EFFECTS OF INGREDIENTS AND PROCESSING VARIABLES ON THE QUALITY OF WHOLE WHEAT BREAD

by

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INTRODUCTION

During the past ten years the baking industry of this country has undergone a dramatic change. Consumers have brought about this change and it involves their increased interest in the numerous variety breads which have become readily available. This decade has seen variety breads increase from 15 to nearly 35 percent of total bread consumption. And, since they fetch a higher price in the marketplace, variety breads may soon account for almost half of the total income from bread sales. (Jackel 1981, Bureau of the Census 1979).

The baking industry has met this increased demand through a step-up in variety bread production and through marketing strategies which capitalize on the interest in this growth area.

Essential to the development of such strategies is an understanding of the reasons behind the variety bread boom. As early as 1966, researchers found that 49 percent of those who bought variety breads, did so on the basis of health, diet, and nutritive factors; 38 percent were most influenced by flavor; and 37 percent chose variety bread for a change (Cain 1966). A recent study (Anon. 1980) shows that consumers are still concerned with the perceived nutritive aspects of bread. It is therefore not surprising that bread nutrition has been subjected to extensive research during the past few years. This study (Anon. 1980) also shows that consumers mainly buy wheat and whole grain bread because of the taste.

The flavor and aroma of bread have also been widely studied. Most of these studies have utilized various chromatographic techniques which separate and identify constituent components of bread volaties. Maga (1974) presents a thorough review of this research.

While the value of chromatographic analysis is uncontested, it is ultimately essential to investigate how consumers perceive the flavor and aroma of bread. This study and others (Maga (1973) demonstrate that humans generally cannot identify single compounds of bread flavor and aroma, despite the fact that these compounds may constitute a major portion of the volatiles. Trained panelists in this study familiarized themselves with the aromas of furfural, acetaldehyde, glucono-delta-lactone, and other bread volatile constituents, but they were unable to identify these aromas in the aroma of sample breads. Instead, they were forced to adopt such terms as yeasty fermented or doughy, which represent complex combinations of odorous components. It is these clusters of volatiles and other bread constituents which consumers regard as bread flavor and aroma; so it is only through subjective assessment that researchers may usefully characterize flavors and aromas as they are perceived by consumers.

Maga (1974) cites many such studies, but nearly all of them focused on white pan bread. When we consider that a recent survey (Anon. 1980) indicated that consumers prefer the flavor of wheat and whole wheat breads to white pan bread, the need for more research in variety bread flavor becomes obvious.

The following study is composed of two parts. Part I deals with the flavor and aroma of whole wheat bread. Its objectives were:

1. To develop the flavor and aroma profile of a typical white pan bread using the method described by Caul and Vaden (1972).
2. To replace the white patent flour with whole wheat flour and develop the resulting bread flavor and aroma profile.
3. To determine the effects of aging on the flavor and aroma of these breads.

Part II of this thesis focuses on some formulation and production aspects of whole wheat bread. Basically, the same breadmaking procedures which were used in making white pan bread are also employed in whole wheat bread production.

Consideration should be given, however, to the differences which exist between whole wheat and white doughs. Much research has been devoted to the study of the rheological characteristics of doughs made with white patent flour, but very little is known about the rheological behavior and subsequent breadmaking quality of whole wheat flours.

Whole wheat bread has come to be identified as a dense compact bread (Ponte 1981), and, in fact, many consumers have developed a preference for that appearance and texture (Anon. 1980). Bakers, on the other hand, attempt to produce bread with the maximum volume while retaining sufficient crumb strength and acceptable appearance and texture. It may therefore be assumed that any success in attaining greater volume and less dense crumb in whole wheat bread would be advantageous to the baker in that it could result in a greater degree of consumer acceptance.

With these goals in mind, Part II of this thesis was undertaken with the following objectives:

1. To determine the effect of particle size (granulation) of whole wheat flour on mixing characteristics and bread quality,
2. To investigate the effect of "low shear" (sheeting) mixing and "high shear" (pin-type) mixing on the quality of whole wheat bread,
3. To evaluate the effects of water, shortening, emulsifier, and oxidant additions on whole wheat dough and bread properties,
4. To determine how the above variables interact to affect the quality of whole wheat bread.

Part I. The Flavor and Aroma of Whole Wheat Bread

LITERATURE REVIEW

Whole wheat bread, by definition, must contain 100% whole wheat flour aside from the other bread ingredients. Thus, its composition differs from white bread in that it contains the bran and germ which are otherwise diverted in the milling process. The presence of these wheat components affects bread flavor and aroma both directly and indirectly.

The bran and germ directly affect the flavor and aroma by contributing their own distinctive characteristics. Bran, with its high level of bitter phenolics (Maga and Lorenz 1973), may lend bitterness to the bread. Germ, on the other hand, contains about 10% sucrose and 14% lipids. It is therefore perceived as being sweet and oily. These lipids, however, are highly susceptible to oxidative rancidity, and may contribute rancid and bitter characteristics.

Indirectly, bran and germ affect bread flavor by causing physical and chemical changes in the dough. Prominent among these changes is a reduction in loaf volume. This occurs largely as a result of the dilution of functional proteins. These gluten proteins, which are mainly responsible for dough development, are present in only slight amounts in the bran and germ. Therefore, the presence of bran and germ, which constitute about 15% of the whole kernel, effectively reduces the percentage of functional proteins available for dough development. For this reason, whole wheat flour is generally milled from higher protein wheat varieties. Also, dry gluten is often added to whole wheat doughs in an effort to counteract the loss in volume (Ponte 1981).

Aside from this dilution effect, bran and germ particles may tear air cells and physically disrupt the dough structure during mixing and subsequent handling of the dough. Also important is the presence of glutathione and thioctic acid in the germ and bran which act as reducing agents and therefore weaken the dough (Pomeranz 1978). In addition, the high enzyme content of the germ may also bring about losses in bread volume as a result of excessive proteolysis of functional proteins.

Low bread volume may affect flavor and aroma in several ways. Firstly, the denser structure conducts heat less rapidly and therefore takes longer to bake. Lower baking temperatures and longer baking times are said to promote optimum flavor development (King 1937). Such baking conditions also favor the development of a thick crust which is characteristic of whole wheat breads and is said to contribute greatly to overall bread flavor (King 1937). Next, we should consider that the mouthfeel of such a dense product is quite different from that of most white breads. Indeed, 10% of consumers tested indicated that they chose whole wheat bread mainly because they prefer its texture (Cain 1966). Perhaps closely related to this texture preference is the manner in which aromatics are released from the bread as it is masticated. Also important is the rate at which these volatiles are formed and lost during and after the baking process.

Another consideration is the role of fermentation time on the development of flavor and aroma. Studies present conflicting evidence as to whether or not longer fermentation results in greater flavor and aroma intensity (Jackel 1962, Becker 1975). Whole wheat doughs generally require less fermentation to achieve an optimum quality loaf than does white dough (Becker 1975, Ford 1977, Ponte 1981). At least one author (Becker 1975) asserts that this shorter fermentation time results in better flavor for whole wheat breads. He also suggested that the fermented yeasty aromatics which result from fermentation may not be desirable in both white and whole wheat breads. The prevailing opinion among bakers, however, is that this fermented yeasty character is a favored attribute. Perhaps these conflicting views arise from the ambiguous nature of the term, "yeasty". Training panel members from the present study sought to describe more specifically these "yeasty" aromatics.

Several studies have investigated the effect of aging on the flavor and aroma of white pan bread. Chromatographic evidence shows a decrease in the concentration of volatile compounds with the storage of bread (Maga 1974). One study (Jackel 1961) demonstrated that individuals perceive lower levels of fermentation flavors and aromas as breads age. Caul and Vaden (1974) used the profile method of flavor analysis (Caul 1957) and were able to follow the fate of individual flavor and aroma notes over a period of 4 days. They found, in crumb flavor, that as sweetness decreased, sourness increased, and the full-bodied doughy characeter became less rounded and more starchy in the aging bread crumb.

Panelists from that study noted that the bread flavor and aroma was never static, and that it exhibited the greatest change between Days 1 and 3. We should note, however, that all notes from the crumb and crusts never exceeded an intensity of 1 (slight) and many were judged to be at the threshold or just recognizable level. It is therefore interesting to consider to what extent consumers perceive flavor and aroma of white bread. James Pence (1967) writes, "The wheaty flavor of flour is really quite a bland flavor but it is also very distinctive". There is no doubt that, however, bland, white bread flavor has found nearly universal acceptance around the world. Since it is primarily used in sandwiches and combined with other foods, white bread's low flavor and aroma intensities may be considered desirable in that they will not interfere with and may even enhance the flavors and aromas of other foods.

Whole wheat bread, on the other hand, is markedly different from white bread in its organoleptic properties (as the following study will attempt to show). It, too, has gained wide acceptance, and its unique properties merit the attention of further research. It must be emphasized, however, that both bread types are equally important in that they both have established markets and long histories of consumer acceptance.

With this in mind, the following study was undertaken. White and whole wheat breads were compared--not to determine superiority of one over the other, but rather to identify in some detail the flavor and aroma attributes of each.

MATERIALS AND METHODS

Breads were prepared in the Department of Grain Science and Industry, Kansas State University. A sponge and dough procedure was used for both white and whole wheat breads. Preliminary tests optimized the absorption, mix time, and oxidation level for both bread types.

