The effect of dried distillers graions particle size on volume and alkalizing agents on pH and acceptability in dried distillers grains baked products
by Jill Kathleen Abbott

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Home Economics
Montana State University
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Abstract:
The addition of sodium bicarbonate (NaHCO3) to baked products containing DDG has shown an increase in product pH and volume to the standard product level in some products. Those products remaining with low volumes may have been the result of particle size of the DDG. Additionally, the extra sodium was considered a concern to those with hypertension. The sieving of ten bourbon DDG samples showed significant differences in particle size distributions ($P<0.05$). DDG sieve fractions in the ground and unground form were baked in quick breads and yeast breads at the 36% level and 33% level respectively. Four of the DDG samples were incorporated at these levels into quick and yeast breads in the unfractionated form both ground and unground. No significant difference was found among baked product volumes due to particle size distribution, sieve fraction size, or grinding of the DDG. Oatmeal muffins and yeast rolls containing 36% DDG and 33% DDG respectively in the ground and un ground form were rated in a consumer taste panel. Consumers found products with DDG acceptable whether the DDG was ground or not. Grinding or milling of the DDG may not be necessary to improve baking properties or to be acceptable by consumers.

Titration of calcium carbonate (CaCO3) against a DDG-distilled water slurry caused pH to rise only after excessive amounts of CaCOg had been added. The use of CaCOg in quick breads did not result in an acceptable final product. Four quick breads and four yeast breads were judged by a trained taste panel containing either full NaCl, reduced NaCl1 no salt, or KCl substitute. The products with KCl salt were unacceptable to panelists. The other three were similar in ratings and in preference and so were included in a consumer taste panel along with a standard bread with no DDG. The product with full NaCl was rated significantly lower than the other three products ($P<0.05$). Consumers may prefer DDG baked products containing reduced salt levels, particularly if extra sodium was added in the form of a neutralizing agent to the formula.

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in

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Jill Kathleen Abbott

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May 15, 1986
Date

Jacquelynn O'Palka
Chairperson, Graduate Committee

Approved for the Major Department

May 15, 1986
Date

Margaret Briggs
Head, Major Department

Approved for the College of Graduate Studies

May 21, 1986
Date

Henry L Parsons
Graduate Dean

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TABLE OF CONTENTS

	Page
LIST OF TABLES	viii
LIST OF FIGURES	xi
ABSTRACT	xii
INTRODUCTION	1
REVIEW OF LITERATURE	4
DDG Utilization	4
Sources of DDG	4
Nutritional Value of DDG	5
Products Formulated With DDG	7
Objectives of Research	16
MATERIALS AND METHODS	17
Distillers' Dried Grains	17
Particle Size Determination	17
DDG Grinding	18
Chemical Analysis of DDG	18
Titration of Alkalizing Agents	19
Product Preparation	20
Yeast Breads	20
Quick Breads	21
Physical Analysis of Baked Products	24
Volume	24
pH	24
Percent Color Reflectance	24
Dough Stability	25
Organoleptic Evaluation	25
Trained Taste Panel	25
Consumer Panels	26
RESULTS AND DISCUSSION	28
Particle Size Distribution	28
Chemical Analysis of DDG	29
Proximate Analysis	29
Lipid Composition	32
Batch variability	32
Effects of frozen storage	38

TABLE OF CONTENTS - continued

	Page
Titration of Alkalizing Agents	40
Sodium bicarbonate titration	40
Calcium carbonate titration	42
Particle Size Effect on Volume	43
Quick Breads	43
Quick breads with 36% DDG sample K	43
Quick breads with 5% and 15% DDG sample K	46
Quick breads with 36% DDG samples A, B, and I	46
Yeast Breads	47
Yeast breads with 33% DDG sample K	47
Yeast breads with 33% DDG samples A, B, and I	49
Volume and Particle Size Distribution	49
Sodium Adjustments in Product Formulas	51
Quick breads	51
Yeast breads	52
Percent Color Reflectance	53
Color Reflectance in DDG Samples	53
DDG sample K fractions	53
DDG samples A, B, and I	54
Color Reflectance in Quick Breads	55
Oatmeal muffins with DDG sample K fractions	55
Oatmeal muffins with DDG samples A, B, and I	56
Oatmeal muffins with salt variations	57
Color Reflectance in Yeast Breads	57
Yeast rolls with DDG sample K fractions	57
Yeast rolls with 33% DDG samples A, B, and I	58
Yeast rolls with salt variations	59
Dough Stability	59
30% DDG, 70% Bread Flour	59
Salt Variations and 30% DDG, 70% Bread Flour	63
Organoleptic Evaluation	64
Particle Size Effect	64
Consumer taste panel, quick breads	64
Consumer taste panel, yeast breads	66
Salt Variations	67
Trained taste panel, quick breads	67
Trained taste panel, yeast breads	69
Consumer taste panel, quick breads	72
Consumer taste panel, yeast breads	72
Conclusions	74
REFERENCES CITED	77

TABLE OF CONTENTS - continued

Page

APPENDICES 83

Appendix A 84
Taste Panel Recording Sheets 84
Appendix B
Titration Curves and Quick Breads Using Calcium Carbonate 89

LIST OF TABLES

Table		Page
1	Yeast roll formulations with $NaHCO_3$ variations	20
2	Yeast roll formulations with salt variations	21
3	Oatmeal muffin formulations with $NaHCO_3$ variations . .	22
4	Oatmeal muffin formulations with alkalizing agent variations	23
5	Oatmeal muffin formulations with salt variations . . .	23
6	Particle size composition of bourbon DDG	29
7	Analysis of DDG samples	30
8	Triacylglycerol quality changes in relative percentage of fatty acid composition of DDG samples B-3 and K-3 .	38
9	Free fatty acid quality changes in relative percentage of fatty acid composition of DDG samples in B-3 and K-3	39
10	Levels of $NaHCO_3$ added to obtain standard product pH in DDG baked products	42
11	The effect of sieve fraction and grinding on volume and pH in oatmeal muffins containing 36% DDG sample K . . .	45
12	Volumes of oatmeal muffins utilizing 5% and 15% DDG sample K ground and unground	46
13	Volume and pH of oatmeal muffins utilizing DDG samples A, B, and I at the 36% replacement level ground and unground	47
14	The effect of sieve fraction and grinding on volume and pH in yeast roll containing 33% DDG sample K	48
15	Volume and pH of yeast rolls utilizing 33% DDG samples A, B, and I, ground and unground	49
16	Oatmeal muffin volumes and particle size distribution in sieve fractions 16 and 80 for DDG samples A,B,I, and K	50

LIST OF TABLES - continued

Table		Page
17	Yeast roll volumes and particle size distribution in sieve fractions 16 and 80 for DDG samples A, B, I and K .	51
18	Volume and pH in DDG oatmeal muffins with salt variations	52
19	Volume and pH in DDG yeast rolls with salt variations .	53
20	Percent color reflectance of DDG sample K fractions . .	54
21	Percent color reflectance of DDG samples A, B, and I .	54
22	Percent color reflectance of oatmeal muffins containing 36% DDG sample K fractions	55
23	Percent color reflectance of oatmeal muffins containing 36% A, B, and I DDG samples unground and ground	56
24	Percent color reflectance of oatmeal muffins containing DDG sample K with salt variations	57
25	Percent color reflectance of yeast rolls containing 33% DDG sample K fractions	58
26	Percent color reflectance of yeast rolls containing 33% DDG samples A, B, and I, unground and ground	59
27	Percent color reflectance of yeast rolls containing 33% DDG sample K and four salt variations	60
28	Farinograph values for yeast roll dough components of 70% bread flour and 30% DDG at various particle sizes .	61
29	Farinograph, DDG composition, and baked product values of yeast roll dough components utilizing DDG sample K of five particle sizes	63
30	Farinograph values for yeast roll dough components of three salt types and levels	64
31	Results of covariance analysis of muffins rating type sex and age interactions	65
32	Results of covariance analysis of yeast rolls rating type, sex and age interactions	66

LIST OF TABLES - continued

Table		Page
33	Analysis of variance results of paired comparison tests of oatmeal muffins with DDG and salt variations	67
34	Tukey's multiple comparison test results of paired comparison tests of oatmeal muffins with DDG and salt variations	67
35	Hedonic ratings of oatmeal muffins containing varying types and levels of salt	68
36	Judge effect on hedonic ratings of oatmeal muffins containing varying types and levels of salt	69
37	Analysis of variance results of Scheffe's model for paired comparison tests of yeast rolls with DDG and salt variations	70
38	Hedonic ratings of yeast rolls containing varying types and levels of salt	70
39	Judge effect on hedonic ratings of yeast rolls containing varying types and levels of salt	71
40	Results of covariance analysis of muffins rating type, sex and age interactions	72
41	Mean ratings of oatmeal muffins with salt variations by consumer taste panelists	73
42	Results of covariance analysis of yeast rolls rating type, sex and age interactions	74
43	Mean ratings of yeast rolls with salt variations by consumer taste panelists	74
44	Volume and pH of oatmeal muffins containing varying levels of $NaHCO_3$ and $CaCO_3$	93

LIST OF FIGURES

Figure		Page
1	Quantitative percentages of lipid fractions of DDG samples B, K and I	33
2	Triacylglycerol quality changes in relative percentage of fatty acid composition of DDG samples B, K and I . .	35
3	Free fatty acid quality changes in relative percentage of fatty acid composition of DDG samples B, K and I . .	36
4	Titration of baking soda ($NaHCO_3$) against DDG samples A, B, I, and K	41
5	Titration of calcium carbonate ($CaCO_3$) in dry gram weights against 112 g DDG sample K in 400 ml room temperature distilled water	90
6	Titration of calcium carbonate ($CaCO_3$) in dry gram weights against 20 g DDG sample D indistilled water at boiling temperature	91
7	Titration of .1N calcium carbonate ($CaCO_3$) against 50 g DDG sample K in 200 ml distilled water	92

ABSTRACT

The addition of sodium bicarbonate ($NaHCO_3$) to baked products containing DDG has shown an increase in product pH and volume to the standard product level in some products. Those products remaining with low volumes may have been the result of particle size of the DDG. Additionally, the extra sodium was considered a concern to those with hypertension. The sieving of ten bourbon DDG samples showed significant differences in particle size distributions ($P<0.05$). DDG sieve fractions in the ground and unground form were baked in quick breads and yeast breads at the 36% level and 33% level respectively. Four of the DDG samples were incorporated at these levels into quick and yeast breads in the unfractionated form both ground and unground. No significant difference was found among baked product volumes due to particle size distribution, sieve fraction size, or grinding of the DDG. Oatmeal muffins and yeast rolls containing 36% DDG and 33% DDG respectively in the ground and unground form were rated in a consumer taste panel. Consumers found products with DDG acceptable whether the DDG was ground or not. Grinding or milling of the DDG may not be necessary to improve baking properties or to be acceptable by consumers.

Titration of calcium carbonate ($CaCO_3$) against a DDG-distilled water slurry caused pH to rise only after excessive amounts of $CaCO_3$ had been added. The use of $CaCO_3$ in quick breads did not result in an acceptable final product. Four quick breads and four yeast breads were judged by a trained taste panel containing either full NaCl, reduced NaCl, no salt, or KCl substitute. The products with KCl salt were unacceptable to panelists. The other three were similar in ratings and in preference and so were included in a consumer taste panel along with a standard bread with no DDG. The product with full NaCl was rated significantly lower than the other three products ($P<0.05$). Consumers may prefer DDG baked products containing reduced salt levels, particularly if extra sodium was added in the form of a neutralizing agent to the formula.

INTRODUCTION

The main by-products of the beverage alcohol industries and of commercial ethanol production are distillers' dried grains (DDG) or brewers' spent grains (BSG). These by-products constitute a major disposal problem. The majority of DDG and BSG are used in animal feed with the remainder treated as refuse.

Corn or barley are the primary feedstocks used for fuel alcohol production, although wheat may be used, depending on the region of the United States. The brewing industry uses barley while the liquor distillers use a grain or fruit mixture. Bourbon, one of the major types of whisky produced in the U.S. (Packowski, 1963) must contain at least 51 percent corn in combination with rye and barley malt (Schoeneman, et al. 1971).

During the fermentation of these grains, most of the carbohydrate is hydrolyzed from the grains, leaving behind a solid wet residue (the "spent" grain). These residues are washed and dried in a grain dryer to produce DDG or BSG. Nutritional analysis of DDG has shown that during the fermentation process, starch reduction results in nearly a threefold concentration of protein, fat, fiber and ash. Research has indicated that dietary fiber in humans may help to prevent such diseases as diverticulosis, colon cancer, hemorrhoids, arteriosclerosis, varicose veins, and appendicitis (Burkitt and

Trowell, 1975). Therefore, researchers have experimented with the use of DDG in human food products to increase protein and fiber content.

Some success has been achieved using DDG in chemically leavened and yeast leavened baked products at low flour replacement levels, however, above 5 percent replacement, color, flavor, volume and texture have been major problems. Part of the difficulty is due to the acidic nature of the DDG, with pH's as low as 4.1. The use of higher than normal levels of sodium bicarbonate (baking soda, $NaHCO_3$) in quick breads and the addition of $NaHCO_3$ to yeast breads to neutralize the acidic DDG batters and doughs has partially helped to increase loaf volume and to improve the textures and flavors. High levels of sodium bicarbonate may not be desirable however, because in some people sodium contributes to the development of hypertension (U.S. Dept. of Health and Human Services, 1980). Substituting other alkalizing agents such as calcium and potassium salts or decreasing salt levels would reduce the increased sodium levels in these products and in the case of calcium, may contribute an additional important nutrient.

Analysis has shown that the high acidity of the DDG is not the only factor contributing to low volume. Gluten development is essential in yeast breads, and is very important in quick breads for optimum volume. Fiber in the dough or batter may cut the gluten strands and interfere with its development. Particle size in DDG varies widely from coarse, almost intact grains to finely ground flour-size particles. What effect the particle size range has on product quality is unknown.

Industry has created a surplus of DDG. This presents an ecological concern and contributes to its low cost. Its apparent human nutritional value, particularly as a fiber source has promoted the experimentation with DDG in human food products. To be acceptable to the consumer, the functional qualities of DDG such as volume must be improved.

REVIEW OF LITERATURE

DDG Utilization

At the present time, the major portion of DDG and BSG are used as animal feed as a fiber and protein source for both ruminants and nonruminants, such as swine (Newman and Gras, 1983). Smaller quantities of spent grain are used in mushroom compost production because of its high protein content (Townsley et al. 1979). The nutritional value of DDG and BSG has lead to experimental testing of both products in the human food supply. Both have been incorporated into various products, including: yeast breads, quick breads, muffins, cakes, cookies, snack food, pasta, cereals, granola and blended foods (Townsley, 1979, Finley, et al., 1976, Dawson, et al., 1984, Wall et al. 1984).

Sources of DDG

Dried distillers' grains (DDG) are the major by-product of the liquor distilling and fuel alcohol industries, while brewers spent grains (BSG) are the main by-products of the brewing industry. The properties of DDG depend on the particular processing techniques and the grain mixture used (Satterlee, 1976). In the United States, the choice of grain and processing methods depends on each distillers' preference as to the desired product within governmental specifications. Whiskies are a blend of corn, rye, malted barley and sometimes wheat. Most bourbon whisky distillers choose

proportions of 60% corn, 28% rye, and 12% barley malt. Beer is made from barley, while fuel alcohol may be processed from barley or corn or occasionally wheat, depending on grain availability and market price.

Processing methods vary in heating and drying temperatures used, acidity levels, and contaminants. Fuel alcohol DDG may not have as high a microbiological quality as brewer/distiller dried grains due to stringent processing requirements since the fermented liquid is not intended for human consumption (Townsley, 1974, Dawson et al. 1984). The various industries also produce a wide variation in DDG color, pH, moisture level and nutritional content (Tsen et al. 1982, Townsley, 1979).

Nutritional Value of DDG

Fiber content of DDG refers to the acid detergent or neutral detergent fiber depending on analysis method chosen. Neutral detergent fiber represents more of the crude fiber and so is generally considered to be more representative of total dietary fiber (Vetter, 1984). Analysis of DDG has shown that the fiber content ranges between 29 and 77 percent (Pomeranz, et al. 1976 Prentice and D'Appolonia, 1977, Finley and Hanamoto, 1980, Ranhotra et al. 1982).

Protein content varies depending on the grain used in processing, and on the processing methods. During protein analysis, incomplete recoveries of amino acids occurred causing lower "true" protein values in corn based DDG according to Ranhotra et al. (1982). Their samples were found to contain an average of 27.5% protein (N X

6.25). An all milo sample contained 34.9% protein. Ranhotra et al. (1982) suggested that nonprotein nitrogenous compounds, primarily from yeast, may have increased the total nitrogen content resulting in an overestimation of the protein content. These compounds may also have caused lower than satisfactory protein efficiency ratios (PER). The amount of yeast (and other products from the trub, which is a precipitate consisting mainly of protein, phenolic compounds, and lipids that is added to spent grain for disposal) in the DDG varies depending on processing methods (Prentice and D'Appolonia, 1977, Finley and Hanamoto, 1980).

