2	1.05	0.43
	6	3.14	0.32
	10	5.35	0.23
Control	0	0	0.50

[a] Protein Dispersibility Index

[b] As is moisture basis

[c] Dry basis

[d] Fat Absorbed per Donut Solids Not Fat (g/g)

Appendix H. Empirical Multiple Linear Regression Model[a] Expressing Fat Absorption by Cake Donuts as a Function of PDI[b] and Quantity of Soy Protein Added.

Variable	Component	Regression Coefficient
	Intercept	0.454779
X_1	PDI ÷ 100	-0.000642
X_2	Quantity of Soy Protein[c]	-0.022003
X_3	(PDI ÷100) times Quantity of Soy Protein	-0.000542

a Multiple R^2 = .93

b Protein Dispersibility Index

c Percent soy protein present in total mix.

Appendix I. Effect of Soy Flour Fractions on Fat Absorption by Cake Donuts

PDI[a]	Fraction	Replacement Level of total mix (% as is)	Soy Protein Added (% d.b.)	gFA/gDSNF[b]
95	Soluble	3.85	2.48	0.21
	Insoluble	1.78	0.55	0.39
80	Soluble	3.67	2.31	0.24
	Insoluble	1.97	0.85	0.37
69	Soluble	3.10	1.81	0.26
	Insoluble	2.54	1.35	0.33
30	Soluble	2.09	0.78	0.40
	Insoluble	3.56	2.36	0.34

a Protein Dispersibility Index

b Fat Absorbed per Donut Solids Not Fat (g/g)

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EFFECT OF SOY FLOUR ON FAT ABSORPTION BY CAKE DONUTS

by

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ABSTRACT

The use of soy flour in a cake donut formula affects water absorption by the batter and fat absorption by the donut. Soy flours with 80, 69, and 30 PDI values were used in preparation of cake donuts with 2, 6, and 10% replacement levels based on weight of mix. Soy flours were fractionated into PDI soluble and insoluble fractions. The fractions were used in the quantities present in the intact soy flour at the 6% replacement level. Grams of fat absorbed per gram of donut solids not fat were measured. Fat absorption varied linearly with PDI and with quantity of soy protein added. Over all PDI flours studied, fat absorption decreased with an increase in quantity of soy protein added. Protein solubility as determined by the PDI procedure had no affect on the relationship between fat absorption and quantity of protein added for donuts prepared with fractions from soy flours with 69 PDI or higher. When based on quantity of protein added, 30 PDI soy flour produced donuts that had significantly higher fat absorption. No significant relationship was found between fat absorption and moisture loss during frying, quantity of non-protein soy flour added, or batter moisture. The functionality of the 30 PDI insoluble fraction appeared most affected by the heat treatment received during processing.