The test formula is typical of a commercial sponge dough white bread. When the unbleached patent flour was replaced with whole wheat flour, the absorption and oxidation levels were increased, and vital wheat gluten was added to obtain satisfactory volume and grain (Table 1).

Table 1.

Ingredients	White Bread % Total	Sponge	Dough	Whole Wheat Bread % Total	Sponge	Dough
Unbleached Patent Flour	100.0	70.0	30.0	---		
Stone Ground Whole Wheat Flour	---	--	--	100.0	70.0	30.0
Water	64.0	42.2	21.8	72.0	47.5	24.5
Yeast	2.0	2.0	--	2.0	2.0	--
Salt	2.0	--	2.0	2.0	--	2.0
Sugar	6.0	--	6.0	6.0	--	6.0
Shortening	2.0	--	2.0	2.0	--	2.0
Non-fat Dry Milk	2.0	--	2.0	2.0	--	2.0
Yeast Food	0.25	0.25	--	0.5	0.5	--
Malted Flour	0.2	--	0.2	--	--	--
Vital Wheat Gluten	---	--	--	2.0	2.0	--

Breads were sliced and wrapped in polyethylene bags one hour after baking, then stored at room temperature for periods of one, three, and five days. At these times breads were examined by a panel of one professor and four graduate students trained in the profile method of flavor analysis. Three of the panelists were students specizlizing in bread research.

At the study's onset, bread ingredients and relevant references such as cracked wheat, nuts, and caramel, were studied by the panelists in order that appropriate terminology be brought under consensus. In addition, a procedure for examining aroma and flavor of the crumb and crust was standardized.

In this method, each panelist privately evaluates the aroma and flavor of the crumb and crust of two slices taken from the sample loaf. The crumb and crust are separated by means of a 7 cm diameter cookie cutter. Those portions are placed in a covered Petri dish to retain some volatiles which would otherwise be lost if exposed. The panelist first removes a crumb portion, places it on a watch glass, and evaluates the aroma--listing each aroma note in order of perception and also noting individual and total (overall) intensities. The crumb piece is then torn and again assessed for the presence of additional volatiles.

The second crumb portion is used for flavor evaluation. First, the panelist rinses his or her mouth with odorless, room temperature, distilled water, and then takes a fourth of the crumb circle and places it on the center of the tongue. With the mouth closed, the tongue then compresses the crumb to expel any volatiles and these notes are recorded as they are perceived. The crumb is then masticated normally, and flavor perceptions are noted. Again, individual and total intensities are recorded. The above flavor evaluation is then repeated using the second, and if necessary, the third and fourth piece to check or refine the recorded impressions. Any impressions which tend to linger in the mouth afterswallowing are also noted as the after-taste.

The crust portions, which remained in the Petri dish during crumb examination, are evaluated for aroma and flavor in the same way as was the crumb.

Following this individual evaluation, the panel leader asks all panelists to read aloud their recorded impressions and an open discussion follows with the intent of clarifying individual responses and tuning in on significant aspects of the profile. At the session's end, the panel leader collects individual response sheets and assimilates them into a general consensus which is compared to previous and future replicates in order to arrive at the profiles which appear in this paper.

Definition of Terms

After-taste: Flavor impressions (tastes, odors, and feelings) perceived in the mouth, nose, and throat after swallowing a sample. These lingering impressions may strongly affect the degree of consumer acceptance. In the case of bread, after-tastes of doughy, yeasty aromatic, and wheaty may be considered desirable while notes of sour and bitter are generally undesirable.

Aroma: Odor and feeling sensations perceived through sniffing a substance

Bitter: One of the primary taste factors which is often associated with the burnt characteristic of bread crust and the bran fraction of whole wheat flour.

Browned: An odor reminiscent of browned (heated) flour. This term is often used to characterize the top and bottom crusts. It describes a complex aroma which probably arises from non-enzymatic browning reactions.

Burnt: An odor or flavor which describes the "sharp", "harsh" characteristic of a charred food. Burnt, as it is perceived in the top crust of bread, is closely associated with a bitter taste.

Caramel: A "complex", "rounded" odor which is characteristically sweet and reminiscent of caramel candy. An acceptable reference for this note was prepared by heating sweetened condensed milk until it solidified. This caramel aroma is often found in both top and bottom crusts.

Doughy: An odor similar to that of uncooked bread dough. This is a complex aroma which gradually diminishes in intensity on storage becoming less "rounded" and more starchy in character.

Doughy-starchy and Starchy-doughy: These terms describe aromas which contain characteristics of both doughy and starchy. The terms are combined due to their closely related nature. Doughy-starchy implies more doughy than starchy, while starchy-doughy indicates more starchy than doughy.

Feeling Factor: An impression which is perceived by the tissues of the mouth, nose, or throat which is neither a taste nor an odor. Feeling factors sometimes associated with breads are "dry mouth-feel", "nose burn", and astringency.

Fermented Sour: An impression of sourness which is closely associated with flavors of a fermented nature.

Flavor: Sensations perceived through the tissues of the mouth, nose, and throat--including tastes, odors, and feelings.

Fruity: An aroma which is characterized as somewhat sweet and estery and reminiscent of the aroma of such fruit as peaches and strawberries.

Lag: A delay in perception when food is taken into the mouth and prepared for swallowing.

Milky-sweet: A sweet note which seems closely associated with a milky impression.

Nutty: An odor which is reminiscent of roasted nuts and which is often associated with an oily flavor and feel. Whole wheat bread is characteristically nutty in flavor and aroma.

Odor: An impression (excluding feeling factors) which is perceived by the nose either through sniffing or when food is in the mouth.

Sour: One of the primary taste factors. It is a characteristic perception caused by acids in foods. Breads typically become more sour as they age.

Starchy: An odor reminiscent of a suspension of wheat starch in water. It is characteristically "sharp" or "raw" in contrast to the "fuller" more "rounded" aroma of doughly.

Sweet: A basic taste factor generally perceived in the presence of sugars. It is usually sensed by the tongue but may also be perceived as an aroma and may be closely associated with other notes.

Taste: Impressions of the primary or so-called "basic" tastes which include sweet, salty, sour, and bitter.

Total Intensity of Aroma (TIA): Odor and nosefeel sensations perceived through sniffing--an assessment of overall intensity.

Total Intensity of Flavor (TIF): An estimate of the overall intensity of all tastes, mouth feelings, and odors perceived when food is eaten; TIF does not, however, include after-tastes.

Wheaty: An odor reminiscent of cracked whole wheat, but generally more complex as perceived in whole wheat bread. The wheaty note in these breads is closely associated with both sweet and nutty.

Yeasty Notes: The dominant contributors to the flavor and aroma of white bread are notes which this panel ascribed to the apparent volatiles produced through yeast fermentation. This yeasty character is complex in nature and changes noticeably upon storage. Three terms were used to describe these notes:

Yeasty Aromatic: The "upper" or "estery" notes which are somewhat fruity and escape rapidly from bread which has been exposed to air or undergone storage.

Yeasty Fermented: The "middle" notes which are less complex than yeasty aromatic yet are still of a fermented nature.

Bottom Yeasty: The "lower" note which is reminiscent of old yeast and may be somewhat objectionable at high levels.

Table 2. Descriptive Flavor Analysis Scale

Intensities are designated by the following symbols:

)(	. . .	Threshold (just recognizable)
½	. . .	Between)(and 1
1	. . .	Slight
1½	. . .	Between 1 and 2
2	. . .	Moderate
2½	. . .	Between 2 and 3
3	. . .	Strong

RESULTS AND DISCUSSION

Flavor and aroma profiles of the white and whole wheat breads appear in Tables 3 and 4. Numbers which appear before each flavor or aroma note indicate the perceived intensity (as described in Table 2). TIF and TIA refer to total intensity of flavor and total intensity of aroma. They represent an overall impression of the sample being studied.

The following discussion deals first with the crumb and crust profiles of white bread, followed by those profiles of whole wheat bread. The tables are arranged so that crumb and crust profiles of both breads may be easily compared.

White Bread Crumb Aroma

The initial and dominant character of fresh white bread is a fragrant estery impression. This appears to arise as a result of yeast fermentation, and was therefore labeled as "yeasty aromatic". Yeasty aromatic was detected on Days 1 and 3, but this estery note diminished until, on Day 5, the top-notes had disappeared leaving middle-yeasty or fermented yeasty character.

Another yeasty note was identified as being reminiscent of old yeast. This was termed bottom-yeasty and was noted at a constant intensity (½) throughout the five day period. Most panel members listed this note last in order of appearance and its presence was thought to be somewhat objectionable. Caul and Vaden (1974) and Jackel (1961) also found that a yeasty note was perceived at a constant level throughout the aging periods.