Rats fed 10% protein diets had poor protein digestibilities (75.6%) when corn distillers grains (CDG) supplied the protein. This was thought to be due to the high fiber content of the diets. Digestibilities were as high as 93% when other proteins such as soy flour and non fat dry milk were added to the diet. CDG had low PERs but not as low as cornmeal protein. (Wall et al. 1984). Other mixed grain BSG have been reported to contain over 25% protein (Pomeranz et al. 1976, Prentice and D'Appolonia, 1977, Kissell and Prentice, 1979).

On a weight basis, the essential amino acid content has compared favorably with foods such as whole wheat flour destined for similar food uses (Prentice and Refsguard, 1978, Prentice and D'Appolonia, 1977). Wu et al. (1984) found the protein contents of hard wheat fermentation products to be higher than those products from corn, while the fat content was lower. Significant increases in lysine, threonine and isoleucine were observed for wheat distillers' grains compared with wheat, which is deficient in lysine and low in threonine

and isoleucine. Fermentation does not seem to improve nutritional qualities in corn DDG. Wall et al. (1984) found corn distillers grains (CDG) to be low in lysine and tryptophan but the lysine level was similar to that of whole corn protein. In other analyses of corn distillers' dried grains with solubles (CDDGS) amino acid composition was similar to that of corn (Wu et al. 1981).

Ranhotra et al. (1982) found carbohydrates (mainly starches) left in the spent grains at levels of up to 25.3%. Fat content ranged from 6.3 to 11.5%. Brewers spent grains have been found to be low in highly soluble minerals (ash measurement), such as potassium and low in B vitamins due to leaching out during wort production and during drying of the wet spent grains (Pomeranz et al. 1976). Ranhotra et al. (1982) however, found high levels of nutritionally significant minerals such as potassium, phosphorus, magnesium, zinc, copper and chromium. High levels of some vitamins, particularly thiamin, riboflavin and niacin were also found. The values of these nutrients are similar to those found in bran fractions of grains.

Products Formulated With DDG

DDG have been incorporated in a number of food items, especially baked products including yeast breads, quick (chemically leavened) breads and cookies. At levels above 5%, DDG replacement of flour significantly alters the color, flavor and baking performance in these products.

The high fiber content of DDG increases its water absorption capacity (Dreese et al. 1982). Work in our laboratory with bourbon

DDG showed that unless the formula chosen already incorporated whole grains, an increase in absorption was necessary to achieve a more desirable product. In quick breads, 0.5 ml. of water per gram of DDG used was added to successful formulations.

Incorporation of DDG in baked products has resulted in a darker color of the item even at levels as low as 6% (Finley and Hanamoto, 1980). Degree of darkening depends on the color of the DDG which is determined by the starting materials and the processing methods (Tsen, et al. 1982). Differences in color were noted by taste panelists in toasted bread with 5% and 10% DDG levels, but were not considered objectionable.

DDG has been more successfully incorporated in quick breads because they are often highly colored and flavored products. Finely milled spent grain was acceptable at 10% and 15% flour replacement levels in muffins containing a highly pronounced flavoring component (Prentice, 1978, Eidet et al. 1984a). Bourbon DDG at a level of 40% was found acceptable in a highly flavored quick bread (O'Palka and Eidet, 1986). Tsen et al. (1982) found that two different DDG resulted in differing acceptabilities in cookies where flour was replaced with 15% and 25% DDG. Highly flavored cookies (bar, spice and chocolate chip) were acceptable by panelists with the DDG, although average cookie diameter was reduced. White sorghum DDG was acceptable in molasses cookies at flour substitution levels up to 50%, and up to 15% replacement was acceptable in sugar cookies (Morad et al. 1984).

Oatmeal cookies with 15% defatted barley DDG were found equally acceptable to control oatmeal cookies (Dawson et al. 1984), suggesting

that the fat content of DDG may have contributed to the flavor. Further quantitative and qualitative analysis of this barley DDG lipid showed that extensive hydrolysis and decomposition of unsaturated fatty acids occurred during DDG processing (Dawson et al. 1984, Eidet et al. 1984b). Subsequent work indicated that degradation of neutral lipid occurred throughout processing (of industrial ethanol). Triacylglycerol levels were decreased and free fatty acid levels were increased. Unsaturated fatty acids, especially linoleic acid were degraded. This hydrolysis of triacylglycerols to free fatty acids (FFA) is undesirable. The FFA may have combined with the chemical leavening agent in the baked products which may have caused soap formation, causing some of the off flavors in these DDG products. A consumer taste panel found granolas containing 7.5% barley DDG, defatted DDG, or the parent barley to be equally acceptable (Dawson et al. 1984). Granola contains no leavening agent. Bookwalter et al. (1984) also found improved flavor in blended foods containing CDG from which the lipid had been extracted. Water washing the CDG to remove residual solubles produced improved flavor ratings of the blended foods containing CDG.

Bourbon distillers often use careful low temperature processing and good sanitation standards which may prevent lipid degradation in the resultant DDG. Work in our laboratory showed minimal lipid degradation in bourbon DDG (O'Palka and Eidet, 1986). Small amounts of neutral lipid degraded but the major portion of lipid in DDG was in the triacylglycerol (TAG) form. Small amounts of monoacylglycerols (MAG) and diacylglycerides (DAG) and free fatty acids were present.

Therefore, the lipid ratios were similar to those found in intact cereal grains.

Recent work in our laboratory has shown that consumer taste panels found carrot-coconut breads containing 40% bourbon DDG and yeast and nut rolls containing 33% DDG acceptable (O'Palka and Eidet, 1986). The breads were judged acceptable only when the typically acidic (pH 4.1) levels were neutralized with increased amounts of sodium bicarbonate in the formulations. Without added sodium bicarbonate, the acidic pH levels caused sour, unacceptable flavors. Increasing the pH to standard control levels also improved otherwise low loaf volumes which has been a major problem with DDG in baked goods. The final acidity or alkalanity of a batter or dough affected the performance of proteins. If too acidic, low volumes, close textures and sour tastes resulted. If too alkaline, higher volumes, coarser textures, and bitter tastes resulted.

Adding sodium bicarbonate to yeast and chemically leavened DDG products brings the pH to an acceptable level but markedly increases the sodium content of the product. This may be undesirable for some consumers since increased sodium intake is associated with some forms of hypertension (U.S. Dept. of Health and Human Services, 1980). Of the average total intake of sodium chloride (NaCl), 26% is supplied in the form of salt from baked goods and mixes (SCOGS-102, 1979). Other alkalizing agents besides sodium bicarbonate exist but many are too expensive, contribute undesirable flavors, contribute more sodium or cause technological problems (Vetter, 1981).

Salt is needed in bakery products for more than its flavor value. Salt strengthens the gluten in bread dough, controls fermentation rates, acts as a preservative, and reduces the water absorption in bread doughs. An alkalizing agent or a salt substitute is needed that when in combination with the existing leavener of sodium bicarbonate or yeast will help to neutralize the acidity of the baked product, not disrupt baking properties, and will not contribute excess sodium.

Breads containing potassium salts may be beneficial to those sensitive to sodium (Parfey et al. 1981). Potassium bicarbonate may be a viable substitution for sodium bicarbonate. It is imported from France at an extremely high cost (Vetter, 1981). Potassium chloride (KCl) alone has been reported to impart unacceptable bitter flavors, and so has been mixed with sodium chloride (NaCl). This salt mixture is used by those who wish to decrease sodium intake, yet not be subjected to a bland (saltless) or bitter tasting product. Some success has been reported using these salt mixtures (Frank and Mickelsen, 1969, Stroh et al. 1985, Wyatt and Ronan, 1982). The extra intake of potassium resulting from the use of the NaCl and KCl salt mixtures does not exceed normal limits (Frank and Mickelsen, 1969).

Experiments with NaCl-KCl mixtures and with KCl alone have produced bread doughs with shorter proof and mixing times over NaCl alone (AIB, 1984, Stroh et al. 1985). No significant effect on dough rheology or baking performance was noted when NaCl was replaced with 40% KCl in wheat yeast breads (Salovaara, 1982a) and loaf volumes were not significantly affected by varying salt types or mixtures in the work done by AIB (1984). Stroh et al. (1985) did find higher volumes

in white pan breads with KCl-NaCl mixtures. Researchers have reported undesirable bitter flavors when using KCl alone or in mixtures. AIB (1984) however, reported a diminishing of the off-flavors with aging of the bread. Breads with KCl were preferred by taste panelists over breads without any salt (AIB, 1984). Frank and Mickelsen (1969) found that KCl contributed as much of a salty flavor as the NaCl portion of the mixture, but KCl alone was reportedly bitter. Salovaara (1982b) showed that replacement levels of salt at 5 and 10% of KCl in yeast breads did not affect the flavor of the breads. At 40% salt replacement significant off-flavors were reported. No difference in bread odor was noticed when 20% of the NaCl was replaced with KCl. Wyatt and Ronan (1982) rated breads generally acceptable that contained 1% KCl which replaced 50% of the NaCl. The off-flavors of potassium chloride may be masked when used in highly flavored products or in those containing the strong-flavored DDG.

Many stringent requirements exist for gas release rate during the leavening process. In chemically leavened products, only a few solid acids are commonly used as chemical leavening agents which meet these requirements. The general reaction is:

$$\underset{\text{(acidic salt)}}{HX} + \underset{\text{(soda)}}{NaHCO_3} \xrightarrow[\text{moisture, heat}]{} \underset{\text{(neutral salt)}}{NaX} + H_2O + CO_2$$

Combinations of two or more different types of leaveners are frequently used since no single leavener can supply the optimum rate in all cases (Kichline et al. 1970). Several calcium salts are commonly used but most are very acidic and thus would not help to

neutralize already acidic DDG products. Dicalcium phosphate dihydrate is one agent that is slightly alkaline at room temperature but it reacts too late in the baking cycle for most products. Calcium carbonate is a readily available, inexpensive, and well absorbed basic salt.

In yeast leavened products, the reaction is dependent on yeast fermentation:

$$\text{SUGAR} + \text{YEAST} \dashrightarrow \text{ALCOHOL} + CO_2$$

In these products, calcium and potassium salts would function as a neutralizing agent by raising the pH.

Besides facilitating gas production, leaveners also contribute to the internal structure of baked goods by their cationic or anionic effect on the other ingredients. Calcium salts may increase dough viscosity (Dubois, 1981). Calcium cations contribute to fine grain, thin cell walls, and increase resiliency in baked goods. Calcium cations are used as dough conditioners which strengthens the gluten crosslinking. An added benefit of calcium salt incorporation would be to increase the levels of calcium in the diet. Low calcium intakes have been implicated in the development of osteoporosis (Whedon, 1959, Chinn, 1981). Ranhotra (1981) found that in yeast leavened breads fed to rats, the calcium in the form of calcium sulfate or in nonfat dry milk was readily available and absorbed. The fiber and phytic acid did not have an adverse effect on absorption, since much of the phytic acid in wheat flour is broken down during the various steps in breadmaking.

Quick breads can tolerate higher levels of DDG than can yeast leavened products because they do not require well developed gluten. Gluten is a protein in wheat flour that is necessary for dough formation in yeast breads. Gluten is responsible for the formation of gas cells for shape, volume and texture of breads. Gluten absorbs water as do starch granules which helps keep baked products soft and fresh. During baking, gas cells stretch and expand, and the starch gelatinizes and absorbs water from the gluten to prevent cell wall collapsing. Additional fiber in yeast breads causes an increased strain on the gluten. Pomeranz (1977) found that at high fiber levels, volumes in bread loaves were significantly lower due to gluten dilution. The fiber disrupted the crumb structure of the bread loaves. Bread loaves were acceptable at a flour replacement level of 7% with wheat bran and cellulose. Lorenz (1976) found that fine triticale bran produced a better grain than coarse bran but loaf volumes were not affected.

Previous work has shown that as percent DDG increased, loaf volume decreased (Prentice and D'Appoloia, 1977, Dreese and Hoseney, 1982, Finley and Hanamoto, 1980, Pomeranz et al. 1976, Morad et al. 1984). At five, ten and fifteen percent levels of DDG substitution loaf volume decreased 0, 11 and 17% for Prentice and D'Appolonia (1977). This could partly be the result of decreased pH due to acidic DDG, or to increased viscosity due to water binding by the DDG.

Tsen et al. (1971) found that adding dough conditioners to protein-rich yeast bread formulations improved loaf volumes. Sodium-Stearoyl-2-Lactylate (SSL) was more effective than Calcium-Stearoyl-2-

Lactylate (CSL). The addition of 0.1 to 0.2 percent soybean lecithin (based on flour weight) to yeast doughs has improved baking properties (Eichberg, 1952). Lecithin, in addition to enhancing the lubricating action of shortening, also directly lubricates the gluten strands and enhances dough elasticity in products made with strong winter wheat flours and shortens the high extensibility of spring wheat flours.

Prentice et al. (1978) successfuly incorporated 15% milled DDG in cookies. They found that adding 1% soy lecithin with 15% DDG and 2% lecithin with 20% DDG improved cookie diameters. Pomeranz et al. (1969) found that sucroesters added to a yeast bread formula counteracted the loaf volume-depressing effect of high protein soy products.

Pomeranz et al. (1976) found that wheat bran decreased loaf volumes of yeast breads, but BSG decreased volumes even more. Crumb grain was also impaired with both fiber types. Dreese and Hoseney (1982) found volumes and mixing times to increase when SSL and shortening were added to yeast breads with DDG. This was due to delayed loaf setting times. When the milled BSG was soaked in water first, mixing time decreased. Prentice et al. (1978) suggested that suitable milling and fractionation of BSG might help to optimize fiber (and nitrogen) contents of particles in the flour-fineness range and that uniformly fine particle size might improve acceptability in cookies.

Wu and Stringfellow (1982) found that after sieving CDG, the protein content of CDG increased as particle size decreased. Fat contents were highest in the smallest particle size fraction through

an 80 mesh screen. Ash content was not altered with sieving. Higher fiber contents were observed in those fractions with larger particle size.

Volume in baked products is influenced by many factors including batter pH, leavening agents and fiber content of flour or grain. Investigating the influence of these and other factors in baked products using DDG will help to determine optimum levels necessary to produce acceptable products.

Objectives of Research

1. To determine particle size composition of ten bourbon dried distillers' grain samples by sieving
2. To determine the effects of particle size in dried distillers' grains on volume in yeast and chemically leavened products
3. To determine a uniform optimum range of particle size of dried distillers' grains required for optimum volume in yeast and chemically leavened products
4. To determine consumer acceptance of yeast and chemically leavened products containing dried distillers' grains and having defined particle sizes
5. To determine the replacement level of alkalizing agents for baking soda necessary to neutralize the pH of dried distillers' grains in yeast and chemically leavened products
6. To reduce sodium content so that it is no greater than the standard yeast and chemically leavened products, and to determine consumer acceptance of these products

MATERIALS AND METHODS

Distillers' Dried Grains

Nine different samples of bourbon DDG (A-I) were supplied by the Distillers Feed Research Council (DFRC). The tenth sample (K) was obtained in Kentucky by the research team. All initial work was done with K and then extended to include A, B, and I samples in physical and chemical tests and in some of the baking trials. These original DDG samples tested were designated B-1, K-1 and I-1. Data obtained on the original samples after one and one half years of frozen storage are referred to as DDG samples B-2, K-2 and I-2. Additional samples of B, K and I were obtained in Fall, 1985 and were designated B-3, K-3 and I-3. Midway through the research, it was learned that DDG samples B and K were from the same plant. They were continued to be treated as samples from different plants, however this information must be considered when analyzing the results.

Particle Size Determination

To determine the particle size composition of each DDG, a 100 g sample of DDG was separated on a nest of sieves (U.S. Standard Testing Series) at 16, 25, 35, 60, 80 and 100 mesh sizes by shaking for ten minutes on a Tyler Ro-Tap mechanical shaker (W.S. Tyler Co., Mentor, Ohio).[1]

[1] Mention of firm names or products does not constitute endorsement by Montana State University over others of a similar nature.

The particle size fraction refers to that portion of the sample remaining on top of the sieve. Multivariate analysis of variance was used to test for parallelism of particle size distribution between samples (SPSS, Inc., 1983).

DDG Grinding

Unfractionated DDG sample K and its selected sieve size fractions of 16, 35, 60, and 80 mesh were ground through a 1/2 millimeter screen on a Cyclone Sample Mill (Type KCL-24A2), UD Corporation, Fort Collins, Colorado. Unfractionated DDG samples A, B and I were ground for baking trials in the same manner.

Chemical Analysis of DDG

The following tests were performed on unfractionated DDG and sieve fraction sizes 16, 35, 60 and 80 for the two batches of B, I and K and for the one batch of unfractionated DDG sample A: neutral detergent fiber (NDF) according to Robertson and Van Soest (1977) as modified by Roth et al. (1982); acid detergent fiber (ADF) according to the Association of Official Analytical Chemists (AOAC) methods (1980); protein content using the Kjeldahl method (N X 6.25) (AOAC, 1970); lipid content by ether extract (AOAC, 1980); and ash content according to AOAC (1980). Quantitative and qualitative lipid analyses were performed on whole DDG samples used in products that underwent baking performance tests (B, I, and K). Triplicate measurements were obtained for batches 2 and 3 of DDG samples B, I and K in the qualitative measurements. Single measurements were obtained for all other analyses. Lipids were extracted using hexane by vacuum

filtration and evaporation under a nitrogen stream. Thin-layer chromatography (TLC) was used to separate the lipids into five bands (Dawson et al. 1984), and the fatty acid profile was determined using gas-liquid chromatography (GLC) (Eidet, 1984b). Analysis of variance (MSUSTAT, Lund, 1983, Snedecor and Cocharan, 1980) was used to compare differences in FFA composition between the two batches (2 and 3) of DDG samples B, I, and K.

Titration of Alkalizing Agents

Several methods were used to determine the amount of each alkalizing agent required to neutralize the acidic DDG. 1). Calcium carbonate (100 mg - 50 g portions) or $NaHCO_3$ (100-300 mg portions) was added in increments to a slurry of one cup (112-138 grams) of DDG samples A, B, I and K mixed with 400 milliliters of distilled water to determine the amount needed to neutralize the acidity of the DDG to pH 7.0. 2). A solution of .1N $CaCO_3$ was titrated in 50-200 milliliter increments against a mixture of 50 grams of DDG and 200 milliliters of distilled water. 3). Increments of 300 milligrams - 10 grams of $CaCO_3$ was titrated against a mixture of 20 grams of sample K DDG and 75 milliliters of distilled water at boiling temperature of 93.5° Centigrade (adjusted for altitude). The appropriate amounts of alkalizing agents ($NaHCO_3$ or $CaCO_3$) were then added to product formulations in addition to the normal leavening system.

Product Preparation

Yeast Breads

DDG samples A, B, I, and K were incorporated in the unfractionated state in both the unground and ground forms (Table 1). DDG sample K was incorporated at each sieve fraction in the unground and ground forms (Table 1). Four salt types and levels were incorporated into the yeast rolls (Table 2). The reduced salt level in roll C was used to compensate for the extra sodium added by the neutralizing agent, $NaHCO_3$.

Table 1. Yeast roll formulations with $NaHCO_3$ variations.

Ingredient	Roll Types	
	Control	33% DDG
Bread flour (g)	59	59
Whole wheat flour (g)	29	---
DDG (g)	---	29
Nonfat dry milk (g)	5.25	5.25
Shortening (g)	3.125	3.125
Sugar (g)	3.125	3.125
Salt (g)	1.375	1.375
Baking soda (g)[a]		1.05
Yeast (g)	1.31	1.31
Water (ml)	55	70
Water temperature (degrees C)	49	49

[a] Amount of soda in grams for each DDG sample is as follows: K = 1.05; A = 1.45; B = .87; I = .87.

The straight dough method was used to make the dinner rolls, replacing 33% of the total flour weight with the various forms of the DDG samples. In the experimental rolls, the DDG, shortening, 75% of the water, and the baking soda ($NaHCO_3$) were mixed with the paddle for five minutes at power 2 using a Kitchen Aid Mixer (Type K5SS, Hobart

Corporation, Troy, Ohio). Then the rest of the water, flour and the remaining dry ingredients were added. Following the first fermentation of thirty minutes, dough was shaped into 22 gram (Table 1) or 44 gram (Table 2) rosettes and allowed to proof again for thirty minutes. The rolls were baked in a conventional oven at 204° C.

Table 2. Yeast roll formulations with salt variations.

Ingredient	Roll Types[a]				
	Control	33% DDG			
		A	B	C	D
Bread flour (g)	470	470	470	470	470
Whole wheat flour (g)	232	---	---	---	---
DDG (G)	---	232	232	232	232
Nonfat dry milk (g)	42	42	42	42	42
Shortening (g)	25	25	25	25	25
Sugar (g)	25	25	25	25	25
Salt/salt substitute (g)	11	11	---	5.7	11
Baking soda (g)	---	8.4	8.4	8.4	8.4
Yeast (g)	10.5	10.5	10.5	10.5	10.5
Water (ml)	440	560	560	560	560
Water temperature (degrees C)	49	49	49	49	49

[a] Roll types as follows: A-Salt; B-No salt; C-Reduced salt; D-Salt substitute (KCl).

Quick Breads

Oatmeal muffins were mixed using the standard muffin method (Charley, 1982) and baked at 204° C in a conventional oven. The DDG, baking soda, and/or calcium salt and milk were soaked for 15 minutes, and were added to the oats and creamed ingredients before adding the flour and rest of the dry ingredients. The muffin batter was weighed out in either 16 g portions into 4.5 X 4.5 cm muffin cups (Table 3) or 60 g portions into 7.6 X 3.17 cm muffin cups (Tables 4 and 5).

DDG samples A, B, I and K were incorporated at a 36% replacement level for the oats and flour (Table 3). To test for the particle size effect on volume, these DDG samples were incorporated in the unfractionated state using both unground and ground forms. In addition, DDG sample K was incorporated at each sieve fraction in the unground and ground forms and in the unfractionated state both unground and ground at 5% and 15% replacement levels (Table 3).

Table 3. Oatmeal muffin formulations with $NaHCO_3$ variations.

Ingredient	Muffin Types			
	Control	5% DDG	15% DDG	36% DDG
Egg (ml)	12	12	12	12
Brown sugar (g)	26.5	26.5	26.5	26.5
Milk (ml)	62.5	69.6	69.6	69.6
Shortening (g)	15.75	15.75	15.75	15.75
Quick rolled oats (g)	18	26.5	20.5	12
White all-purpose flour (g)	31.25	29.5	29.5	29.5
Baking powder (g)	1.6	.8	.8	.8
Salt (g)	1.5	1.5	1.5	1.5
Baking soda (g)	---	.64	.64	[a]
DDG (g)	---	3	9	17.75

[a] Amount of soda in grams for each DDG sample as follows: K = .64, A = 1.065; B = .89; I = .89.

DDG sample K was incorporated at the 36% replacement level in the unfractionated, unground form to determine the effect of alkalizing agents other than $NaHCO_3$ and the effect of salt level and salt type variations on the baked product. Batches were baked to include no $NaHCO_3$, to include three levels of salt (NaCl) and to include one level of potassium chloride (KCl) (Tables 4 and 5). The reduced salt level in muffin C was used to compensate for the extra sodium added by the neutralizing agent, $NaHCO_3$.

After cooling, muffins and rolls were placed in freezer bags and frozen for 24 hours before physical tests were performed, or frozen until needed for taste panel evaluation.

Table 4. Oatmeal muffin formulations with alkalizing agent variations.

Ingredient	Muffin Types		
	No $NaHCO_3$	$NaHCO_3$	$CaCO_3$
Egg (ml)	24	24	24
Brown sugar (g)	53	53	53
Milk (ml)	139	139	139
Shortening (g)	31.5	31.5	31.5
Quick rolled oats (g)	24	24	24
White flour (g)	59	59	59
Baking powder (g)	1.6	1.6	1.6
Baking soda (g)	---	1.3	---
Calcium carbonate (g)	---	---	1.3, 2.6, or 3.9
Salt (g)	3	3	3
DDG (g)	35.5	35.5	35.5

Table 5. Oatmeal muffin formulations with salt variations.

Ingredient	Muffin Types[a]				
	Control	36% DDG			
		A	B	C	D
Egg (ml)	96	96	96	96	96
Brown sugar (g)	212	212	212	212	212
Milk (ml)	500	556	556	556	556
Shortening (g)	126	126	126	126	126
Quick rolled oats (g)	144	95	95	95	95
White flour (g)	250	237	237	237	237
Baking powder (g)	12.8	6.4	6.4	6.4	6.4
Salt/salt substitute (g)	12	12	---	8.5	12
Baking soda (g)	---	5	5	5	5
DDG (g)	---	142	142	142	142

[a]Muffin types were as follows: A-Salt; B-No salt; C-Reduced salt; D-Salt substitute (KCl).

Physical Analysis of Baked Products

Volume

Product volume was measured 24 hours after removal from the oven using the rapeseed displacement method. (Cathcart and Cole, 1938). Analysis of covariance, multi-factor and multivariate analysis of variance methods (MSUSTAT, Lund, 1983, Snedecor and Cocharan, 1980) were used to analyze the effects of particle size and salt types and levels on volume.

pH

A slurry was made by blending ten grams of each muffin or roll with 40 ml. of distilled water in a Waring Commercial Blendor (Type SJT, New Hartford, Conn.) for 30 seconds. The pH of this slurry was determined using a pH meter (Corning Scientific Instruments, Model 7, distributed by Van Waters and Rogers, Inc., Medfield, MA.). Triplicate measurements were performed on each batch.

Percent Color Reflectance

The percent reflectance of color for each muffin and roll and whole or fractionated DDG was determined using an Agtron reflectance spectrophotometer (M-500-A Magnuson Engineering, Inc., San Jose, CA.). Each baked product was blended for 30 seconds in an Osterizer (Galaxie Type, Oster Corporation, Milwaukee, Wisconsin) before color determinations were made. Triplicate measurements were performed on each batch.

Dough Stability

Stability of the yeast bread dough components was determined using a farinograph (Brabender Corporation, Rochelle Park, N.J. Type FT3, No. 438). A single measurement of stability was made for each formula that used ground or unground, unfractionated and fractionated DDG sample K at 30% flour replacement levels. Stability was determined once for each formula that incorporated 30% whole unground DDG sample K with salt, with decreased salt, and with the salt substitute of KCl. Multiple regression analysis (MSUSTAT, Lund, 1983, Snedecor and Cocharan, 1980) was performed to determine relations between percent water absorption and particle size; percent water absorption and protein content of the DDG fraction and valorimeter dough quality score values and baked product volumes at each particle size fraction.

Organoleptic Evaluation

Trained Taste Panel

The yeast rolls and oatmeal muffins containing 33% and 36% unground bourbon DDG sample K and either standard salt levels, no salt, reduced salt or a potassium-chloride salt substitute were judged in a screening taste panel by ten trained judges. A paired comparison test and a nine-point hedonic test were used for rating the samples (Appendix A). Judges rated coded samples in individual booths in a darkened room under 25 watt blue colored lights. Room temperature distilled water was provided for rinsing palates between samples. The judges consisted of 7 females and 3 males. Ages ranged from 21 to 37, with a mean age of 30.8 years. The Scheffe model for paired

comparison preference tests with Tukey's multiple comparison test was used to determine effects of treatment on preference (Gacula and Singh, 1984). This model allows for effects due to the order of presentation of items of a pair. Multifactor analysis of variance (MSUSTAT, Lund, 1983, Snedecor and Cocharan, 1980) was used to analyze judge and treatment effect on hedonic ratings.

Consumer Panels

Two consumer taste panels were conducted in the Main Mall Shopping Center in Bozeman, Montana. Untrained panelists recorded their age and sex and rated the yeast and quick breads using a nine point hedonic scale (Appendix A). The rolls and muffins were sliced and placed on coded trays. Room temperature distilled water was provided to rinse palates between samples. Only properly completed hedonic forms were tabulated. The first panel conducted on December 1, 1985, rated yeast breads and quick breads (oatmeal muffins) where 33% and 36% of the flour and oats were replaced with bourbon DDG sample K, both ground and unground. Judges were required to taste either the pair of muffins or the pair of yeast rolls, but not both, unless they desired. The yeast rolls were rated by 94 judges, of whom 63 were females and 31 were males. Ages ranged from 6 to 70 years old with a mean age of 26.9 years. The muffins were rated by 102 judges of whom 66 were females and 36 were male. Ages ranged from 5 to 82 years old, with a mean age of 29.4 years.

The second taste panel on December 7, 1985 was conducted to test yeast rolls and quick breads (oatmeal muffins) where 33% and 36% of

the flour and oats were replaced with the unground bourbon DDG sample K and either salt, no salt, or reduced salt were added. These were compared against a standard control with no DDG and with a normal salt level. Judges were required to taste either all four of the yeast roll samples or all four of the muffin samples, and were allowed to taste all eight samples if they desired. The yeast rolls were rated by 96 judges, of whom 59 were females and 37 were males. Ages ranged from 5 to 74 years old, with a mean age of 30.13 years. The muffins were rated by 100 judges, of whom 61 were females and 39 were males. The ages of the judges ranged from 3 to 80 years with a mean age of 31.47 years.

Multivariate and covariance analysis of variance methods (MSUSTAT, Lund, 1983, Snedecor and Cocharan, 1980) were used to determine the effects of age and sex on roll or muffin preference. Multivariate and covariance analysis methods (MSUSTAT, Lund, 1983, Snedecor and Cocharan, 1980) were also performed to determine if type of roll or muffin, age or sex affected the rating of the products.

RESULTS AND DISCUSSION

Particle Size Distribution

As shown in Table 6, multivariate analysis of variance found significant differences ($P<0.05$) in particle size distribution among all ten samples of DDG (A-I). As sieve size number increased, the mesh opening and thus the particle size decreased. Sample C may have been ground, as it appeared much finer than the other samples, which would explain the large percentage of material in the sieve 35 fraction size.

The same test of parallelism was performed to compare differences between two batches from the same plant for DDG samples B-1 versus B-3, K-1 versus K-3, and I-1 versus I-3. Statistically significant differences ($P<0.05$) were found in particle size distribution in all three comparisons, particularly for sample K, although the differences may be of minor practical significance.

The percent distribution of each sieve fraction was averaged among DDG samples A, B, and I and compared to DDG sample K distribution, The average of A, B, and I particle size distribution was significantly different ($P<0.05$) from sample K as shown in Table 6. These results indicate that variation in grain composition and processing methods among producers of bourbon, resulted in DDG with varying particle size distributions. Differences may exist among batches in the same plant.

Table 6. Particle size composition of bourbon DDG.

	Percent DDG on Top of Sieve						
Sieve Size	16	25	35	60	80	100	throughs
Mesh Size	14	24	32	60	80	100	> 100
DDG Sample							
A	35 ±2	31 ± .8	16 ± .2	13 ±1	2 ± .3	.2 ±.3	.5 ±.9
B-1	19 ±1	36 ±2	22 ± .4	19 ±1	4 ± .1	.3 ±.4	.5 ±.8
B-3	22 ±3	39 ± .5	22 ±1	14 ±2	1 ± .3	trace	trace
C	2 ± .2	10 ± .1	71 ±3	12 ±4	1 ± .8	.1 ±.2	1 ±.8
D	7 ±1	26 ±2	28 ± .3	34 ±2	5 ± .5	.6 ±.2	.2 ±.4
E	17 ± .4	31 ± .5	24 ± .5	24 ± .4	5 ± .2	trace	trace
F	26 ± .6	32 ±3	22 ±1	17 ± .8	.6± .5	trace	trace
G	2 ± .4	20 ± .9	26 ± .2	38 ± .4	11 ± .5	2.0 ±.3	2 ±1
H	15 ± .3	28 ± .4	25 ± .3	28 ±2	4 ±1	trace	trace
I-1	7 ± .2	20 ± .2	20 ± .2	35 ±2	13 ± .8	.8 ±.3	2 ±2
I-3	7 ± .7	17 ± .9	18 ± .6	33 ± .7	24 ± .8	.6 ±.6	.1 ±.2
K-1	13 ±1	30 ±1	24 ± .8	27 ± .8	7 ± .3	trace	trace
K-3	8 ± .5	25 ± .4	26 ± .3	31 ± .3	7 ± .6	.9 ±.3	2 ±.4
A,B,I mean	12	21	13	18	6	.3	.7

Chemical Analysis of DDG

Proximate Analysis

The chemical composition of the unfractionated DDG samples were quite similar, except for the fiber content, based on two analyses per sample (Table 7). Sample I had a much higher fiber content (NDF and ADF) than did the other samples. Samples K and B were produced at the same plant, although they may have undergone different fermentation times. Batch K-1 is known to have undergone a 4-day fermentation, however, it had the higher pH. The original grains used and differences in processing may have resulted in DDG samples with varying pH's and chemical composition.

Table 7. Analysis of DDG samples[a].

DDG Sample	Dry matter %	Protein %	Ether extract %	NDF %	ADF %	Ash %	pH
B-1							
unfractionated	88.5	26.6	7.7	36.4	11.1	4.0	4.05
sieve 16	89.6	25.6	10.8	30.7	8.8	4.0	
sieve 35	89.8	26.7	8.1	32.5	10.0	4.0	
sieve 60	89.7	27.2	6.8	33.2	11.5	4.0	
sieve 80	91.1	29.7	5.3	30.9	b	b	
B-3							
unfractionated	91.3	26.4	9.8	29.8	9.8	3.8	4.05
sieve 16	91.3	24.5	10.7	30.0	10.2	3.8	
sieve 35	91.7	26.6	9.1	30.4	11.0	3.8	
sieve 60	91.6	27.8	8.1	30.5	10.3	3.8	
sieve 80	91.4	27.7	6.5	35.0	14.8	4.0	
K-1							
unfractionated	90.9	26.9	7.3	35.2	13.1	4.1	4.30
sieve 16	90.2	24.0	11.7	32.1	11.4	3.9	
sieve 35	90.2	25.4	8.1	34.1	11.9	4.0	
sieve 60	90.1	26.9	7.2	34.5	12.8	3.9	
sieve 80	90.4	30.7	6.6	27.6	10.7	4.3	
K-3							
unfractionated	91.8	25.4	8.1	35.5	12.9	3.5	4.0
sieve 16	91.6	23.2	9.3	33.6	11.2	3.6	
sieve 35	91.7	24.7	8.3	38.0	11.9	3.5	
sieve 60	91.6	27.9	7.0	36.7	12.9	3.5	
sieve 80	91.6	29.0	6.9	32.8	12.1	3.9	
I-1							
unfractionated	93.1	25.5	8.9	46.7	19.3	3.3	4.05
sieve 16	93.9	16.0	5.1	60.5	21.0	1.6	
sieve 35	92.8	25.8	10.7	46.7	18.2	2.7	
sieve 60	91.6	33.1	9.7	34.2	15.0	4.0	
sieve 80	90.7	34.3	8.1	20.9	10.5	5.8	
I-3							
unfractionated	92.8	26.4	9.8	46.7	19.1	3.8	3.83
sieve 16	94.0	12.9	5.8	63.7	22.7	1.7	
sieve 35	93.3	22.9	9.8	48.6	15.8	2.8	
sieve 60	92.1	32.3	10.9	33.1	13.6	4.0	
sieve 80	91.4	33.4	10.6	19.4	13.3	5.6	
A							
unfractionated	88.2	24.4	8.3	33.3	12.2	3.8	3.86

[a]The standard deviation was 2.0% for the NDF and ADF, and 0.5% for all other analyses.
[b]There was not enough sample for analyses.