Table 3. Crumb Flavor and Aroma for White and Whole Wheat Breads

	Day 1	Day 3	Day 5
<u>White Bread</u>			
Crumb Aroma	1 Yeasty Aromatic 1 Milky-Sweet 1 Doughy ½ Yeasty TIA = 1	1 Yeasty Aromatic ½ Milky-Sweet ½ Doughy-Starchy ½ Fermented Sour ½ Yeasty TIA = ½-1	½ Yeasty Fermented ½ Starchy-Doughy ½ Milky-Sweet ½ Fermented Sour ½ Yeasty TIA = ½-1
Crumb Flavor	1 Yeasty Aromatic 1 Doughy-Starchy Lag ½ Milky-Sweet ½ Sour)(Yeasty TIF = 1	½ Yeasty Aromatic ½-1 Doughy-Starchy Long Lag)(Milky-Sweet 1 Sour)(Yeasty TIF = ½-1	½ Starchy-Doughy ½ Yeasty Fermented Long Lag)(Milky-Sweet 1 Sour)(Yeasty TIF = ½
Crumb After- taste	Sweet Sour Doughy	Sour Doughy	Sour Doughy
<u>Whole Wheat Bread</u>			
Crumb Aroma	1½ Wheaty 1 Nutty ½-1 Sweet 1 Doughy TIA = 1-1½	1-1½ Wheaty 1 Nutty ½-1 Sweet ½-1 Doughy TIA - 1-1½	1 Wheaty 1 Nutty ½-1 Doughy ½ Sour ½ Sweet TIA = 1
Crumb Flavor	1½ Wheaty 1 Nutty ½-1 Doughy Lag ½ Sweet ½ Sour)(Bitter TIF = 1½-2	1 Wheaty ½-1 Nutty)(-½ Doughy Lag ½ Sweet ½-1 Sour)(Bitter TIF = 1-1½	1 Wheaty ½ Nutty Lag ½ Sweet ½-1 Sour)(Bitter TIF = 1
Crumb After-taste	Sour Wheaty	Sour Wheaty	Sour Wheaty

Table 4. Crust Flavor and Aroma for White and Whole Wheat Breads

	Day 1	Day 3	Day 5
<u>White Bread</u>			
Top Crust Aroma	1 Burnt 1 Browned ½ Caramel TIA = 1	1 Browned 1 Burnt ½ Caramel TIA = 1	½-1 Browned ½ Burnt ½ Caramel TIA = ½
Top Crust Flavor	½ Browned ½ Burnt 1 Bitter)(Sour TIF = ½-1	Lag ½ Browned ½ Burnt ½ Sour)(Bitter TIF = ½	Lag ½ Browned)(-½ Burnt ½ Sour)(Bitter TIF = ½
Top Crust After-taste	Bitter Burnt	Sour Bitter	Sour Bitter
Bottom Crust Aroma	½ Browned)(Caramel TIA = ½	)(Fruity ½ Browned)(Caramel TIA = ½	)(Fruity)(Browned)(Caramel TIA =)(
Bottom Crust Flavor	)(-½ Browned)(Sweet)(Sour TIF = ½	)(Fruity ½ Browned)(Sweet ½ Sour TIF =)(-½	)(Fruity)(Sweet)(Browned)(Sour TIF =)(
Bottom Crust After-taste	Caramel	Sour	Sour
<u>Whole Wheat Bread</u>			
Top Crust Aroma	1 Browned 1 Burnt ½ Wheaty ½ Caramel TIA = 1-½	1 Browned 1 Burnt ½ Caramel ½ Wheaty TIA = 1	½-1 Browned ½ Burnt ½ Caramel ½ Wheaty TIA = ½-1
Top Crust Flavor	½-1 Browned ½-1 Burnt ½ Sour 1 Bitter TIF = 1-1½	1 Burnt)(Sweet ½ Browned 1 Sour 1 Bitter TIF = 1	½ Burnt ½ Browned ½ Sour ½ Bitter TIF = ½-1
Top Crust After-taste	Bitter Sour	Bitter Sour	Bitter Sour

Table 4. Crust Flavor and Aroma (concluded)

	Day 1	Day 3	Day 5
Whole Wheat Bread			
Bottom Crust Aroma	1 Browned 1 Wheaty)(Sweet TIA = ½-1	½-1 Browned ½-1 Wheaty)(Sweet TIA = ½	½-1 Wheaty ½ Nutty)(-½ Browned)(Sweet TIA = ½
Bottom Crust Flavor	½-1 Browned ½ Sweet ½ Wheaty ½ Sour)(Bitter TIF = ½-1	½ Wheaty ½ Nutty ½ Browned)(Sweet ½ Sour)(Bitter TIF = ½-1	½ Wheaty ½ Nutty ½ Browned)(-½ Sweet ½ Sour)(Bitter TIF = ½
Bottom Crust After-taste	Bitter Sour	Bitter Sour	Bitter Sour

The sweetness detected in the aroma and flavor was described as milky-sweet since it was perceived as being closely associated with a creamy-milky aromatic. (It is interesting to note that the milky-sweet character is probably not entirely due to the presence of non-fat dry milk since, in a separate study, milky-sweet was also identified in breads which did not contain non-fat dry milk.) The milky-sweet note declined after Day 1 (from 1 to ½) and remained constant into Day 5.

The term doughy was used to describe an aroma perceived as similar to the aroma of uncooked bread dough. It was a complex and full aroma until Day 3 when it seemed to lose much of its rounded character, revealing a raw or starchy nature. By Day 5 the crumb aroma possessed more of a starchy character than doughy.

A sour note appeared in the aroma on Day 3. The panel described this impression as fermented sour. The term implies a complex quality, perhaps resulting from a combination of organic acids. Its intensity remained constant (½) into Day 5.

White Bread--Crumb Flavor

The overall or total flavor intensity (TIF) decreased (from 1 to ½) as the bread aged. This is important considering the fact that breads may age for two or three days before consumption by the consumer. It was fairly difficult for panel members to distinguish individual notes in the flavor of bread with a low TIF.

The initial flavor impression of the bread considered of the volatiles expelled upon compression in the mouth. On Day 1, yeasty aromatic was detected first then doughy-starchy. By Day 3, both notes had decreased in intensity and on Day 5 the doughy-starchy had become primarily starchy-doughy. It should also be noted that, on Day 5, starchy-doughy was detected before the yeasty-fermented note, thereby indicating a substantial change in initial flavor impression.

Following these expelled volatiles was a time lag in flavor perception while the crumb was being masticated. This lag increased in duration as the bread aged. Such a flavor lag may become important when we consider the tendency for many Americans to eat at a fairly rapid rate. Any delay in the onset of flavor perception may therefore be detrimental to the overall acceptability of the product.

Following the lag, milky-sweet was detected. Its intensity decreased (from ½ to)() by Day 3 and remained at the threshold level into Day 5.

On Day 1, a sour note was identified. It increased in intensity (from ½ to 1) by Day 3 and remained constant into Day 5.

Bottom-yeasty was noted at the threshold level throughout the five day period.

White Bread--After-Taste

Sweet, sour, and doughy were the impressions left in the mouth after tasting on Day 1. On Days 3 and 5 only sour and doughy remained, reflecting crumb flavors which were less sweet and more sour.

White Bread--Crust Aroma and Flavor

The top crust was characterized as having a burnt, browned, and caramel aroma which decreased in overall intensity as it aged.

The crust flavor contained these same aromatics and was also sour and bitter. The sourness increased through Day 5 (from)(to ½), possibly overiding bitterness.

The top crust after-taste was bitter and burnt on Day 1 then sour and bitter on Days 3 and 5.

The bottom crust aroma was perceived as browned and caramel until Day 3 when a fruity character was noted at threshold level.

The bottom crust flavor contained browned, sweet, and sour on Day 1, preceded by the appearance of the same fruity aromatic on Day 3. At this point it should be noted that no pan grease was used so as not to contribute additional volatiles to the crust aroma.

The total intensities of both top and bottom crusts decreased as the bread aged, and as expected top crust total intensities were greater than those of the bottom crusts.

Whole Wheat Bread--Crumb Aroma

The flavor and aroma profiles of whole wheat bread are strikingly different from that of white bread. A major difference is seen in the absence of any yeast-related notes. Instead, the relatively strong impressions of wheaty and nutty predominate.

The wheaty aromatic, which is reminiscent of cracked wheat, slightly decreases (1½-1) as the bread ages while the nutty character remains constant (1).

As in the white bread aroma, total intensity decreases with age, yet, the sour aromatic was not detected until Day 5. There was no starchy character in the whole wheat crumb, and the total intensity of the aroma was slightly greater than that of white bread.

Whole Wheat Bread--Crumb Flavor

The crumb flavor was characterized by the aromatics, wheaty, nutty, and doughy. These decreased in intensity through the aging period and on Day 5 doughy was not detected.

Following the lag, the taste factors sweet, sour, and bitter were noted. As in white bread, sour increased with age. Unlike white breads, however, sweetness remained constant. The bitter constituent, detected as threshold level, was not perceived by some panelists.

The total flavor and aroma intensities for the whole wheat crumb were considerably greater than those noted for white bread. However, both exhibited the same trend of decreasing intensities as the breads aged.

Whole Wheat Bread--Crumb After-Taste

The crumb after-taste was sour and wheaty throughout the five-day period.

Whole Wheat Bread--Crust Aroma and Flavor

The top crust aroma was characterized as browned, burnt, wheaty, and caramel. Only the browned and burnt intensities showed decreases into Day 5.

Besides its characterizing wheaty factor, the flavor had notes in common with white bread: browned, burnt, sour, and bitter, with a bitter and sour after-taste. But all total flavor intensities were stronger than those of white bread and no lag was observed during aging. A very low level sweet taste occurred only on Day 3.

The bottom crust aroma was browned, wheaty, and sweet with nutty appearing on Day 5.

The flavor was browned, sweet, wheaty, sour, and bitter; again, with nutty making a late appearance on Day 3.

The after-taste was bitter and sour, unlike white bread bottom crust in which bitter was detected in neither flavor nor after-taste.

Conclusions

The results of this study corroborated the work of Caul and Vaden (1972) in demonstrating the flavor and aroma changes in white bread as it ages. As in the Caul and Vaden (1972) study, panelists found that the characteristic sweet, aromatic, complex flavor and aroma of fresh white bread became less sweet, more sour, and less complex on aging. In addition, new information was generated concerning the flavor lag which is a delay in the onset of flavor release during mastication. This lag period increased in duration as the bread aged.

Replacing white patent flour with whole wheat flour allowed panelists to identify the specific flavor and aroma changes which occur as a result of this change in flour type. The whole wheat breads exhibited strikingly different flavor and aroma profiles compared to those of the white breads. A major difference, undoubtedly evident to consumers, is the greater level of overall aroma and flavor in all regions of whole wheat bread.

The yeasty notes which characterized white bread flavor and aroma were entirely absent from the whole wheat profile. Possibly, the predominant nutty and wheaty impressions masked these notes. As in white bread, sourness increased and most other notes decreased in intensity as the whole wheat bread aged. Unlike white bread, however, sweetness did not decrease but instead remained constant in whole wheat bread throughout the five-day period. Another important difference is in the detection of bitter in the whole wheat crumb. Most panelists could detect bitter at a threshold level, although it did not carry into the after-taste. The overall intensity of the whole wheat bread was significantly greater than that of white bread.

The results of this study describe the significant flavor and aroma differences which exist between white and whole wheat breads as they age. Whether or not these differences are responsible for consumer decisions or acceptability cannot be ascertained from a study of this kind. Further research in the form of market surveys and other consumer-based studies should be conducted to correlate specific flavor and aroma attributes to product preference. In addition, further flavor profile research may better elucidate the specific contributions of bran and germ in the development of the characteristic nutty-wheaty nature of whole wheat bread. This information may help development specialists better formulate whole wheat type products with specific goals of flavor attributes in mind.

Part II. The Effects of Granulation, Mixing Method, and Formulation on the Quality of Whole Wheat Bread

LITERATURE REVIEW

As was mentioned in Part I of this thesis, whole wheat bread requires special consideration with regard to production methods and conditions. The following study focuses on the mixing stage of the breadmaking operation.

Wheat is unique among the grains in that when it is mixed with water, an extensible, elastic dough is formed which, under the right conditions, will yield bread with a high specific volume and a fine, evenly distributed grain. These attributes are, however, difficult to achieve when using whole wheat flour. As was discussed in Part I, the presence of bran and germ introduces a host of difficulties to the developing dough.

Flour Granulation

Several granulations of whole wheat flour are commercially available, from extra-fine to coarse. These floursyield breads varying in appearance, texture, and possibly flavor.

Coarse flours generally result in bread having a rough exterior appearance and a relatively coarse, open grain. Bran flakes are clearly visible in the crumb and crust of this bread.

Fine whole wheat flour yields bread with a fairly smooth crust and a fine, even grain. There are generally no visible bran flakes and the crumb tends to be of a uniform dark color compared to the coarse flour crumb which is lighter in color (Moder 1980).

A fine granulation is generally recommended to achieve maximum volume of whole wheat bread. This recommendation is supported by three studies (Bohn and Machon 1933, Shetlar and Lyman 1944, and Moder 1980) which report slight improvements in volume with the finer granulation.

It is interesting to consider what chemical effects may result in the dough from the finer grinding of bran and germ particles. As was mentioned in Part I, bran and germ contain reducing agents and enzymes which are known to affect dough in a deleterious way. Grinding these wheat components may increase the rate of release of these compounds into the dough. Fine whole wheat flour doughs develop faster than those of a coarse granulation. This may largely be a result of differences in the rate of hydration of the particles, but it may also involve the increased rate of release of active compounds into the dough.

Dough Mixing

The mixing of whole wheat doughs is said to be very critical, because even a slight amount of overmixing may result in poor quality bread. For this reason, bakers recommend slightly undermixing the dough (Cain 1966, Becker 1975). The causes of this low mixing tolerance are unclear. One theory is that the effect is due largely to the disruptive influence of bran and germ particles. It is thought that these particles may actually disrupt the formation of a continuous gluten network which is in the process of dough development. Another important factor may be the presence of glutathione which is known to decrease both mixing time and tolerance.

If the movement of bran and germ particles in the dough does, in fact, damage the gluten network, then the manner in which dough is mixed takes on great importance. It is generally known that whole wheat doughs are best mixed at a slower speed than that of white doughs (Ponte 1981). Whether this recommendation should be applied to all granulations and all types of mixers is not known.

Dough mixers vary considerably in design. The most commonly used mixer in large-scale bakeries is the horizontal bar-type. This mixer develops a dough by the movement of horizontal bars through the dough mass in a manner which applies energy of compression, stretching, and shear. Retail bakers often use vertical mixers equipped with dough hooks. These mixers also apply compression, stretching, and shear to the dough.

Breadmaking research, on the other hand, generally makes use of pin-type mixers, such as the Mixograph, National Mixers, GRL Mixers, and Hobart/McDuffy Mixers. These mixers all employ more shearing than with the horizontal bar-type and dough hook mixers.

If, in fact, whole wheat doughs are damaged by excessive shearing, then the use of such mixers as the Mixograph and National Mixer for whole wheat research may be questioned.

One objective of the following study was to ascertain the effect of high shear mixing compared with "gentle" (no shear) mixing on the quality of whole wheat bread. "Gentle" mixing was achieved through use of a sheeter which is analogous to "dough brake" mixing.

The Dough Brake (Sheeting) Method of Mixing

Dough brakes are the principal means of dough mixing in many areas of the world, including parts of Southeast Asia, Africa, Central and South America, and elsewhere (Tweed 1979, Moss 1980). Dough brakes usually consist of a pair of steel rolls through which dough is repeatedly folded and passed. Thus, the dough undergoes sheeting which refers to the compression and stretching of the dough (without tearing or shearing) to achieve optimum dough development.

Due to the labor intensive nature of the dough brake, its use has been limited to small-scale operations and has only recently been the subject of research. Kilborn, et al. (1972, 1981) found that the dough brake is a highly efficient means of mixing. They investigated several methods of using the brake to develop the dough. Each of these methods produced bread which was comparable to bread mixed with their GRL 200 and 1000 (pin-type) mixers. They also found that the dough brake consumed less energy to develop doughs than was used by these other mixers. Bushuk and Hulse (1974) compared bread made by sheeting with that produced by the Chorleywood process which utilizes high speed, energy intensive mixing. They found little or no difference between the qualities of the two bread types. These results indicate that sheeting is capable of producing breads equal in quality to those produced by laboratory pin-type mixers.

With regard to the mixing of whole wheat doughs, however, the suitability of dough brake mixing has yet to be established. The two studies which have investigated aspects of whole wheat dough mixing (Moder 1980, Bohn and Machon 1933) used pin-type mixers and no consideration was given to the effect of mixing action on the subsequent quality of the breads.

The present study attempts to ascertain the applicability of the sheeting method of dough development in the production of whole wheat bread. It will be determined whether or not this sheeting method produces bread equal to or better than bread made with the pin-type mixer.

Two flour granulations and various levels of water, oxidant, shortening, and emulsifier were tested for each method in an attempt to determine the role of these ingredients in whole wheat dough development and the subsequent quality of the bread.

Absorption

Absorption may be generally defined as "the amount of liquid that is required to give a dough with proper handling and machining properties and that will produce the best final baked product." (Pyler 1979)

The absorption of whole wheat flour is generally several percentage points higher than that of white patent flour. This is due to the fact that wheat bran seems to absorb more water (on a weight per weight basis) than do endosperm particles. Despite this increased absorption, optimum whole wheat doughs are generally stiffer than white doughs (Bohn and Machon 1933, Ponte 1981).

The effect of whole wheat flour granulation on water absorption has not been elucidated. It would seem likely that large bran and germ particles would hydrate more slowly than those which are small. It is also conceivable that the increased surface area of finer granulations may result in differences in the manner and extent of water binding in the finished loaf compared with that of the coarser granulation flour.

It has been observed in our laboratory that whole wheat bread exhibits mold growth more rapidly than does white bread. This may indicate that much of the water in the whole wheat bread exists as free water rather than being bound to starch, protein, or other components.

The presence of more free water is interesting in light of research by Derby et al. (1975). They found that during the baking of doughs starch undergoes gelatinization only to a limited extent. This is the result of starch having to compete for water with other dough constituents.

In whole wheat doughs, the additional water which is absorbed by bran and germ particles may be readily available for starch gelatinization. An x-ray diffraction study[1] suggests that starch is more completely gelatinized in whole wheat bread than in white bread made from the same wheat.

These results may, in part, explain why stiffer whole wheat doughs tend to yield bread with greater volume and finer grain than do slacker doughs. The stiffer doughs would probably result in less starch gelatinization and, therefore, less disruption of cell walls which may depend

[1]Victor Ke, unpublished data

on the presence of intact starch granules for maintenance of structural integrity.