Sieving of DDG samples into four particle size fractions showed some consistent trends in chemical composition between samples, based on two analyses performed on each sample (Table 7). Samples B and K were produced at the same plant, so can be considered as replicates. In all samples, as particle size decreased from sieve number 16 to 80, the protein percent increased. The protein content of the sieve fractions of the DDG I samples had a greater spread than that found in the other DDG samples. In samples B and K, lipid percent (ether extract) decreased as particle size decreased. In sample I, lipid percent varied slightly among sieve fractions of both batches of I-1 and I-3.

NDF value varied among samples. In samples K-1, K-3, and B-1 NDF percent increased as particle size decreased, until the finest fraction size, sieve 80 when it decreased. NDF increased in the finest sieve 80 fraction of sample B-3. NDF decreased with decreasing particle size in both I-1 and I-3 samples. ADF values were affected similarly by particle size. Sample B-3 seems to have a higher percentage of fiber in the finest sieve fraction.

Dry matters in all samples appeared only slightly altered by sieving the DDG, although they slightly decreased with decreasing particle size in the I-1 and I-3 samples. Ash contents were quite similar among sieve fractions for all DDG samples, except in samples I-1 and I-3, where ash percentages increased with decreasing particle size.

Lipid Composition

Batch variability

A comparison of the quantitative (TLC) percentages of lipid fractions was made between the two batches (1 and 3) obtained for each of the three DDG samples (B, I and K), assuming an experimental error of ± 5%. Figure 1 shows considerable differences in the triacylglycerol (TAG) portion in all samples. DDG samples B and K are known to be from the same plant, although were treated as different. Both DDG batches B-3 and K-3 had a higher percentage of TAG than the DDG batches of B-2 or K-2. Concomitant decreases in the free fatty acid (FFA) and sterol ester bands were noted in B-3 and K-3 batches. DDG samples B and K were obtained from a plant that utilizes either a 3-day or a 4-day fermentation period, which was not specified except for DDG sample K-1. It was produced in a 4-day fermentation period. The 4.3 pH of K-1 is higher than the other B or K samples, which would not lend to speculation that longer fermentation times result in more acidic DDG samples. However, other factors in processing may have caused a more acidic DDG. The more acidic DDG may be more prone to acid hydrolysis. The FFA content was 9% lower in K-3 (pH 4.0) than in K-1 (pH 4.3), which may indicate acid hydrolysis occurred within the FFA of K-3 during processing.

Noticeable differences occurred between the two batches of DDG sample I. The TAG portion was 8% lower in the I-3 batch than in the I-1 batch. Increases were seen in the monoacylglycerol-diacylglycerol (MAG-DAG) and sterol ester bands. No appreciable differences were observed in the FFA band, even though the pH of I-3 (3.83) was lower

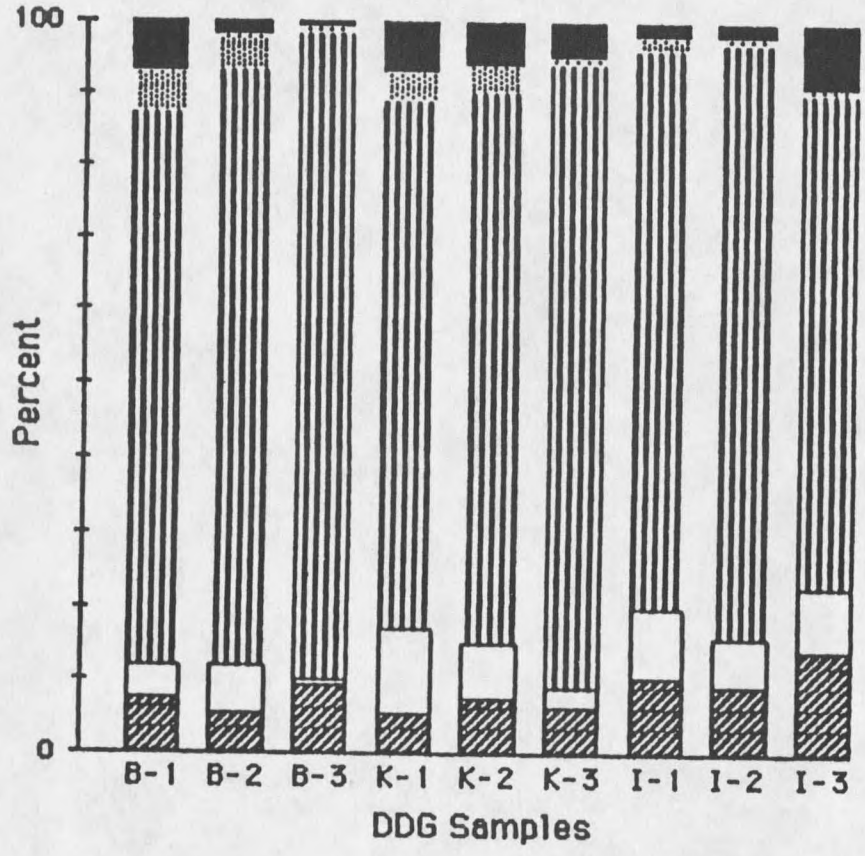


Figure 1. Quantitative percentages of lipid fractions of DDG samples B, K and I.

Standard deviation of each fraction = ± 5.0%

= Mono-diacylglycerols

= Free Fatty Acids

= Triacylglycerols

= Methyl-Ethyl Esters

= Sterol Esters

than the pH of I-1 (4.05). These differences may be due to the original grain used or subtle variations in processing. Given the approximately 5% variability due to experimental error in the TLC technique, these results must be treated with caution.

Comparison of the qualitative lipid composition in the TAG band among these two different batches (1 and 3) of each of B, I and K DDG samples showed no consistent trends, assuming a mean standard deviation of ± 1.0% (Figure 2). There was virtually no difference found among the two batches of sample B. K-3 and I-3 had less linoleic acid (18:2) than K-1 and I-1 by 8% and 9% respectively. There was 5% more oleic acid (18:1) in I-3 than in I-1. In the FFA band, slight differences were observed only among DDG samples K and I (Figure 3). Linoleic acid was lower by 5% and 12% in samples K-3 and I-3 respectively.

The lower levels of linoleic acid found in both the TAG and FFA bands of I-3 and K-3 batches compared to I-1 and K-1 may be a result of processing variations between batches. A higher oxidation rate in the second batches may have resulted in increased breakdown of linoleic acid from the TAG band to form secondary reaction products such as short-chained aldehydes, ketones and hydroxyl compounds. Percent dry matter of a material influences the degree of oxidation. Very dry food products (ie. percent moistures of about 2-5%) are more prone to oxidation. A slight increase in percent moisture retards oxidation, while further increases accelerate the process (Fennema, 1985). The percent moistures of these DDG samples varied slightly between batches, but were probably similar enough so that percent

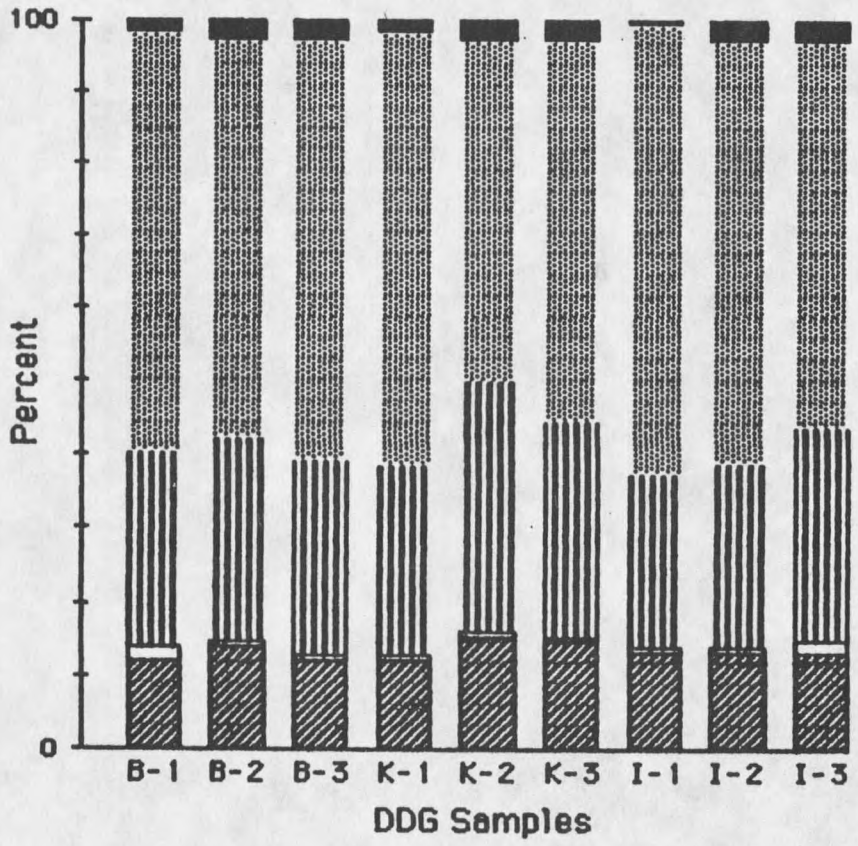


Figure 2. Triacylglycerol quality changes in relative percentage of fatty acid composition of DDG samples, B, K, and I.

Standard deviation of each fraction = ± 1.0%

= Palmitic (16:0)

= Stearic (18:0)

= Oleic (18:1)

= Linoleic (18:2)

= Linolenic (18:3)

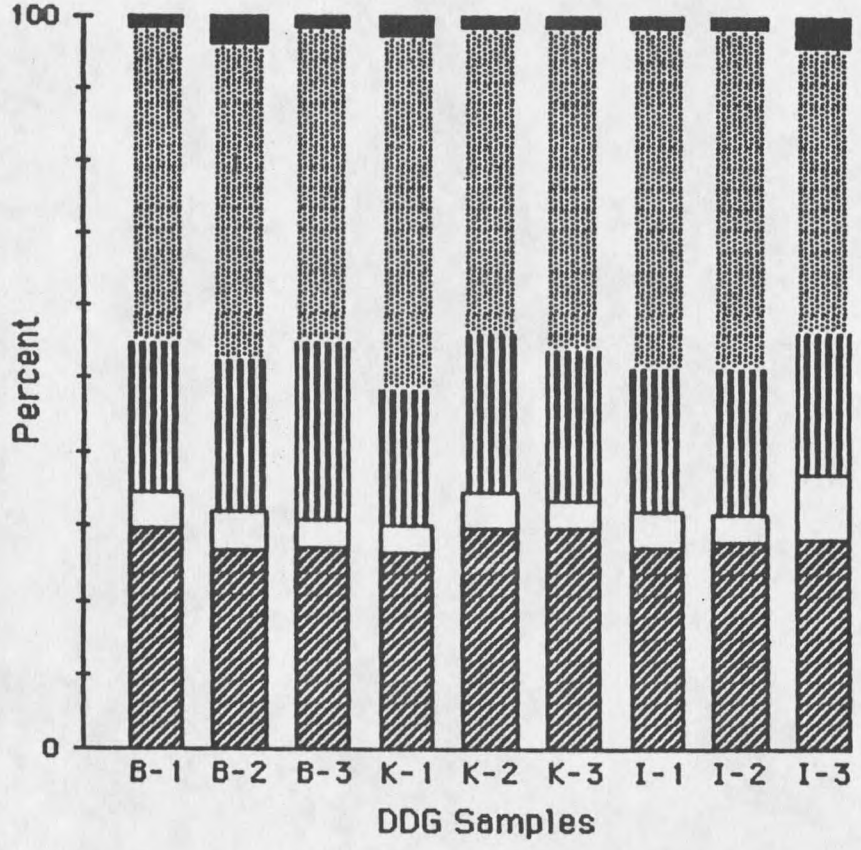


Figure 3. Free fatty acid quality changes in relative percentage of fatty acid composition of DDG samples B, K, and I.

Standard deviation of each fraction = ± 1.0%

= Palmitic (16:0)

= Stearic (18:0)

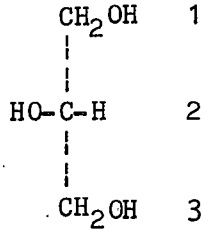
= Oleic (18:1)

= Linoleic (18:2)

= Linoleic (18:3)

moisture differences were not affecting the oxidation rate of the fatty acids. All samples were held in frozen storage which should have prevented them from being susceptible to oxidation from high temperature exposure. Processing variations at the plant may have caused the slight differences shown in free fatty acid composition between the two DDG batches from the same plant.

The placement of a specific fatty acid at each of the three positions on the TAG molecule is also important because fatty acids in the outer positions of the TAG molecule are more susceptible to oxidation (Barnes, 1983). The conventional stereospecific numbering of glycerol is as follows (Fennema, 1985):



Bourbon DDG consist primarily of corn. In corn oil, linoleic acid occupies either position 1 or 2 of the TAG molecule, which is determined by random distribution (Fennema, 1985). The variations shown in linoleic acid levels in the TAG bands could be due to its variations in placement on the TAG molecule. It may be that lower levels of linoleic acid resulted when it was present in the number 1 position on the TAG and was thus preferentially oxidized. The limitations of the TLC and GLC techniques may also explain the variations shown.

Treating samples B and K as different batches from the same plant, analysis of variance was performed to compare FFA percentage differences in the FFA band and in the TAG band between samples B-3 and K-3 (Tables 8 and 9). Comparisons could not be made between B-1 and K-1 due to lack of treatment replication. Significant differences were shown in palmitic acid, 16:0 ($P<0.05$) and linoleic acid, 18:2 ($P<0.01$) in the TAG band (Table 8). Batch K-3 contained less linoleic acid attached to acylglycerols than batch B-3. In the FFA band, significant differences were shown between palmitic acid ($P<0.01$) and between oleic acid, 18:1 ($P<0.01$) (Table 9). Batch K-3 had higher levels of palmitic acid and less free oleic acid than batch B-3. These results suggest that differences may occur in FFA content between two batches of DDG from the same plant, but given technique limitations, the differences may hot be of practical significance.

Table 8. Triacylglycerol quality changes in relative percentage of fatty acid composition of DDG samples B-3 and K-3.

	Fatty Acid Percent				
DDG Sample	Palmitic (16:0)	Stearic (18:0)	Oleic (18:1)	Linoleic (18:2)	Linolenic (18:3)
B-3	12 ± 1.0[a]	1 ± .02	26 ± .4	58 ± .7[b]	3 ± .1
K-3	14 ± .6[b]	1 ± .9	28 ± 2.6	52 ± 1.4[a]	3 ± .2

[ab]Values in the same column that do not share a common superscript differ significantly, $P<0.05$ for palmitic, and $P<0.01$ for linoleic.

Effects of frozen storage

Examining the effects of 1 1/2 years of frozen storage on the quantitative lipid composition of the DDG samples (1 and 2) revealed a consistent trend only in the TAG band (Figure 1). Increases in the TAG

band over storage time were of 6% in sample B, 3% in sample K, and 6% in sample I. These increases in TAG were offset by decreases in sample B by primarily the MAG-DAG and sterol ester bands, and in samples K and I by primarily the FFA band. These differences may be small enough to be considered a result of the expected 5% experimental error.

Table 9. Free fatty acid quality changes in relative percentage of fatty acid composition of DDG samples B-3 and K-3.

DDG Sample	Fatty Acid Percent				
	Palmitic (16:0)	Stearic (18:0)	Oleic (18:1)	Linoleic (18:2)	Linolenic (18:3)
B-3	26 ± .3[a]	4 ± .1	23 ± .3[b]	41 ± 1.5	2 ± .6
K-3	29 ± .8[b]	4 ± .1	20 ± .1[a]	44 ± .3	1 ± .5

[ab]Values in the same column that do not share a common superscript differ significantly, $P<0.01$.

Comparison of the qualitative lipid composition in the TAG band showed a consistent decreasing trend in linoleic acid among DDG samples (1 and 2) after storage time (Figure 2). Decreases of 5% in sample B-2, 13% in sample K-2 and 4% in sample I-2 occurred. In sample K-2 an 8% increase in oleic acid and a 3% increase in palmitic acid were also noted. Oleic acid content increased by 4% in sample I-2.