Shortening and Emulsifiers

It is generally necessary to incorporate some sort of liquid or solid fat (shortening) into any breadmaking formula. Shortening addition results in improvements in volume, grain, and eating properties. The mechanism for this improvement is not fully understood, but recent research has brought forth some interesting ideas.

Apparently shortening plays an important role in mixing. Jung *et al.* (1981), through measurements of dough densities and scanning electron microscopy, concluded that while shortening does not cause more air to be incorporated into the dough, it does allow the formation of more and smaller cells during the mixing stage.

Shortening also appears to delay the setting of the bread crumb in the oven (Junge and Hoseney 1981), thereby allowing it to raise longer and higher, resulting in greater volume compared to bread made without shortening. This would seem to indicate that shortening delays the gelatinization of the starch, but differential scanning calorimetry did not confirm this difference in starch gelatinization between breads made with and without shortening.

Moder (1980) showed that the improving effect of shortening was greater with whole wheat flour than with white patent flour from the same wheat variety. This result is interesting in light of the previously mentioned data which indicate that starch from whole wheat breads is more completely gelatinized than that of white breads. If shortening's main effect is in delaying the gelatinization of starch during baking, and, given that shortening improves whole wheat bread volume more than that of white bread, then one might assume that the rate and extent of starch gelatinization play an important role in determining the volume and grain of whole wheat bread.

Apparently, emulsifiers act in a similar way. Shogren, et al. (1980) and Hoseney (1976) compared various surfactants and found that diacetyl tartaric acid esters of monoglycerides (DATA) outperformed most other surfactants. Moder (1980) used it in his work with whole wheat breads. He found that breads which contained one percent DATA and no shortening exhibited better volume and grain than breads made with both 0 and 3% shortening. For this reason, DATA was chosen for use in the following study. DATA has GRAS (generally recognized as safe) status with the FDA, and there is no limit for its addition to bread doughs.

Oxidation

Most flours require the addition of an oxidant in order to produce the optimum quality loaf. Underoxidized and overoxidized breads both exhibit low volume, coarse grain, and poor appearance.

Oxidation requirements of whole wheat flour were investigated by Bohn and Machon (1933). They found that coarser granulation flours required more oxidant addition than did finer granulations.

Considering the presence of reducing agents in bran and germ, it seems likely that oxidation is of primary importance in whole wheat bread production.

In addition, it is important to consider the extent and rate of oxygen incorporation into the dough while mixing since a certain amount of oxidation occurs as a result of this action (Pyler 1978). Since the following study compares two types of mixing actions, the potassium bromate level was varied. This was done to determine the combined effects of particle size and mixing procedure on oxidation requirements.

MATERIALS AND METHODS

Flour

The whole wheat flour used for this study was donated by the Pillsbury Co., Minneapolis, Minnesota. Whole wheat flours of two granulations were obtained. These flours were reported to have originated from the same blend of wheats. Table 5 gives the proximate analysis of these flours.

Table 5. Proximate Analysis for Whole Wheat Flours

Flour granulation	Moisture %	Protein %	Ash %	Fat %	Crude fiber %
Fine	12.1	13.9	1.7	2.0	2.5
Coarse	12.4	13.9	1.7	1.6	2.9

Mailhot and Miller (1981) have suggested specifications for some ingredients used in variety breads. For whole wheat flour they recommend a maximum moisture of 14.0%, 1.6% +/- 0.2% ash, and a minimum of 14.0% protein. The flour used in this study falls within these specifications with the exception of protein. However, subsequent dough and bread characteristics indicated that the protein content was sufficient.

Table 6. Whole Wheat Flour Farinograph Results

Flour granulation	Arrival time (min.)	Peak time (min.)	Departure time (min.)	Tolerance index (BU's)	Stability (mins.)	Time to breakdown (mins.)	Absorption %
Fine	4.0	6.4	17.5	18	13.5	17.5	69.4
Coarse	4.8	7.0	17.0	20	12.2	17.8	69.0

The two flours were run on the Brabender Farinograph using AACC method 54-21 (constant flour weight procedure.) Table 6 presents the averaged results from two replicates, while the farinograph curves are shown in Figure 1 .

Both flours performed satisfactorily in that their curves indicate relatively good tolerance and stability. The fine granulation flour appeared to hydrate more rapidly, as is evidenced by its shorter arrival time, compared to the coarse granulation. In addition, the peak time of the fine flourwas less than that of the coarse flour. The coarse granulation flour also appeared to break down more rapidly than does the fine granulation.

Granulation

Granulation was determined using the sieve combination recommended by Mailhot and Miller (1981). Sieves were secured on a Rotap Sieve Shaker and the flour was allowed to sift for two minutes. Table 7 presents the average granulations of three replicates for each test flour as well as granulations suggested by Mailhot and Miller.

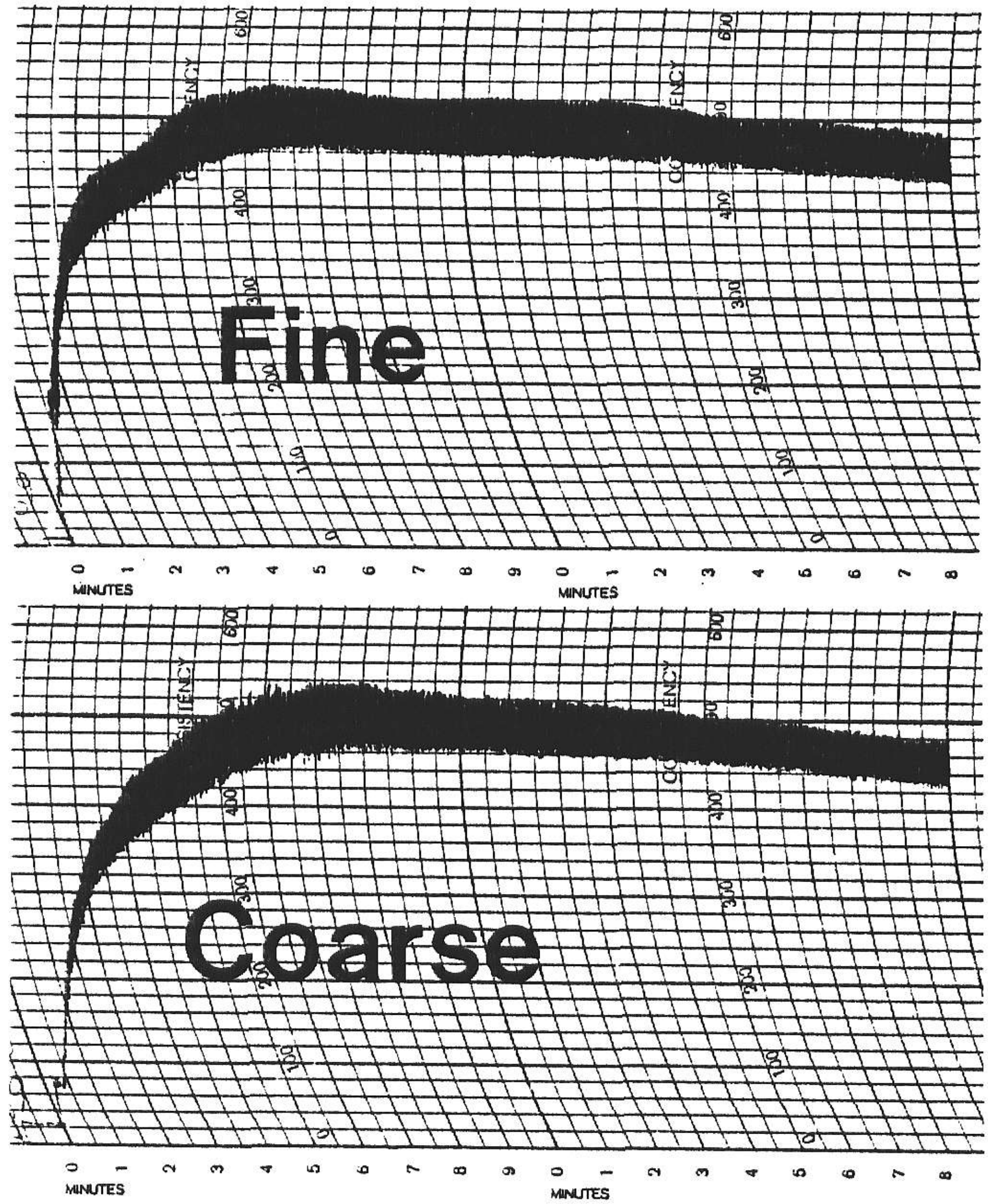


Figure 1. Farinograph curves for fine and coarse whole wheat flours.

Table 7. Whole Wheat Flour Granulation

U.S. Standard Sieve #	Fine Actual %	Fine Recommended %	Coarse Actual %	Coarse Recommended %
on 20	0	1	11	11
on 45	14	11	40	14
on 80	50	12	28	20
on 120	30	13	10	18
through 120	6	63	10	37

In comparing the suggested specifications with the actual results obtained from the flours used in this study, it is clear that some differences exist. This is not surprising when we consider the many milling methods which are employed in producing whole wheat flour. In one method, wheat is milled into its various fractions and then recombined and sold as whole wheat flour. Another technique involves grinding the wheat kernel directly to the desired granulation. Each of these methods may yield flours with various granulations of bran, germ, and endosperm particles.