Comparison of the qualitative lipid composition in the FFA band showed no appreciable differences in FFA composition after 1 1/2 years frozen storage between DDG samples I-1 and I-2 (Figure 3). In DDG sample B, a 4% increase in palmitic acid and a two-fold increase in linolenic acid (18:3) were observed. A 7% decrease in linoleic acid

was shown after storage time in sample K-2. Linolenic acid was decreased by 1 1/2 times, although, as in the other DDG samples, this represents only a minor decrease, since linolenic acid is present in such small amounts.

It is likely that those differences found of 5% or less were due to technique limitations and that the quantitative lipid composition of the DDG samples remained quite stable during the frozen storage time in all three DDG samples. The larger percentage differences shown in free fatty acids may be real. The decreases of linoleic acid may be the result of its oxidation during storage. Some preferential oxidation of linoleic acid may have occurred if it was present in the number 1 position on the TAG molecule. It may have been further oxidized to form secondary reaction products.

Titration of Alkalizing Agents

Sodium bicarbonate titration

As indicated in Figure 4, DDG samples varied in the amount of baking soda ($NaHCO_3$) needed to raise their pH's. However, the gradual increasing trend was fairly consistent among samples. The amount of $NaHCO_3$ needed (112-138 g) to neutralize each DDG to pH 7.0 was 5,640 mg for sample K, 8,400 mg for sample I, 10,800 mg for sample B, and 12,000 mg for sample A. The amounts appeared dependent on the starting pH of the DDG sample before $NaHCO_3$ was added. That with the lowest sample pH (A) required the most $NaHCO_3$, and that with the highest sample pH (K) required the least $NaHCO_3$. The starting sample pH's were 3.7 for A, 4.0 for B, 4.05 for I, and 4.3 for K.

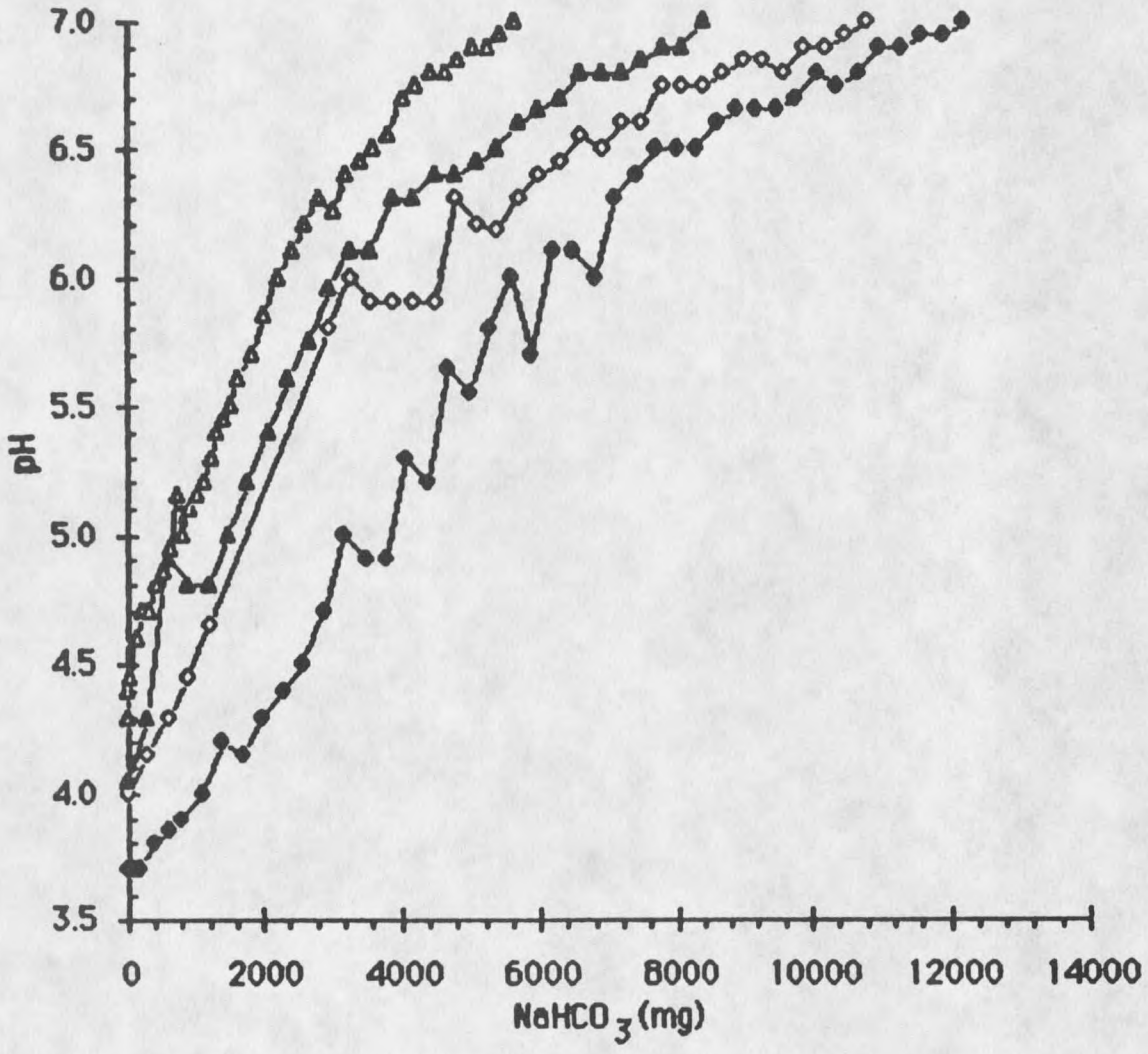


Figure 4. Titration of baking soda ($NaHCO_3$) against DDG samples A, B, I, and K.

◆ = A ◇ = B

▲ = I △ = K

Based on the titration curves, the amount of $NaHCO_3$ needed to achieve a product pH close to the standard was determined for each DDG sample per gram of DDG in the formula (Table 10). Those baked products incorporating DDG with lower pH's required more $NaHCO_3$ to bring their product pH up to the standard product pH. Amounts required ranged from .03 to .06 g $NaHCO_3$/g DDG.

Table 10. Levels of $NaHCO_3$ added to obtain standard product pH in DDG baked products.

DDG Sample	Weight of $NaHCO_3$ added to product per gram of DDG	
	Quick Breads (pH 6.57)	Yeast Breads (pH 5.92)
A	.06 g $NaHCO_3$	.05 g $NaHCO_3$
B	.05 g $NaHCO_3$	.03 g $NaHCO_3$
I	.05 g $NaHCO_3$	.03 g $NaHCO_3$
K[a]	.03 g $NaHCO_3$	.02 g $NaHCO_3$

[a]For sample K, .05 g $NaHCO_3$ per g DDG was actually incorporated in both products based on decision by previous researchers.

Calcium carbonate titration

Calcium carbonate ($CaCO_3$) is a known neutralizer of acids, as it increases pH, although it may decrease the volume of a baked product (Jackel, 1969). It is inert in baking and does not add available carbon dioxide to a baking powder (Conn, 1965). It was therefore, considered as a possible alkalizing agent for use in baked products utilizing the typically acidic DDG. It was discovered to be an ineffective alkalizing agent for DDG due to the large amounts found necessary to raise the pH of DDG.

$CaCO_3$ was titrated in three forms against DDG sample K (Appendix B). The addition in the dry gram weight form required 7.7 g of $CaCO_3$/g DDG to obtain the standard product pH in a yeast bread formula. In a boiling water medium, the $CaCO_3$ was fairly insoluble, requiring 26.8 g of $CaCO_3$ to raise the pH of 20 g of DDG from 4.75 to 5.25. The third titration of DDG using .1N $CaCO_3$ required 50 g/g DDG which also was unacceptable.

Particle Size Effect on Volume

Quick Breads

Quick breads with 36% DDG sample K

Oatmeal muffins were baked to determine the effects of particle size treatments (sieve fraction) and grind on volume (Table 11). Grinding the DDG had no significant effect on volume. The mean volumes among the five fractions were 22.29 cc ± 1.52 for the muffins baked with unground DDG fractions, and 22.35 cc ± 1.12 for the muffins baked with ground DDG fractions.

The particle size (sieve fraction) of DDG was not significantly associated with the volume of the baked muffin ($P>.05$). No statistically significant difference was found between volumes of any of the products baked with DDG or between the standard with no DDG ($P>0.1$). Subjective analysis of the volume means did indicate the products with DDG had lesser apparent volumes than the standard. The volumes ranged from 20 cc in the muffin baked with unfractionated, unground DDG to 26 cc in the standard muffin. The appearance of the standard muffin was more acceptable, as it was rounded, with even

crumb and texture. All muffins with DDG had a dense texture and were flat-topped. Reduced volumes in products with 36% DDG may be due to some other variable besides particle size of the DDG. It could be the result of less gluten available due to replacement of the flour with DDG.

The pH's were within a narrow range, since they had been adjusted by the addition of the neutralizing agent ($NaHCO_3$) to be close to the standard product. Neither NDF nor protein content of the DDG fraction had a significant effect on volume.

The lipid content of each fraction was shown to have a marginally significant effect (P=.044) on the volume of the baked muffin product. A linear contrast of lipid effect on volume for each fraction was performed to account for the discrepancies in the number of observations between lipid content and volume meaurements. This contrast found lipid to have no significant effect on volume. Lipids are known to influence the gas cell structure and stability in batters and doughs (Barnes, 1983). Lipid composition of the flour, as well as the proportion of lipid to protein content helps to determine the nature of the gas cell structure. This effect may influence the volume of the baked product. No consistent relationships have been found between lipid content of flours and baking performance, probably because of the dominant effect of protein quality differences. In oatmeal muffins, lipid added to the product formula in the form of shortening may have overcome any differences that the lipid content of the DDG and flour may have had (Barnes, 1983).

Table 11. The effect of sieve fraction and grinding on volume and pH in oatmeal muffins containing 36% DDG sample K.

DDG Sample	Volume[a] (cc)	Combined mean volume[a] (cc)	pH	Combined mean pH[a]
Unfractionated, unground	20 ± 2.3		6.49 ± .06	
Unfractionated, ground	21 ± 1.5		6.42 ± .1	
Combined		21a		6.45ab
Sieve 16, unground	23 ± 3.7		6.50 ± .02	
Sieve 16, ground	24 ± 2.9		6.46 ± .06	
Combined		24a		6.48a
Sieve 35, unground	22 ± 6.1		6.46 ± .05	
Sieve 35, ground	22 ± 4.7		6.46 ± .04	
Combined		22a		6.46a
Sieve 60, unground	24 ± 3.3		6.47 ± .02	
Sieve 60, ground	22 ± 4.0		6.36 ± .08	
Combined		23a		6.42ab
Sieve 80, unground	22 ± 1.9		6.32 ± .01	
Sieve 80, ground	23 ± 1.2		6.25 ± .09	
Combined		22a		6.28b
Standard, no DDG		26a ± 1.6		6.59a ± .05

[a]Volume and pH values are the means of three batches. Values in the same column that do not share a common letter (a,b) differ significantly, $P<0.05$.

The sieve fraction of DDG incorporated had a statistically significant effect on the pH of the baked muffin ($P<0.01$). The lowest product pH was found with that using the smallest DDG particle size (sieve 80). Grinding each sieve fraction produced a statistically significant effect on pH ($P<.05$). The mean pH of all unground fractions was 6.45 and the mean pH of all ground fractions was 6.39. Although statistically significant, the magnitude of the pH differences was not considered to be large enough to significantly affect product quality.

Quick breads with 5% and 15% DDG sample K

Oatmeal muffins were baked with DDG sample K at the 5% and 15% replacement levels in the unground and ground states. Mean volumes were analyzed to see if at lower levels of DDG replacement, particle size influenced volume (Table 12). Reducing the particle size of the DDG in the muffins by grinding did not change muffin volume significantly when compared to muffins baked with the unground DDG sample ($P>.05$). Mean volumes ranged from 102 cc to 103 cc.

Table 12. Volumes of oatmeal muffins utilizing 5% and 15% DDG sample K ground and unground.

DDG Level and Form	Volume[a] (cc)
5% unground	102 ± 5.4
5% ground	103 ± 4.2
15% unground	102 ± 4.1
15% ground	101 ± 6.8

[a] Volume values are the means of ten samples.

Quick breads with 36% DDG samples A, B, and I

The particle size effect of DDG on volume was tested in oatmeal muffins using three additional DDG samples (A, B and I) replacing 36% of the flour in both ground and unground forms. Volumes were not different between muffins baked with ground and unground DDG when using any of the three samples (Table 13). The grinding treatment did not significantly alter pH in muffins baked with any of these three DDG samples (Table 13).

Table 13. Volume and pH of oatmeal muffins utilizing DDG samples A, B, and I at the 36% replacement level ground and unground.

DDG sample	Volume[a] (cc)	pH[a]
A unground	35 ± .7	6.33 ± .01
A ground	33 ± .9	6.29 ± .10
B unground	33 ± .2	6.53 ± .08
B ground	32 ± 4.4	6.50 ± .09
I unground	35 ± 2.2	6.67 ± .03
I ground	34 ± 2.0	6.66 ± .08

[a]Volume and pH values are the means of three batches.

Yeast Breads

Yeast breads with 33% DDG sample K

Yeast rolls were analyzed to determine the effect of particle size (sieve fraction) and grind on volume (Table 14). Grinding the DDG fractions did not produce statistically significantly different volumes. The mean volumes among the five fractions were 42 ± 5.3 cc for the yeast rolls baked with unground DDG fractions and 44 ± 5.5 cc for the yeast rolls baked with ground DDG fractions.

Yeast roll volumes were not affected by the sieve fraction of DDG that was incorporated. A significant difference was measured between the volumes of the rolls using fractions of DDG and of the standard roll ($P<0.1$). The standard roll volume was 55 cc compared with the lowest DDG roll volume of 42 cc made with sieve fraction 16. Subjective examination of the standard yeast rolls showed them to have higher apparent volumes than those rolls using DDG. Although not statistically significant, all rolls using ground DDG had slightly higher volumes than all rolls using the same fraction of DDG unground,

except with rolls using the coarsest sieve fraction 16. No consistent trend in volumes was found however, from coarse to finest fraction.

Table 14. The effect of sieve fraction and grinding on volume and pH in yeast rolls containing 33% DDG sample K.

DDG sample	Volume[a] (cc)	Combined mean volume[a] (cc)	pH[a]	Combined mean pH[a]
Unfractionated, unground	41 ± 5.2		6.31 ± .09	
Unfractionated, ground	44 ± 9.0		6.28 ± .06	
Combined		43a		6.29a
Sieve 16, unground	43 ± 3.5		6.27 ± .06	
Sieve 16, ground	41 ± 1.2		6.26 ± .05	
Combined		42a		6.27a
Sieve 35, unground	40 ± 8.5		6.32 ± .08	
Sieve 35, ground	46 ± 6.8		6.31 ± .1	
Combined		43a		6.31a
Sieve 60, unground	43 ± 8.1		6.34 ± .03	
Sieve 60, ground	44 ± 4.9		6.25 ± .05	
Combined		44a		6.29a
Sieve 80, unground	41 ± 3.3		6.15 ± .04	
Sieve 80, ground	45 ± 6.2		6.12 ± .14	
Combined		43a		6.14b
Standard, no DDG	55 ± 8.7		5.92 ± .07	

[a]Volume and pH values are the means of three batches. Values in the same column that do not share a common letter (a,b) differ significantly, $P<0.05$.

Since no volumes were similar between yeast rolls incorporating the various DDG fractions, no significant effects were found on volume due to protein, lipid or fiber content or pH.

Difference in pH due to grinding the DDG were not significant, but fraction size of DDG did cause a difference ($P<.01$). Among the five DDG fractions, the finest of sieve 80 had the lowest pH (6.14) and is statistically different from all others in the LSD multiple comparison test. As with quick breads, incorporation of ground DDG or

of the finest sieve fraction resulted in a slight decrease in the pH of the baked product, but the pH's were not considered low enough to affect product quality.

Yeast breads with 33% DDG samples A, B, and I

The particle size effect of DDG on yeast roll volume was tested using three additional DDG samples (A, B and I) replacing 33% of the flour in both ground and unground forms. Volumes were not statistically significantly different between yeast rolls baked with ground and unground DDG when using any of the samples A, B, or I (Table 15). pH did not significantly affect product volume in any of the three DDG samples. As previously noted, the pH values were adjusted by the $NaHCO_3$ neutralizing agent to be within a range close to the standard product. The grinding treatment did not significantly alter pH in yeast rolls baked with any of these three DDG samples.

Table 15. Volume and pH of yeast rolls utilizing 33% DDG samples A, B, and I, ground and unground.

DDG Sample	Volume[a] (cc)	pH[a]
A unground	45 ± .9	5.83 ± .6
A ground	49 ± 2.8	6.12 ± .02
B unground	46 ± 6.4	6.17 ± .1
B ground	47 ± 5.7	6.09 ± .08
I unground	45 ± .7	6.00 ± .1
I ground	44 ± 4.6	5.97 ± .04

[a]Volume and pH values are the means of two batches for sample A, and three batches for samples B and I.

Volume and particle size distribution

Analysis of variance of the volumes of oatmeal muffins made with DDG samples A, B, I, and K found only muffins baked with sample K to

be significantly different from the others (Table 16). Muffins with sample K had the lowest volumes. This DDG sample K contained a higher percentage of the coarser particle size than did sample I, but it also contained more of the fine particle size than was found in samples A and B.