Whole Wheat Bread Formula

The sponge and dough and straight dough methods are among the two most prevalent breadmaking procedures. Of these two, the straight dough method is generally less tolerant to processing variations and therefore more readily shows differences between treatments, so it was chosen for use in this study.

The formula used in the study appears in Table 8 . It is typical of formulas used to produce commercial whole wheat bread.

Table 8. Whole Wheat Bread Formula

Ingredient	%	Weight (grams)
Whole wheat flour	100	280
Water	variable	variable
Sugar	6	16.8
Shortening	variable	variable
Salt	2	5.6
Vital wheat gluten	2	5.6
Non-fat dry milk	2	5.6
Instant dry yeast	1	2.8
Potassium bromate	variable	variable
DATA (emulsifier)	variable	variable

An all-purpose partially hydrogenated soybean oil shortening (Richtex) from Kraft Inc. was used. In addition, the emulsifier, diacetyl tartaric acid ester of monoglycerides or DATA (Panodan-SDK) was obtained from Grindsted Products, Inc. This product is a highly viscous fluid and was combined with the flour just before mixing.

A dry instant yeast (Fermipan) from G. B. Fermentation Industries, Inc. was used. This yeast was rehydrated in a sugar solution prior to mixing to insure adequate dispersion and hydration in the dough (Bruinsma and Finney 1981).

Mixing Methods and Energy Requirements

All doughs were initially mixed on a National Mixer, Model 17LT, using a two quart capacity bowl. This mixer utilized four moving pins attached to the mixing head and two stationary pins in the bowl to impart energy to the dough. The National Mixer was chosen because its pin-type mixing action imparts a tearing and shearing action to the dough. This characteristic is ideally suited for this study which attempts to determine the effect of high shear mixing on the quality of whole wheat bread. Another advantage of this mixer is in its adaptability to power and energy measurements.

These measurements were made possible with the use of a power input meter, designed by researchers (Kilborn and Dempster 1965) at the Canadian Grain Research Laboratory, and constructed by the Physics Department of Kansas State University.

The unit is connected to the mixer motor and measures the electrical resistance which results from the dough's resistance to mixing. Thus, the power imparted to the dough is displayed in watts and the accumulated energy or work appears as watthours. It is therefore possible to determine work requirements for the test doughs. In addition, a chart recorder (Omniscribe, Houston Instruments, Inc.) draws a mixing curve which is similar in appearance to farinograph or mixograph curves.

Preliminary work with the power meter demonstrated that the Hobart/McDuffy pin-type mixer did not yield a curve with a distinctive peak, and instead recorded many peaks and valleys during dough mixing. The curve was, therefore, difficult to interpret. The National Mixer, on the other hand, exhibited a distinctive peak and was therefore judged to be more useful for the purposes of this study.

In order to measure a gentle sort of mixing, a method was used which employs only stretching and compression. This is the dough brake or sheeting method of mixing.

A Rondo sheeter was used in the following study; its reversible belt and readily adjustable roll gap width allowed doughs to be effectively sheeted and folded as was described by Kilborn and Tipples (1974). The dual roll gap technique of sheeting was used. Kilborn and Tipples found that method to be a highly efficient way of developing a dough. It involves folding a dough in half, turning it 90^{0}, passing it through the rolls, reducing the roll gap, passing the dough through again, re-setting to the first gap, then repeating the process. In this way, the dough receives X number of passes and is folded ½(X-2) times. In order for the dough to receive the maximum amount of work during each pass, the following equation was derived. The equation determines optimum gap proportions.

$$\text{Gap width \#1} = (3/2)\ \text{Gap width \#2}$$

Using this equation, several gap combinations were tried. The combination of Gap #1 = 4.5 mm and Gap #2 = 3.0 mm seemed to be most satisfactory under all variable conditions. Narrower gaps tended to tear those doughs with higher absorptions, while wider gaps did not seem to impart sufficient energy to develop doughs in a reasonable amount of time.

Breadmaking Procedure

Preliminary bakes were conducted to determine optimum conditions for subsequent trials. Various levels of the independent variables, absorption, shortening, potassium bromate, mix time, and number of passes through the sheeter were investigated. From these results, ranges and intermediate levels were set to conform to the response surface design.

In optimizing the mixing procedure, it was necessary to adjust the ingredient weight so as not to overload the mixer. Whole wheat doughs are generally mixed stiffer than white doughs, but a constant flour weight of 480 grams mixed without undue strain on the mixer. From each dough 500 grams was scaled and, upon baking, it approximately yielded a one pound loaf.

It is common knowledge that the temperature of a dough coming from the mixer does influence the resulting bread quality. It is therefore important to monitor dough temperatures in experimental and commercial baking, and, if possible, to control them as well.

Preliminary work in this study revealed that dough temperatures varied considerably (from 70^{o} to 82^{o}F). This was due largely to differences in mixing procedure. Doughs mixed with the sheeting method consistently showed relatively low dough temperatures (70^{o} to 74^{o}F) due to their repeated contact with the sheeter's steel rolls which appeared to act as a heat sink. Raising the temperature of the ingredient water did not prevent these doughs from eventually reaching room temperature upon repeated sheeting.

Doughs mixed in the National Mixer exhibited consistently higher temperatures than did the sheeted doughs. Ice water (32^{o}F) was used in an attempt to lower these temperatures, but still the temperatures tended to be 3 to 6^{o}F higher than those of the sheeted doughs. Bake-shop procedures often call for the addition of ice to further lower dough temperatures, but it was thought that this could interfere with energy measurements of the doughs. Instead, it was decided that all doughs mixed on the National Mixer would use 32^{o}F water and that all sheeted doughs use 75^{o}F water. This resulted in average dough temperatures of 77^{o} and 72^{o}F for the National Mixer doughs and the sheeter doughs, respectively.

An effort was made to determine the importance of these temperature differences. Since the dough pieces were of a relatively small size, it was thought that they might readily reach the ambient temperature of the fermentation cabinet (85^{o}F). This was shown to be true when dough temperatures were monitored for test doughs which originally varied in temperature from 72^{o} to 78^{o}F. By the end of the fermentation period all doughs had arrived at the cabinet's temperature of 85^{o}F. Statistical analysis of covariance confirmed that dough temperature in this study did not significantly affect the dependent variables of proof time, specific volume, and grain score (average correlation coeficients (r) = -0.49, -0.03, and -0.04, respectively).

Optimum fermentation time was found to be three hours. This appears to be somewhat long in view of the general belief that whole wheat doughs require shorter fermentation times than do white doughs. But, perhaps the colder doughs used for this study (average dough temperature out of the mixer was 74^{O}F) require more fermentation time than do warmer doughs (a dough temperature of 78^{O}F is sometimes recommended for whole wheat doughs).

Pin-Type Mixing Procedure

All dry ingredients except yeast were blended in advance, while shortening and emulsifier were added just before mixing. Bromate solution was added to the dough water.

The dry yeast and an equal amount of sugar were dissolved in 50 ml. of 95^{O}F water and allowed to sit for five minutes. This was then poured along with the dough water onto the dry ingredients. At this point, the mixer was started, and simultaneously the power input meter was turned on. The chart recorder had been previously calibrated to a full scale response of 0 to 200 watts. Mixing was then allowed to proceed for the specified time.

After mixing, the dough was gently rounded by hand then allowed to ferment at 85^{O}F, 86% relative humidity for 105 minutes. At this time it was hand punched and allowed to ferment for an additional 75 minutes.

The dough piece was then scaled to 500 grams and twice sheeted through a National sheeter at settings of 7/16 (11 mm) and 1/4 inch (4.5 mm). After triple folding, the dough was allowed to rest for 15 minutes; at which time it was molded in a Moline molder with rolls set at 2 and 1 with the pressure plate height at 1 inch (2.5 mm) back and 7/8 inch (2.3 cm) front.

The dough was then panned and allowed to proof at 105^{O}F, 90% relative humidity until it rose to 1 cm above the top of the pan. It was then baked at 425^{0} F for 21 minutes.

Volumes were determined immediately after baking by rape seed displacement, and the loaves were then weighed for specific volume determination.

Sheeter (Dough Brake) Mixing Procedure

Ingredients were scaled and doughs were mixed as in the pin-type mixing procedure. At three minutes mix time the mixer was stopped and the dough was gently rounded by hand. It was then taken to the sheeter and a light dusting of flour was applied. The dough piece was then passed twice through the rolls at gap widths of 20 mm. and 10 mm. At that point, the dough was ready to be sheeted through gap widths of 4.5 mm. then 3.0 mm., then folded, turned 90^{0}, and the process repeated for a specific number of times as determined by the experimental design.

After sheeting, the dough was fermented, rounded, panned, proofed, and baked as in the previous procedure.

Bread Scoring

Grain characteristics were observed and noted one day after baking. An optimum crumb grain exhibits small, uniform holes which have thin cell walls and are slightly elongated. A rating scale of 0 to 10 was used in which 10 represents the best possible grain and 0 is the worst.