Table 16. Oatmeal muffin volumes and particle size distribution in sieve fractions 16 and 80 for DDG samples A, B, I, and K.

DDG Sample[b]	Volume[a] (cc)	Percent[a] sieve 16	Percent[a] sieve 80
A	35 ± .7b	35 ± 2.0d	2 ± .5a
B	33 ± .2b	19 ± 1.4c	4 ± .1a
I	35 ± 2.2b	7 ± .2a	13 ± .8c
K	20 ± 2.3a	13 ± 1.1b	7 ± .3b

[a]Volume and percentages are the means of three batches and sievings. Values in the same column that do not share the same letter (a, b, c, d) differ significantly, $P<0.01$.
[b]DDG samples were incorporated at the 36% level in the unground form.

Analysis of variance of the volumes of yeast rolls made with DDG samples A, B, I, and K found no statistically significant differences among any of the four yeast rolls, although the particle size distribution of the four samples differed significantly (Table 17). As was shown in Table 6, sample K was significantly different from the average of samples A, B, and I in particle size distribution. These differences however, do not show a consistent association between particle size and volume.

DDG are a concentrated source of fiber which may cause a weakening in the product of the gluten that is present in the wheat flour. These influences on the gluten proteins are there regardless of the particle size of the DDG. Bourbon DDG are composed primarily of

corn which contains no gluten proteins (Bennion, 1980), but if the grain composition of the DDG contributed some gluten proteins, they may have been denatured during processing. The lack of gluten and the weakening effect of the DDG fiber on the gluten proteins present in the wheat flour may be preventing higher volumes in DDG baked products. The lack of starch in DDG may possibly have contributed to the development of poor dough structure, which may also have contributed to the lower volumes found in the DDG baked products (Paul and Palmer, 1972).

Table 17. Yeast roll volumes and particle size distribution in sieve fractions 16 and 80 for DDG samples A,B,I and K.

DDG Sample[b]	Volume[a] (cc)	Percent[a] sieve 16	Percent[a] sieve 80
A	45 ± .9a	35 ± 2.0d	2 ± .5a
B	46 ± 6.4a	19 ± 1.4c	4 ± .1a
I	45 ± .7a	7 ± .2a	13 ± .8c
K	41 ± 5.2a	13 ± 1.1b	7 ± .3b

[a]Volume and pH values are the means of two batches for sample A, and of three batches for samples B, I, and K, and percentages are the means of three sievings for all samples. Values in the same column that do not share the same letter (a,b,c,d) differ significantly, $P<0.01$.
[b]DDG samples were incorporated at the 33% level in the unground form.

Sodium Adjustments in Product Formulas

Quick Breads

The type and level of salt incorporated in oatmeal muffins with DDG significantly affected the product volume and pH ($P<0.01$), as shown in Table 18. Tukey's multiple comparison test found that the volumes of all muffins with DDG were considered the same, but muffins with DDG with a full sodium chloride (NaCl) level and muffins with DDG

with an equal replacement of potassium chloride (KCl) were also not found statistically different from the standard muffins.

The pH's of all muffins with DDG were not statistically different, although all except those with no salt had pH's statistically lower than that of the standard muffin.

Table 18. Volume and pH in DDG oatmeal muffins with salt variations.

Salt Type and Level	Volume[a]	pH[a]
Full NaCl, DDG	105 ± .0ab	6.23 ± .06a
No Salt, DDG	90 ± 13.2a	6.33 ± .03ab
Reduced NaCl, DDG	90 ± 5.0a	6.27 ± .03a
Full KCl, DDG	105 ± .0ab	6.05 ± .2a
Standard, no DDG, full NaCl	112 ± 5.8b	6.58 ± .2b

[a]Volumes and pH values are the means of three batches. Values in the same column that do not share the same letter (a,b) differ significantly, $P<0.01$.

Yeast Breads

Tukey's multiple comparison test indicated that the DDG yeast roll with no salt had a statistically significantly ($P<0.05$) higher volume than the yeast rolls with reduced salt, full NaCl or KCl, and also had a volume as high as the standard roll with no DDG (Table 19). All product pH's including the standard roll were not statistically significantly different from one another. These results do not indicate a conclusive relationship between the amount of NaCl incorporated and the volume in a DDG yeast bread product. It does appear that in products which include $NaHCO_3$ as a neutralizing agent, leaving out the salt can result in acceptable product volumes. Substituting KCl for NaCl appears to have similar effects as using a full NaCl level on volumes in DDG yeast bread products.

Table 19. Volume and pH in DDG yeast rolls with salt variations.

Salt Type and Level	Volume[a] (cc)	pH[a]
Full NaCl	87 ± 15.3a	5.93 ± .03
No Salt	103 ± 2.9ab	6.00 ± .0
Reduced NaCl	90 ± 5.0a	5.85 ± .05
KCl	87 ± 10.4a	5.82 ± .03
Standard, no DDG, full NaCl	127 ± 18.9b	5.97 ± .2

[a]Volume and pH values are the means of three batches. Values in the same column that do not share the same letter (a,b) differ significantly, $P<0.05$.

Percent Color Reflectance

Color Reflectance in DDG Samples

DDG sample K fractions

As recommended by Agtron (1970), red and yellow were chosen for percent color reflectance analysis, as they most closely resemble the color of the DDG samples. Significant differences ($P<0.01$) in the percent color reflectance occurred among unfractionated and fractionated DDG K samples in both the unground and ground state (Table 20). Each fraction when ground, was lighter or had an increased percent reflectance of red and yellow. Percent color reflectance increased linearly from the coarsest fraction (sieve 16) to the finest fraction (sieve 80) of those left in the original unground state. Grinding caused all fractions to be more alike in percent reflectance in both the red and yellow mode. Generally, the finer particle sizes of DDG appeared to be higher in reflectance, except in the finest fraction (sieve 80) where grinding caused a lower reflectance of the sample.

Table 20. Percent color reflectance of DDG sample K fractions

DDG Sample	Percent Reflectance[a]	
	Red	Yellow
Unfractionated, unground	34.5 ± .5b	25.0 ± 3.2ab
Unfractionated, ground	49.0 ± .5fg	40.0 ± .0d
Sieve 16, unground	29.0 ± .6a	22.0 ± 1.0a
Sieve 16, ground	48.0 ± 1.0f	39.0 ± 1.5d
Sieve 35, unground	34.0 ± .3b	25.0 ± .6ab
Sieve 35, ground	50.0 ± .3g	40.0 ± .6d
Sieve 60, unground	36.0 ± .6c	27.0 ± .6b
Sieve 60, ground	49.0 ± .3fg	39.5 ± .5d
Sieve 80, unground	40.5 ± .9d	31.0 ± .6c
Sieve 80, ground	46.0 ± .3e	37.0 ± .3d

[a]Percentages are the means of three samples. Values in the same column that do not share a common letter (a,b,c,d,e,f,g) differ significantly, $P<0.01$.

DDG samples A, B, and I

Grinding the DDG caused significant color differences in DDG samples A, B, and I ($P<0.01$) in both red and yellow reflectance (Table 21). All ground samples had higher reflectance values in both modes over the unground samples, as was found with DDG sample K.

Table 21. Percent color reflectance of DDG samples A, B, and I.

DDG Sample[b]	Percent Reflectance[a]	
	Red	Yellow
A unground	25.0 ± .09	17.0 ± .01
A ground	43.0 ± .6a	33.0 ± .3a
B unground	36.0 ± .4	27.0 ± .5
B ground	49.0 ± .0a	39.0 ± .1a
I unground	29.0 ± .7	20.0 ± .3
I ground	35.0 ± .9a	26.0 ± .3a

[a]Percentages are the means of three batches. Ground sample with the letter a is significantly different than the unground sample of the same DDG, $P<0.05$.

Color Reflectance in Quick Breads

Oatmeal muffins with DDG sample K fractions

Table 22 shows that neither grinding nor sieving the DDG had a significant effect on yellow or red color reflectance of the baked muffin. A statistically significant color difference was found between the standard muffin with no DDG and any muffin containing a DDG fraction. The standard control muffin was observed as lighter in color than those muffins with DDG, probably due to the dark color of the DDG. Although the raw DDG samples were significantly lighter when ground, once incorporated into a muffin the color difference was not evident.

Table 22. Percent color reflectance of oatmeal muffins containing 36% DDG sample K fractions.

DDG Fraction Used	Percent Reflectance[a]	
	Red	Yellow
Unfractionated, unground	32.5 ± .9a	25.0 ± 1.0a
Unfractionated, ground	33.0 ± .8a	25.0 ± 1.2a
Sieve 16, unground	34.0 ± 1.9a	26.0 ± 1.9a
Sieve 16, ground	34.0 ± 1.6a	26.0 ± 1.4a
Sieve 35, unground	34.0 ± .7a	26.0 ± 1.0a
Sieve 35, ground	33.0 ± 1.7a	25.0 ± 1.7a
Sieve 60, unground	31.0 ± 3.0a	24.0 ± 2.3a
Sieve 60, ground	32.0 ± .6a	26.0 ± 1.5a
Sieve 80, unground	33.0 ± 1.7a	26.0 ± 2.9a
Sieve 80, ground	33.0 ± 1.8a	25.5 ± 1.8a
Standard, no DDG	42.0 ± 2.6b	34.0 ± 1.4b

[a]Percentages are the means of three batches. Values in the same column that do not share a common letter, a,b differ significantly, $P<0.05$.

Oatmeal muffins with DDG samples A, B, and I

Analysis of variance of red and yellow color reflectance means in muffins containing either A, B, or I unfractionated DDG samples in the ground and unground state showed a significant ($P<0.05$) difference only in muffins with DDG sample B. Table 23 shows muffins with ground DDG sample B to have slightly ($P<0.05$) higher yellow reflectance than muffins with sample B in the unground state. Otherwise, grinding the DDG does not appear to alter the quick bread product color. All raw DDG samples had significantly higher red or yellow reflectance when ground, but incorporation into a muffin product only altered the color of the muffin with sample B. Increased yellowness was shown in the muffin with ground DDG sample B, as was shown in the raw ground DDG sample.

Table 23. Percent color reflectance of oatmeal muffins containing 36% A, B, and I DDG samples unground and ground.

DDG Sample Used[b]	Percent Reflectance[a]	
	Red	Yellow
A unground	28.5 ± .1	21.0 ± .2
A ground	27.0 ± 1.4	19.5 ± 1.1
B unground	32.0 ± 1.8	23.0 ± .4
B ground	32.5 ± 1.0	24.5 ± .8a
I unground	27.0 ± .4	19.0 ± .6
I ground	27.0 ± .8	19.0 ± .2

[a]Percentages are the means of two batches for DDG sample A, and of three batches for DDG samples B and I. The ground sample with the letter a is significantly different, $P<0.05$ than the unground sample of the same DDG.

[b]All DDG samples are in the unfractionated form.

Oatmeal muffins with salt variations

Analysis of variance found significant differences ($P<0.05$) in red and yellow reflectance among the five muffins shown in Table 24. The standard muffin had higher red and yellow reflectance over all muffins with DDG. Muffins with equal levels of sodium chloride (NaCl) or potassium chloride (KCl) were different from each other in percent red and yellow reflectance but were not different from muffins with reduced NaCl or with no salt. Comparing the muffins with DDG, those with a full NaCl level had the lowest color reflectance, and the muffin with the same level of KCl had the highest color reflectance.

Table 24. Percent color reflectance of oatmeal muffins containing DDG sample K with salt variations.

Salt Type and Level	Percent Reflectance[a]	
	Red	Yellow
Full NaCl	33.0 ± 1.8a	24.0 ± 1.8a
Reduced NaCl	33.5 ± 1.3ab	24.0 ± 1.0ab
No Salt	33.5 ± 0.9ab	24.5 ± 0.5ab
Full KCl	37.0 ± 0.9b	27.5 ± 1.2b
Standard, no DDG	44.0 ± 2.3c	33.0 ± 1.9c

[a]Percentages are the means of three batches. Values in the same column that do not share a common letter (a,b,c) differ significantly, $P<0.05$.

Color Reflectance in Yeast Breads

Yeast rolls with DDG sample K fractions

Table 25 shows that neither grinding nor sieving the DDG had a significant effect on yellow or red color reflectance of the baked yeast roll. The standard yeast roll with no DDG had significantly higher ($P<0.05$) yellow or red reflectance than any roll containing a

DDG fraction. Observation of the baked products found that except for sieve 80, all rolls with ground DDG fractions were slightly darker than those rolls with unground DDG, unlike the color differences found in the raw DDG fractions. The rolls baked with the finest particle size of sieve fraction 80, were slightly lighter when ground than when unground. Differences observed among reflectance values in the raw ground DDG were not significant when the DDG was incorporated into a yeast roll product at the 33% level.

Table 25. Percent color reflectance of yeast rolls containing 33% DDG sample K fractions.

DDG Fraction Used	Percent Reflectance[a]	
	Red	Yellow
Unfractionated, unground	34.5 ± 1.6a	27.0 ± 2.2a
Unfractionated, ground	34.0 ± .6a	26.5 ± 2.1a
Sieve 16, unground	35.0 ± .5a	28.5 ± .2a
Sieve 16, ground	35.0 ± .1a	28.0 ± .3a
Sieve 35, unground	34.0 ± 2.5a	26.5 ± 2.1a
Sieve 35, ground	33.0 ± .5a	25.5 ± .4a
Sieve 60, unground	35.0 ± 1.0a	27.0 ± .8a
Sieve 60, ground	35.0 ± 1.4a	27.0 ± 1.3a
Sieve 80, unground	34.5 ± .5a	27.0 ± .5a
Sieve 80, ground	34.5 ± 1.3a	27.0 ± 1.5a
Standard, no DDG	54.0 ± 3.6b	45.5 ± 1.6b

[a]Percentages are the means of three batches. Values in the same column that do not share the same letter (a,b) differ significantly, $P<0.05$.

Yeast rolls with 33% DDG samples A, B, and I

Grinding DDG samples B or I did not significantly affect reflectance differences in the red or yellow mode (Table 26). Grinding DDG sample A produced a yeast roll with significantly lower

red and yellow reflectance. The raw DDG sample A was lighter when ground, but once baked into a yeast bread, the ground DDG produced a roll that was darker than the roll containing unground DDG. Therefore, some DDG when ground, may alter the final yeast bread product color.

Table 26. Percent color reflectance of yeast rolls containing 33% DDG samples A, B, and I, unground and ground.

DDG Sample Used	Percent Reflectance[a]	
	Red	Yellow
A unground	30.0 ± .7	22.0 ± .4
A ground	26.0 ± .8a	18.0 ± .7a
B unground	33.0 ± .5	26.0 ± .8
B ground	31.5 ± 1.2	24.0 ± 1.7
I unground	28.5 ± 1.0	20.5 ± 1.1
I ground	28.5 ± 1.5	20.5 ± 1.3

[a]Percentages are the means of two batches for DDG sample A and of three batches for DDG samples B and I. The ground sample with the letter a is significantly different than the unground sample of the same DDG sample ($P<0.05$).

Yeast rolls with salt variations

No significant difference ($P>0.1$) was found in red or yellow reflectance between any of the muffins with DDG incorporating salt variations (Table 27). The standard yeast roll had significantly increased red and yellow reflectance over all others ($P<0.01$).

Dough Stability

30% DDG, 70% Bread Flour

The effects of sieving and grinding of the DDG on dough stability as measured by farinogram values was determined. Comparisons were made

among sieve fractions from coarse to fine particle size, and within each sieve fraction in the ground and unground states.

Table 27. Percent color reflectance of yeast rolls containing 33% DDG sample K and four salt variations.

Salt Type and Level	Percent Reflectance[a]	
	Red	Yellow
Full NaCl	36.0 ± 1.5a	28.0 ± 1.0a
Decreased NaCl	38.5 ± 2.0a	30.0 ± 2.6a
No NaCl	37.0 ± .8a	28.5 ± .5a
Full KCl	37.5 ± 1.4a	29.0 ± 1.3a
Standard, no DDG, full NaCl	56.0 ± 2.4b	47.0 ± 2.4b

[a]Percentages are the means of three batches. Values in the same column that do not share a common letter (a,b) differ significantly, $P<0.01$.

Particle size of the DDG, as represented by sieve fraction, had a nearly significant effect ($P=.054$) on the percent of water absorption, as determined using farinogram values (Table 28). Fraction size might have been more significant had the number of sample been larger ($n = 5$). In the unground fractions, percent water absorption increased linearly as particle size decreased from fraction 16 to 80. In the ground fractions, percent water absorption was similar among fractions. Grinding the sieve fractions increased significantly ($P<0.05$) the percent water absorption. Each ground fraction required more water than its corresponding unground fraction, but the increase was not dependent on the sieve fraction (particle) size.

Arrival time measures the rate at which the water is taken up by the flour. Arrival times were longer in the unground fractions of sieve 16 and 35 than in their corresponding ground fractions (Table

28). Larger particle sizes take longer to hydrate. The similarities in arrival times in sieve fraction numbers 60 and 80 unground and ground are probably because of their already fine unground particle size. The differences in arrival times shown from coarse to fine fractions in the unground state indicates that DDG composed of extremely coarse particles may cause longer hydration times when incorporated into yeast bread doughs.

Table 28. Farinograph values for yeast roll dough components of 70% bread flour and 30% DDG at various particle sizes.

	Farinograph Values					
DDG Form[b]	Percent water absorption[a]	Arrival time (min.)	Peak time (min.)	Stability (min.)	Departure (min.)	Valorimeter
Unfractionated, unground	70.9a	6.5	8.5	3.0	9.5	70
Unfractionated, ground	73.4	4.5	6.5	4.0	.5	62
Sieve 16 unground	71.3ab	7.5	9.0	4.0	11.5	72
Sieve 16 ground	76.8	4.8	6.5	3.8	8.5	60
Sieve 35 unground	74.4bc	5.5	6.5	3.0	8.5	62
Sieve 35 ground	78.9	4.8	6.0	3.3	8.0	60
Sieve 60 unground	76.2bc	5.0	6.5	4.3	9.3	62
Sieve 60 ground	78.9	5.3	6.3	2.8	8.0	60
Sieve 80 unground	78.0c	5.3	6.5	3.0	8.3	62
Sieve 80 ground	78.3	5.5	6.8	3.0	8.5	62

[a]Values that do not share a common letter (a,b,c) differ significantly ($P<0.1$) among unground sieve fractions.
[b]DDG sample K-2 used in all measurements.

Peak time or mixing time is an indication of dough stability. It is the point just before the dough begins to weaken. Peak times tend to increase as particle size decreases and as percent water absorption increases (D'Appolonia and Kunerth, 1984). Results in Table 28 show no statistically significant increase of peak times with decreasing

particle size. Longer departure times often indicate stronger flours (D'Appolonia and Kunerth, 1984). No consistent trends among fractions whether ground or unground in departure or stability times were shown.

No statistically significant relationship was shown between percent water absorption and the volume of the baked product (Table 29) at each DDG fraction, whether ground or not. A significant relation was shown between percent protein of each sieve fraction and the percent water absorption in the unground fractions ($P = 0.068$). Had sample size (4) been larger, this relationship might have been statistically more significant. Percent water absorption increased linearly with protein increases in all unground fractions and in the ground fractions with the exception of sieve size 80. Grinding the fractions produced similar particle sizes among the sieve fractions, yet water absorption increased nearly linearly in these fractions from coarse to fine sieve fraction sizes. These results suggest that the percent water absorption increases may have been due more to the protein differences in each fraction than from the change in particle size.

No statistically significant difference was found between volumes of yeast rolls, so comparisons between volume and farinogram values cannot be made Table 29). Some positive correlation has been found between loaf volumes and valorimeter values using products made with wheat (D'Appolonia and Kunerth, 1984). The valorimeter value is a quality score based on the dough's development (peak) time and tolerance to mixing (indicated by the departure time). No consistent change in valorimeter values were observed between sieve fractions.

The highest valorimeter value was observed with sieve fraction 16, unground.

Based on a small number of observations, as particle size of DDG decreased, protein content increased and more water was absorbed. Neither of these parameters affected either dough stability nor dough quality. Bourbon DDG are low or lacking in gluten, which probably influenced farinograph data and baking values.

Table 29. Farinograph, DDG composition, and baked product values of yeast roll dough components utilizing DDG sample K of five particle sizes.

DDG Form[a]	Percent protein	Percent water absorption	Baked product volume (cc)	Valori-meter
Unfractionated, unground	26.9	70.9	41.0	70
Unfractionated, ground	26.9	73.4	44.0	62
Sieve 16, unground	24.0	71.3	43.0	72
Sieve 16, ground	24.0	76.8	41.0	60
Sieve 35, unground	25.4	74.4	40.0	62
Sieve 35, ground	25.4	78.9	46.0	60
Sieve 60, unground	26.9	76.2	43.0	62
Sieve 60, ground	26.9	78.9	44.0	60
Sieve 80, unground	30.7	78.0	41.0	62
Sieve 80, ground	30.7	78.3	45.0	62

[a] DDG sample K-2 was used in all measurements.

Salt Variations and 30% DDG, 70% Bread Flour

Comparison of yeast roll volumes with farinograph percent water absorptions showed no statistically significant relationship based on amount or type of salt used, nor was there a statistically significant difference among volumes compared to valorimeter values (Table 30). The valorimeter value in the 2% NaCl formula was considerably higher than in the other two formulas. These data are the result of a small

number of observations but may indicate that NaCl incorporated at the 2% level produces a more stable high quality dough. NaCl may produce improved loaves over those using KCl salt.

Table 30. Farinograph values for yeast roll dough components[a] of three salt types and levels.

	Farinograph values						
Salt Variation	Yeast roll volume (cc)	Percent water absorption	Arrival time (min)	Peak time (min)	Stability (min)	Departure (min)	Valorimeter
2% NaCl	86.7	73.1	7.5	12.0	8.0	15.5	82
1% NaCl	90.0	72.6	6.75	9.5	6.75	13.5	72
2% KCl	86.7	71.3	7.25	9.0	6.75	14.0	70

[a]Dough components consisted of 70% bread flour and 30% DDG sample K in the unfractionated form.

Organoleptic Evaluation

Quick and yeast breads were evaluated by trained and consumer taste panelists to determine differences and acceptability on a particle size variable and on a salt variable.

Particle Size Effect

Consumer taste panel, quick breads

Oatmeal muffins containing 36% unground DDG or 36% ground DDG were sampled by 102 untrained panelists. A large number of judges (at least 50-100) is required in a consumer panel due to the inexperience of the judges and the presence of many uncontrolled variables (Campbell et al. 1979).

Data analyzed by covariance methods showed that the type of muffin and the sex of the judge had no effect on the rating but the

age of the judge did significantly ($P<0.05$) affect rating results (Table 31). The mean ratings were high for both muffin types. Muffins with unground DDG had a mean rating of 7.13 ± 1.5 and muffins with ground DDG had a mean rating of 7.08 ± 1.5, on a scale of 1-9, where 1 = dislike extremely, and 9 = like extremely (Appendix A). Rating of the muffins decreased by .1 for each increase in age group. Ages were grouped as follows: 5-10, 11-14, 15-19, 20-29, 30-39, 40-49, 50-59, 60-69, 70-79, and 80-89.

Table 31. Results of covariance analysis of muffins rating type, sex and age interactions.

	Probability of a Larger F-Value		
	Type	Sex	Age
Rating	0.8432	0.3893	0.0213*

*Significant at the $P<0.05$ level.

The literature indicates that young children are able to discriminate among tastes reliably (Thomas and Murray, 1980) which suggests that ratings of products by young children should not be different than ratings by adults. The correlation found here between decreased age and increased rating may be due to the fact that children and the younger members of the population prefer whole grain products. Recent introduction into the marketplace of whole grain products may have enabled the younger people a greater exposure, and thus an increased preference for them as compared to the older people.

Consumer taste panel, yeast breads

Yeast rolls containing 33% unground DDG or 33% ground DDG were sampled by 94 untrained panelists. Data analyzed by covariance methods showed that muffin type and age of judge had no effect on the rating, but the sex of the judge significantly ($P<0.01$) affected rating results (Table 32). The mean ratings were moderate for both roll types. Rolls with unground DDG had a mean rating of 6.43 ± 1.7 and rolls with ground DDG had a mean rating of 6.35 ± 1.7. The mean rating by females was 6.492 and the mean rating by males was 6.177.

Table 32. Results of covariance analysis of yeast rolls rating type, sex and age interactions.

	Probability of a Larger F-Value		
	Type	Sex	Age
Rating	.7655	.0054**	.5974

**Significant at the $P<0.01$ level.

Consumers did not prefer baked products with DDG in the ground form. Products with ground DDG had a slightly sticky mouthfeel. In both quick and yeast breads they rated those with unground DDG slightly higher, although the difference was not statistically significant. This suggests that DDG may be successfully incorporated into a leavened product without grinding or milling. These results indicated that consumers like baked products with DDG at least slightly or moderately and that quick breads with DDG may be preferred over yeast breads with DDG.

Salt Variations

Trained taste panel, quick breads

The Scheffe model for paired comparison directional tests indicated a significant difference ($P<0.01$) among muffins with variations of salt type and level (Table 33). Panel members could not tell the difference between those muffins that contained either full NaCl levels, reduced NaCl levels, or no salt. Panelists could tell the difference and significantly preferred ($P<0.05$) each of those muffins over muffins containing a full level of KCl salt replacement (Table 34).

Table 33. Analysis of variance results of paired comparison tests of oatmeal muffins with DDG and salt variations.

Variance	DF	SS	MS	F-Ratio
Order effects	1	.0162	.0162	
Main effects	3	43.648	14.549	13.072**
Total	60	106.0	1.767	
Error	56	62.336	1.113	

**Significant at the $P<0.01$ level.

Table 34. Tukey's multiple comparison test results of paired comparison tests of oatmeal muffins with DDG and salt variations.

Pairs[a]	Observed main effects difference
A,B	.2
A,C	.375
A,D	.975[b]
B,C	.175
B,D	1.175[b]
C,D	1.350[b]

[a]Samples in pairs are as follows: A = full NaCl; B = no salt; C = reduced salt; D = full KCl.

[b] Differences greater than the critical value of .6322 are significant at the $P<0.05$ level.

The hedonic (like-dislike) ratings of the four muffin types were significantly different due to muffin type ($P<0.05$) and judge ($P<0.01$). Table 35 shows the mean ratings for the muffins and the differences due to muffin type, by Tukey's multiple comparison test. Muffins with reduced NaCl and muffins with KCl differed from each other but neither differed from those with full NaCl or with no salt. The highest rating was 5.25 for the muffins with reduced NaCl and the lowest rating was 4.0 for the muffins with full KCl. The hedonic scale ranged from 1-9, where 1 = dislike extremely and 9 = like extremely (Appendix A). The mean rating for all muffins was 4.8 which indicates a low acceptability of the products. The paired comparison test showed that the muffin with full KCl salt replacement was significantly different from the other three muffin types, but in the hedonic test, although rated lowest, it was only found significantly lower than the muffin with reduced NaCl.

Table 35. Hedonic ratings of oatmeal muffins containing varying types and levels of salt.

Muffin Type	Hedonic Rating[a]
Full NaCl	4.8 ± 2.3ab
Reduced NaCl	5.3 ± 1.7b
No Salt	5.1 ± 1.8ab
Full KCl	4.0 ± 1.9a

[a]Values are the means of ten ratings. Values that do not share the same letter (a,b) differ significantly, $P<0.05$.

Four significantly different groups of judges were found based on hedonic ratings (Table 36). Some judges, on the average, disliked all samples (judges 1 and 2) and some judges liked all samples (judges 9

and 10). There was a significant judge effect and a significant treatment effect, but the interaction between the two was not significant. These results show that even though some panelists disliked or liked all samples, muffins still differed significantly due to the salt type and level incorporated.

Table 36. Judge effect on hedonic ratings of oatmeal muffins containing varying types and levels of salt.

Judge	Hedonic Rating[a]
1	2.3 ± .5a
2	3.1 ± 1.2ab
3	3.9 ± 1.5abc
4	5.0 ± .8bcd
5	5.3 ± .7bcd
6	5.3 ± 3.1bcd
7	5.3 ± 1.2bcd
8	5.4 ± 2.4bcd
9	5.9 ± 1.7cd
10	6.5 ± .7d

[a]Values are the means of four ratings. Values that do not share the same letter (a,b,c,d) differ significantly, $P<0.05$.

Trained taste panel, yeast breads

The Scheffe model for paired comparison directional tests indicated an insignificant F-ratio for yeast rolls containing the four salt level variations (Table 37). Panel members could not tell the difference between any of the yeast rolls.

Although no difference between rolls was indicated by the paired comparison test, analysis of the mean hedonic ratings indicated differences in like-dislike. The type of yeast roll and the judge significantly ($P<0.01$) affected the hedonic ratings of the four types of yeast rolls. The mean ratings for the rolls and the differences

due to type of roll by Tukey's multiple comparison test are shown in Table 38. Rolls with reduced NaCl and rolls with KCl were significantly different from each other but each were not different from the other two rolls. The roll with reduced NaCl was rated the highest, at 5.75, and the roll with KCl was rated the lowest, at 4.1. The mean rating of all rolls was 5.0 indicating no strong likes or dislikes.

Table 37. Analysis of variance results of Schéffe's model for paired comparison tests of yeast rolls with DDG and salt variations.

Variance	DF	SS	MS	F-Ratio
Order effects	1	.4163	.4163	
Main effects	3	8.5	2.833	1.96
Total	60	90.0	1.5	
Error	56	81.08	1.447	

Table 38. Hedonic ratings of yeast rolls containing varying types and levels of salt.

Yeast Roll Type	Hedonic Rating[a]
Full NaCl	4.6 ± 1.8ab
Reduced NaCl	5.75 ± 1.8b
No Salt	5.4 ± 1.7ab
Full KCl	4.1 ± 1.6a

[a]Values are the means of ten ratings. Values that do not share the same letter (a,b) differ significantly, $P<0.05$.

Tukey's multiple comparison test found that yeast roll hedonic ratings were significantly ($P<0.05$) grouped by two types of judges (Table 39). One significant group rated the products low (judge 1) and another significant group rated the products moderately high (judges 8, 9, and 10). Although, on the average, some judges did not like any

samples and some liked all samples, the type and level of salt incorporated was significant enough to affect the rating.

Table 39. Judge effect on hedonic ratings of yeast rolls containing varying types and levels of salt.

Judge	Hedonic Rating[a]
1	3.0 ± .9a
2	4.0 ± .8ab
3	4.1 ± 3.0ab
4	4.4 ± 1.6ab
5	5.1 ± 2.2ab
6	5.1 ± 1.5ab
7	5.3 ± 1.6ab
8	6.0 ± 1.1b
9	6.3 ± 1.2b
10	6.4 ± .5b

[a]Values are the means of four ratings. Values that do not share the same letter (a,b) differ significantly, $P<0.05$.

The results from both trained taste panels suggest that DDG baked products with reduced NaCl or with no salt may be preferred over products with full formula NaCl levels. Recent concern over the link between high sodium consumption and hypertension may have caused consumers to decrease NaCl intake. Consumers may be learning to adjust to and prefer lower sodium or NaCl levels in their diet. KCl does not appear to be an acceptable salt replacement at a full level in DDG baked products. Therefore, quick breads and yeast breads with KCl were not included in the consumer taste panels. The other three types were rated similarly enough to be included in the consumer panel.

Consumer taste panel, quick breads

Three oatmeal muffins containing 36% unground DDG and either full NaCl, reduced NaCl or no salt, and a fourth standard oatmeal muffin containing no DDG and a full NaCl level were sampled by 100 untrained panelists. Covariance analysis showed that type of muffin significantly ($P<0.01$) affected the rating of the muffins, but neither age nor sex of the judge had a significant effect ($P>0.1$), as is shown in Table 40.

Table 40. Results of covariance analysis of muffins rating type, sex and age interactions.

	Probability of a Larger F-Value		
	Type	Sex	Age
Rating	.0015**	.1070	.3331

**Significant at the $P<0.01$ level.

The mean ratings by muffin type are shown in Table 41. The DDG muffin with full NaCl salt was rated statistically significantly lower than the other three muffins by the LSD multiple comparison method at the 0.05 level. The more conservative Tukey's test found no significant difference among muffin types.

Consumer taste panel, yeast breads

Three yeast rolls containing 33% unground DDG and either a full NaCl level, reduced NaCl, or no salt, and a fourth standard roll with no DDG and a full NaCl level were sampled by 96 untrained panelists. Covariance analysis showed that type of yeast roll and sex of the judge significantly ($P<0.01$) affected the rating results, but age did

not (Table 42). The mean ratings by type are shown in Table 43. Again, the roll with reduced salt had the highest rating, although it was only rated statistically significantly different from the roll with full NaCl salt. The roll with full NaCl salt was not significantly different from the roll with no salt, but was different from the other two rolls. This suggests that yeast rolls with no salt and full NaCl salt may not be as desirable. The average rating by females for all four yeast roll types was 6.84, and the average rating by males was 6.12.

These results indicate that quick breads and yeast breads with DDG are liked as well as, or better than those without DDG. Breads incorporating DDG may be more acceptable if the salt (NaCl) level is reduced to provide a sodium level that compensates for the extra sodium added by the neutralizing agent, $NaHCO_3$.

Table 41. Mean ratings of oatmeal muffins with salt variations by consumer taste panelists.

Oatmeal Muffin Type	Mean Rating
Full NaCl	6.29^{a}
Reduced NaCl	7.01^{b}
No Salt	7.07^{b}
Standard, no DDG, full NaCl	7.06^{b}

^{ab}Values that do not share the same superscript differ significantly, $P<0.05$.

Table 42. Results of covariance analysis of yeast rolls rating type, sex and age interactions.

	Probability of a Larger F-Ratio		
	Type	Sex	Age
Rating	.0000**	.0095**	.6955

**Significant at the P<0.01 level.

Table 43. Mean ratings of yeast rolls with salt variations by consumer taste panelists.

Yeast Roll Type	Mean Rating
Full NaCl, DDG	5.78[a]
Reduced NaCl, DDG	7.135[b]
No Salt, DDG	6.125[ab]
Standard, no DDG, full NaCl	7.031[b]

[ab]Values that do not share the same superscript differ significantly, P<0.05.