Experimental Design

Response Surface Methodology (RSM), as described by Cochran and Cox (1957). was used in this study. The technique involves the use of a partial factorial design so that many variables may be simultaneously investigated without the burdensome necessity of testing every combination. This is made possible by use of a computer program which takes observed data points and uses them to derive models. These models are in the form of equations which can approximately predict the influence of any combination of independent variables, such as absorption and mix time, on the value of any dependent variable, such as grain score.

The study was divided into four separate experiments. Each of these had five variables which were each tested at five different levels. The levels of each independent variable are presented in Tables 9 and 10, while the overall design used for each experiment appears in Table 11.

The first two experiments involved the mixing of fine (experiment 1) and coarse (experiment 2) whole wheat flours in the National Mixer. Independent variables were: mix time, shortening, DATA, absorption, and potassium bromate.

The third and fourth experiments utilized fine (experiment 3) and coarse (experiment 4) whole wheat flours in mixing by the sheeting method. Independent variables were: number of passes through the sheeter, shortening, DATA, absorption, and potassium bromate.

Dependent variables common to all experiments were: dough temperature, proof time, loaf volume, specific volume, loaf weight, grain score, curve height, and work input.

As a part of the response surface program, dependent variables were used as input data and the regression coefficients for the model of each variable were generated as computed by the Taylor expansion equation. In order to best present these data, model equations were used to predict the results of any combination of variables on the values of dependent variables. This was done by giving all but two of the independent variables specific values and then generating a contour plot which shows the response of one dependent variable for two independent variables. In this way, relationships among the variables could be graphically represented.

Table 9. Pin-Type Mixing (Experiments 1 and 2) Variables and Their Levels for RSM Study

Variables	Symbol	Code				
		-2	-1	0	1	2
Mix time (min.)	x_1	4	5.25	6.5	7.75	9.0
Shortening (%)	x_2	0	1.50	3.0	4.50	6.0
DATA (%)	x_3	0	0.25	0.5	0.75	1.0
Absorption (%)	x_4	68	69.75	71.5	73.25	75.0
Potassium bromate (ppm)	x_5	0	7.50	15.0	22.50	30.0

Table 10. Sheeting (Dough Brake) Mixing (Experiments 3 and 4) Variables and Their Levels for RSM Study

Variables	Symbols	Code				
		-2	-1	0	1	2
# of passes through sheeter	x_1	0	25.00	50.0	75.00	100.0
Shortening (%)	x_2	0	1.50	3.0	4.50	6.0
DATA (%)	x_3	0	0.25	0.5	0.75	1.0
Absorption (%)	x_4	68	69.75	71.5	73.25	75.0
Potassium bromate (ppm)	x_5	0	7.50	15.0	22.50	30.0

Table 11. RSM Design for Five Variables at Five Levels

Number	Variables				
	x_1	x_2	x_3	x_4	x_5
1	-1	-1	-1	-1	1
2	1	-1	-1	-1	-1
3	-1	1	-1	-1	-1
4	1	1	-1	-1	1
5	-1	-1	1	-1	-1
6	1	-1	1	-1	1
7	-1	1	1	-1	1
8	1	1	1	-1	-1
9	-1	-1	-1	1	-1
10	1	-1	-1	1	1
11	-1	1	-1	1	1
12	1	1	-1	1	-1
13	-1	-1	1	1	1
14	1	-1	1	1	-1
15	-1	1	1	1	-1
16	1	1	1	1	1
17	-2	0	0	0	0
18	2	0	0	0	0
19	0	-2	0	0	0
20	0	2	0	0	0
21	0	0	-2	0	0
22	0	0	2	0	0
23	0	0	0	-2	0
24	0	0	0	2	0
25	0	0	0	0	-2
26	0	0	0	0	2
27	0	0	0	0	0
28	0	0	0	0	0
29	0	0	0	0	0
30	0	0	0	0	0
31	0	0	0	0	0
32	0	0	0	0	0

RESULTS AND DISCUSSION

As is the case with any study using the RSM method of statistical analysis, results are primarily in the form of contour plots. For this reason, the discussion of results is based mainly on the interpretation of these plots. It is therefore important to mention that the contour plots are not observed data, but are instead predicted data points which arise from the computer generated equations. These equations are derived from experimental results which can be found in Appendix Tables 1 and 2.

The RSM program is designed to assess each dependent variable separately. Thus, several equations in the following general form are calculated.

$$\text{Dependent variable} = B + A_1(MT) + A_2(SH) + A_3(EM) + A_4(ABS) + A_5(KBR) + A_6(MT^2) + A_7(MT)(SH) + A_8(SH^2) + A_9(MT)(EM) + A_{10}(SH)(EM) + A_{11}(EM^2) + A_{12}(MT)(ABS) + A_{13}(SH)(ABS) + A_{14}(EM)(ABS) + A_{15}(ABS^2) + A_{16}(MT)(KBR) + A_{17}(SH)(KBR) + A_{18}(EM)(KBR) + A_{19}(ABS)(KBR) + A_{20}(KBR^2)$$

MT = mix time or number of passes, SH = shortening, EM = emulsifier (DATA), ABS = absorption, KBR = potassium bromate.

The degree to which the observed results fit the generated equation is given in the form of the regression coefficient, R^2. Also derived were the probabilities associated with these coefficients. These values are given for each dependent variable in Table 12. A regression coefficient of 1 would indicate that all observed data points fit the model equation exactly. In general, any coefficient which falls below 0.8 should be regarded with suspicion. Such low values may either result from experimental error or from the inability of the model equation to satisfy the observed response. The probabilities which accompany the regression coefficients indicate the likelihood that the generated equation does not fit the experimental results. Thus, probabilities of 0.05 and below are considered acceptable.

Table 12 shows that some of the dependent variables exhibit low regression coefficients and high probabilities, therefore it is doubtful that the RSM equations are meaningful in the evaluation of these variables. Dough temperature, proof time, and weight all have average regression coefficients of less than 0.8 and probabilities higher than 0.05. For this reason they may be considered to either be independent of the variables tested or that their standard deviations are sufficiently high to disguise any observable trends.

The values of curve height and work input yield data which is pertinent to the evaluation of the rheological behavior of the doughs. Since work input is generally recognized as an important parameter in dough mixing, it was used to generate contour plots instead of the variable, curve height.

Contour plots were generated for both volume and specific volume of the experimental loaves. Some controversy exists as to which parameter is a more valid source of comparison. For this study, plots of the two

Table 12.

Dependent variable	Experiment #	Granulation	Total regression R^2	Total regression Probability	Mean
Dough temperature	1	Fine	0.679	0.409	77.8
	2	Coarse	0.695	0.359	75.5
	3	Fine	0.766	0.159	72.1
	4	Coarse	0.680	0.409	72.5
Curve height	1	Fine	0.958	0.0001	81.3
	2	Coarse	0.901	0.004	43.0
	3	Fine	0.686	0.386	37.8
	4	Coarse	0.765	0.160	24.7
Work input	1	Fine	0.994	0.0001	17.5
	2	Coarse	0.965	0.0001	9.97
	3	Fine	0.901	0.0043	5.48
	4	Coarse	0.977	0.147	3.61
Proof time	1	Fine	0.637	0.545	47.9
	2	Coarse	0.836	0.043	50.8
	3	Fine	0.914	0.217	48.3
	4	Coarse	0.690	0.375	50.6
Loaf volume	1	Fine	0.894	0.006	2220.0
	2	Coarse	0.818	0.062	2216.0
	3	Fine	0.975	0.016	2308.0
	4	Coarse	0.823	0.056	2259.0
Specific volume	1	Fine	0.904	0.0033	4.94
	2	Coarse	0.835	0.042	4.94
	3	Fine	0.817	0.063	5.16
	4	Coarse	0.830	0.048	5.04
Weight	1	Fine	0.712	0.304	449.0
	2	Coarse	0.680	0.406	449.0
	3	Fine	0.691	0.371	448.0
	4	Coarse	0.718	0.288	448.0
Grain Score	1	Fine	0.831	0.046	7.49
	2	Coarse	0.703	0.332	5.36
	3	Fine	0.960	0.046	7.88
	4	Coarse	0.957	0.056	5.86

variables were nearly identical so it was decided to limit the presentation to those plots which used specific volume.

<u>Absorption and Mix Time</u>

The optimum absorption for any given breadmaking system depends upon a host of formula and processing variables. This study sheds some light on the effects of flour granulation, shortening level, and mixing method on the absorption requirements of whole wheat bread.

Figures 2 and 3 show the effects of various levels of absorption and mix time on the specific volume of the fine granulation whole wheat bread. All other variables were held constant with the exception of shortening which was set at 0% in Figure 2, and at 6% in Figure 3 . In comparing the two plots it is clear that the apparent optimum conditions shift as the level of shortening is increased. With no shortening in the formula, the optimum absorption is at about 73% with a corresponding mix time of 5 minutes. With 6% shortening, the optimum absorption has decreased to about 71% with the longer mix time of 8 minutes.