Conclusions

The addition of $NaHCO_3$ to baked products with DDG have resulted in improved volumes by increasing the pH to the level found in the standard product without DDG, both in this study and by O'Palka and Eidet, (1986). Protein, lipid and fiber (NDF) content did not affect product volumes.

Quantitative and qualitative analysis of lipid composition of three of the DDG samples (B, I, and K) used in baking indicated only minor degradation of lipid content in DDG held in frozen storage. Linoleic acid was slightly reduced in the TAG bands of all samples, and in the FFA band of one sample (K), probably due to some oxidation. Marginal differences in lipid composition were observed in two different batches of DDG from the same plant, with differences

occurring in the TAG percentage and in the linoleic acid percentage of the TAG and FFA bands. These differences were found in two of the three DDG samples tested, (I and K) and may be due to the limitations inherent in TLC and GLC techniques or to subtle differences in original grain used and in processing between batches.

The particle size distribution of bourbon DDG varies among producers. The distribution and percentage of coarse and fine particles within a DDG sample was not associated with final volumes of quick and yeast breads. Products baked with four different sieve fractions of one DDG (K) did not vary significantly in volume, nor did products baked with the sieve fractions in the ground form. Incorporating four different unfractionated DDG (A, B, I, and K) in the ground form produced products with no significantly different volumes than products utilizing the DDG in the unground form.

Grinding the DDG produced an increased percent reflectance (a lighter color of the raw material), but once incorporated into a baked product, grinding had little effect on the product color. Quick breads and yeast breads baked with DDG were darker in color than a standard bread with no DDG.

There was no significant difference among ratings of quick and yeast breads containing unfractionated DDG in the ground or unground form by a consumer taste panel. Consumers indicated acceptance of both products. These results indicate that consumers accept DDG in baked products regardless of differences in particle size of DDG used or of product volume or color. Grinding or milling of DDG does not appear necessary.

Calcium carbonate was ineffective in raising the pH of DDG both in titration procedures and when baked into quick breads. Quick or yeast breads incorporating DDG and baked with KCl salt substitute to decrease sodium content were not found acceptable in flavor by trained taste panelists, although the products did have acceptable pH's and volumes. Baked products containing reduced NaCl levels to produce a sodium level which compensated for the sodium in $NaHCO_3$ were found to be more acceptable by trained panelists and by consumers than products containing a full amount of NaCl. Consumers rated baked products with DDG and reduced salt or without salt as acceptable as the standard product with no DDG and a full NaCl level, although the standard products had slightly increased volumes. Yeast breads may be more desirable with reduced salt levels than with no salt. These results indicat that the volumes in chemically and yeast leavened DDG products did not influence taste panel ratings.

If $NaHCO_3$ is used to neutralize the otherwise acidic product baked with DDG, it may be necessary to decrease the overall sodium content by reducing the amount of NaCl salt in the formula for increased product acceptability.

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REFERENCES CITED

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APPENDICES

APPENDIX A

Taste Panel Recording Sheets

PAIRED COMPARISON
DIFFERENCE TEST

NAME _____ DATE _____

Product _____

Examine these two samples for _____

1. Is there a difference in _____ between the two samples?

   Yes _____ No _____

2. Indicate the degree of difference in _____ between the two samples by checking one of the following statements:

		Check One
_____	is extremely better than _____	_____
_____	is much better than _____	_____
_____	is slightly better than _____	_____
	No difference	_____
_____	is slightly better than _____	_____
_____	is much better than _____	_____
_____	is extremely better than _____	_____

3. Rate the _____ of the samples.

_____	_____
Good _____	Good _____
Fair _____	Fair _____
Poor _____	Poor _____

Comments:

Booth Number_____

Food Evaluation Test

Product_____

Check the appropriate block:

	SAMPLE NUMBER					
Like Extremely						
Like Very Much						
Like Moderately						
Like Slightly						
Neither Like nor Dislike						
Dislike Slightly						
Dislike Moderately						
Dislike Very Much						
Dislike Extremely						

Comments:

Name_____

Date_____

PRODUCT:_____

DATE:_____

DIRECTIONS: PLEASE PLACE A CHECK (✓) NEXT TO THE PHRASE THAT BEST DESCRIBES HOW YOU FEEL ABOUT EACH OF THE PRODUCTS.

	PRODUCT		PRODUCT
LIKE EXTREMELY		LIKE EXTREMELY	
LIKE VERY MUCH		LIKE VERY MUCH	
LIKE MODERATELY		LIKE MODERATELY	
LIKE SLIGHTLY		LIKE SLIGHTLY	
NEITHER LIKE NOR DISLIKE		NEITHER LIKE NOR DISLIKE	
DISLIKE SLIGHTLY		DISLIKE SLIGHTLY	
DISLIKE MODERATELY		DISLIKE MODERATELY	
DISLIKE VERY MUCH		DISLIKE VERY MUCH	
DISLIKE EXTREMELY		DISLIKE EXTREMELY	

SEX:_____

AGE:_____

PRODUCT:_____

DATE:_____

DIRECTIONS: PLEASE PLACE A CHECK (✓) NEXT TO THE PHRASE THAT BEST DESCRIBES HOW YOU FEEL ABOUT EACH OF THE PRODUCTS.

	PRODUCT	PRODUCT	PRODUCT	PRODUCT
LIKE EXTREMELY				
LIKE VERY MUCH				
LIKE MODERATELY				
LIKE SLIGHTLY				
NEITHER LIKE NOR DISLIKE				
DISLIKE SLIGHTLY				
DISLIKE MODERATELY				
DISLIKE VERY MUCH				
DISLIKE EXTREMELY				

SEX:_____

AGE:_____

APPENDIX B

Titration Curves and Quick Breads Using Calcium Carbonate

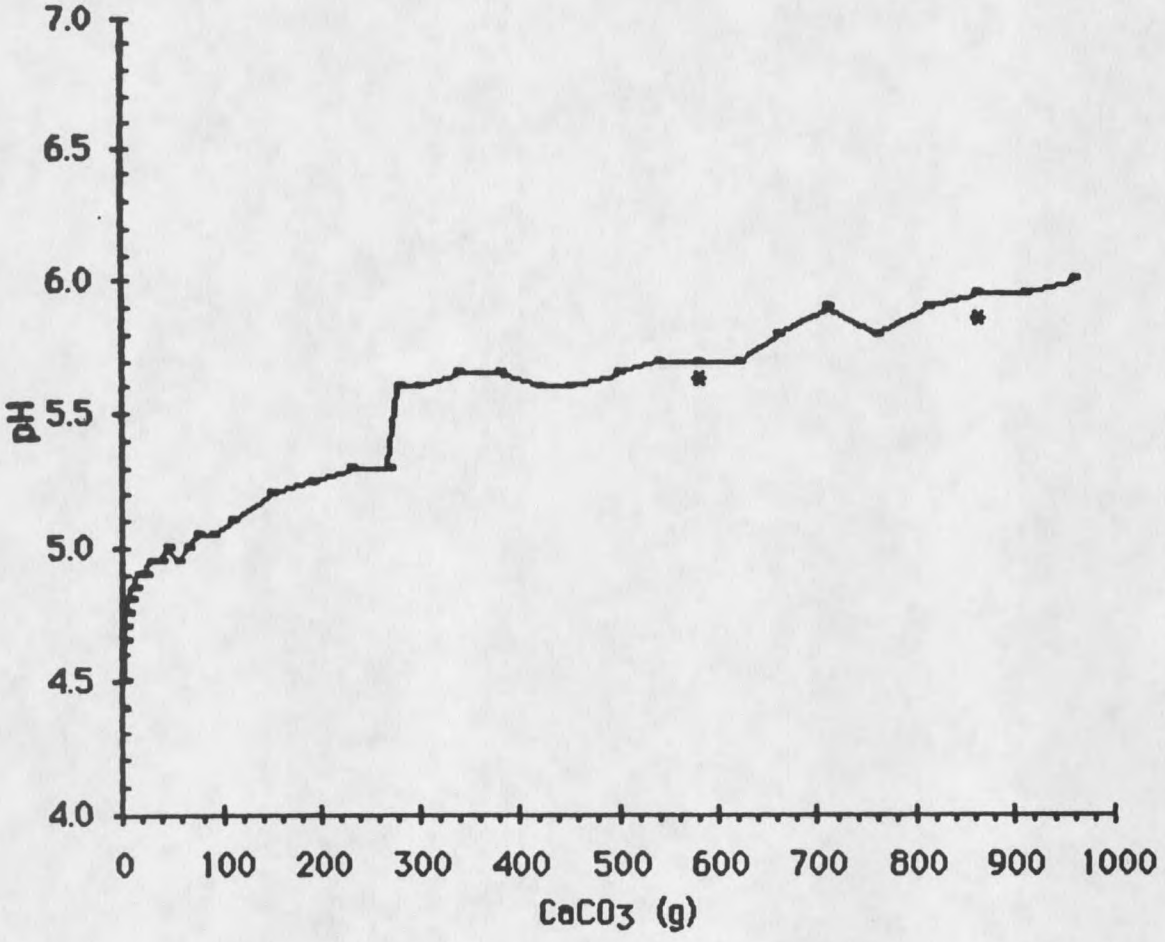

Figure 5. Titration of calcium carbonate ($CaCO_3$) in dry gram weights against 112 g DDG sample K in 400 ml room temperature distilled water.
*Added 100 ml distilled water.

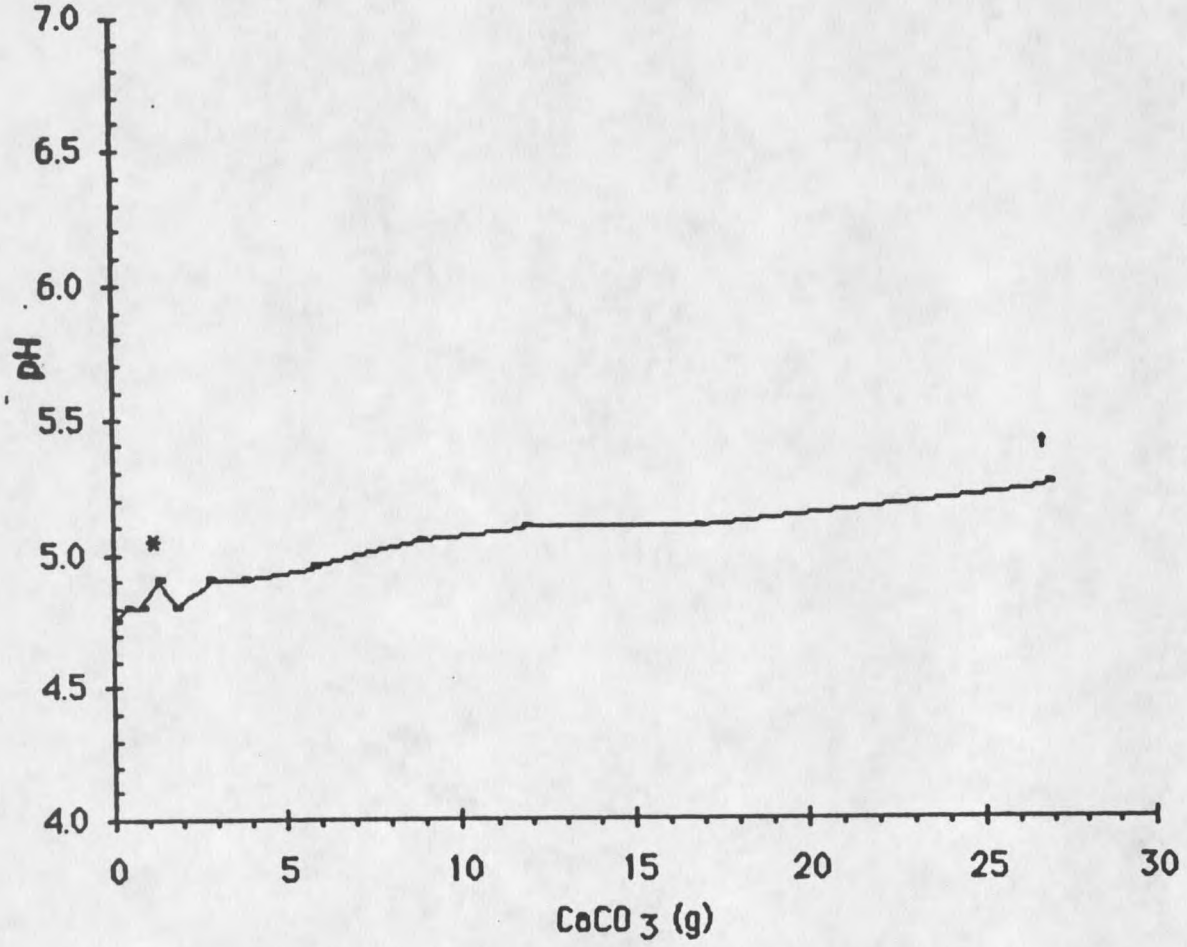

Figure 6. Titration of calcium carbonate ($CaCO_3$) in dry gram weights against 20 g DDG sample K in distilled water at boiling temperature.
*Added 50 ml distilled water.
+Added 25 ml distilled water.

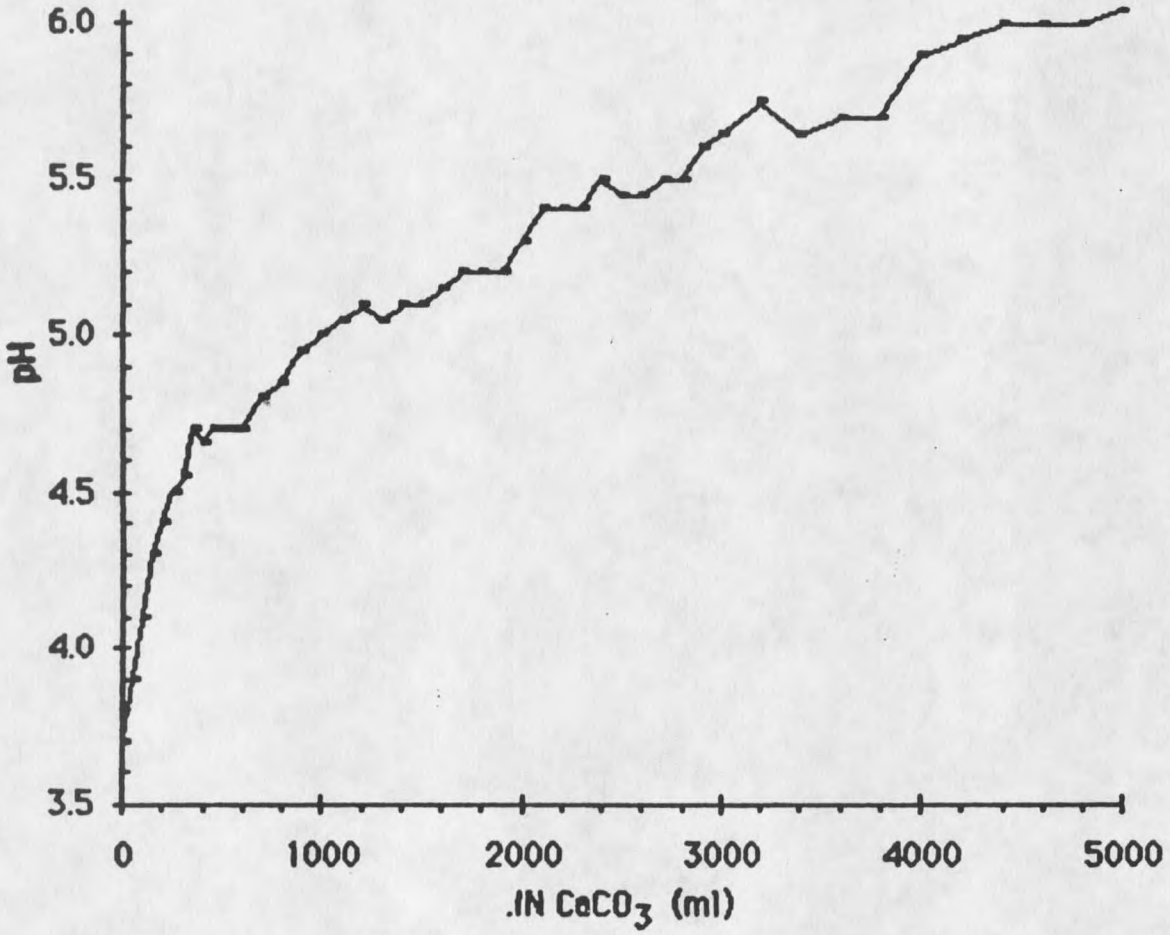

Figure 7. Titration of .1N calcium carbonate ($CaCO_3$) against 50 g DDG sample K in 200 ml distilled water.

Table 44. Volume and pH of oatmeal muffins containing varying levels of $NaHCO_3$ and $CaCO_3$.

Alkalizing Agent	Volume[a]	pH[a]
1.3 g $NaHCO_3$	100 ± 5.0	6.55 ± .05
1.3 g $CaCO_3$	90 ± 5.0	5.47 ± .03
2.6 g $CaCO_3$	98 ± 2.8	5.48 ± .04
3.9 g $CaCO_3$	100 ± 5.0	5.48 ± .1
No agent	90 ± 5.0	5.40 ± .0

[a]Volume and pH values are the means of three muffins.

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