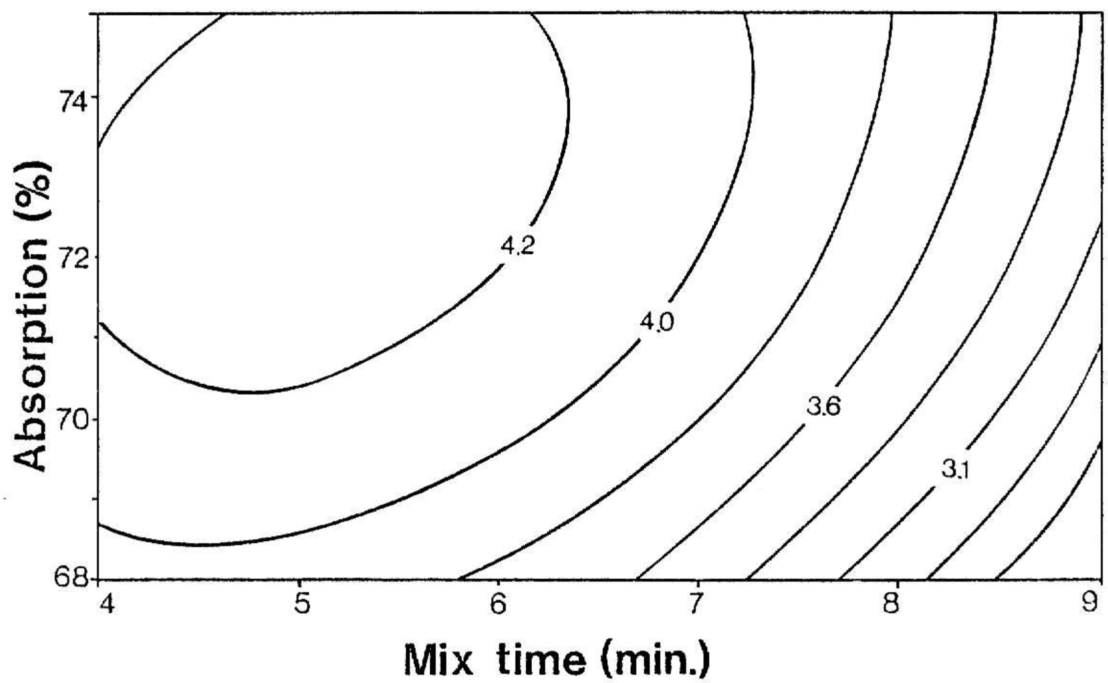
This same trend is apparent for the dependent variable of grain score.

Figures 4 and 5 reveal that nearly the same conditions which are optimum for achieving specific volume are also optimum for achieving the highest grain scores.

The breads made with the coarse granulation whole wheat flour exhibit strikingly different contour plots. Instead of the elliptical shapes apparent in the fine granulation plots, diagonal contours are present. Figures 6 and 7 show the effect of absorption and mix time on the specific

Fig. 2. Contour plot of specific volume (cc/g.) for absorption and mix time of fine whole wheat flour mixed in pin-type mixer. (0% shortening, 0.5% DATA, and 15 ppm $KBrO_3$.)

Fig. 3. Contour plot of specific volume (cc/g.) for absorption and mix time of fine whole wheat flour mixed in pin-type mixer. (6% shortening, 0.5% DATA, and 15 ppm $KBrO_3$.)


4.2
4.0
3.6
3.1
74
72
70
68
Absorption (%)
4
5
6
7
8
9
Mix time (min.)

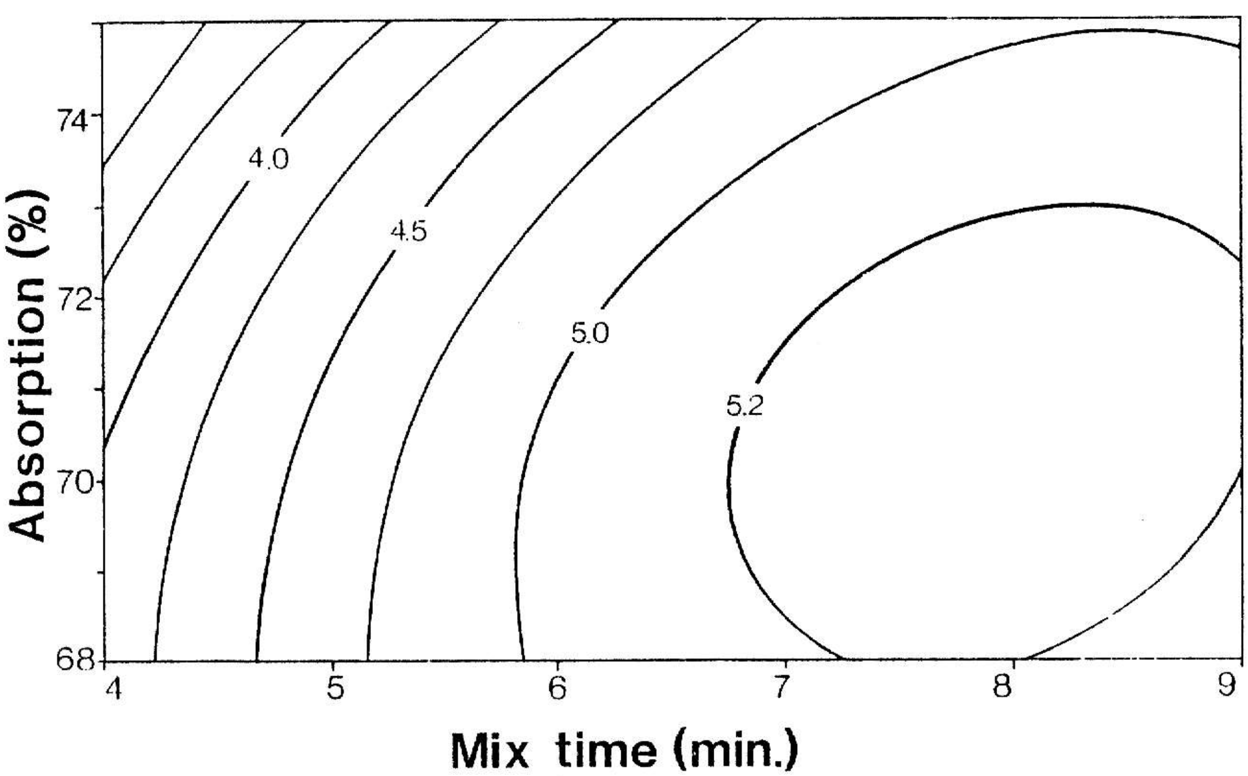
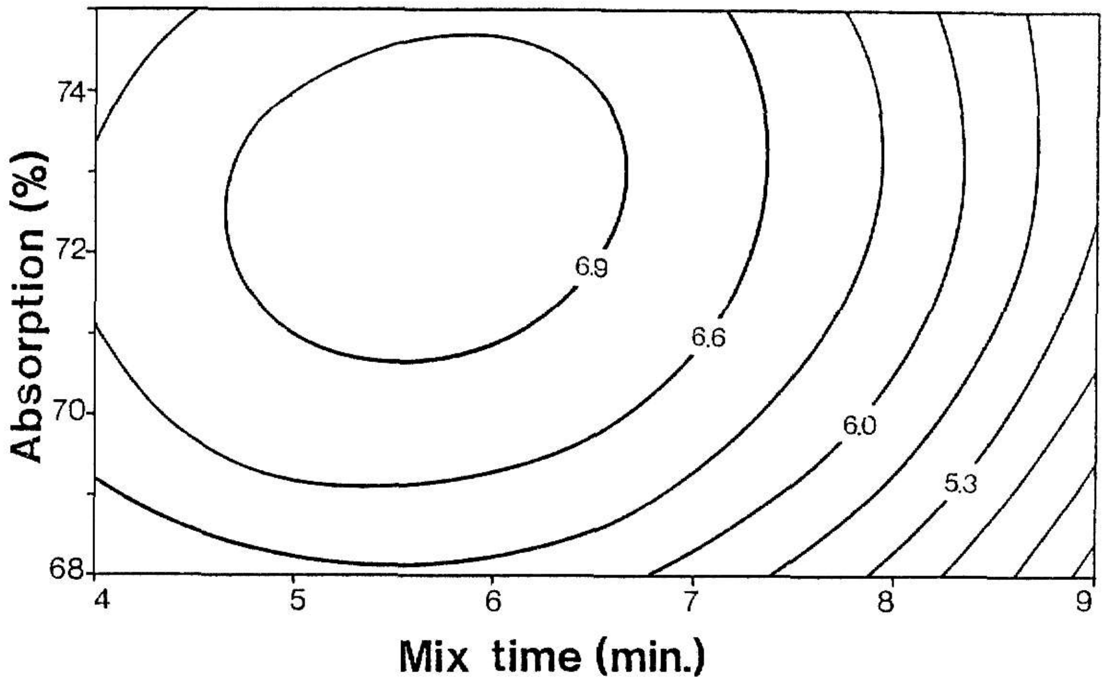

4.0
4.5
5.0
5.2
74
72
70
68
Absorption (%)
4
5
6
7
8
9
Mix time (min.)

Fig. 4. Contour plot of grain score for absorption and mix time of fine whole wheat flour mixed in pin-type mixer (0% shortening, 0.5% DATA, and 15 ppm $KBrO_3$).

Fig. 5. Contour plot of grain score for absorption and mix time of coarse whole wheat flour mixed in pin-type mixer (6% shortening, 0.5% DATA, and 15 ppm $KBrO_3$).


Absorption (%)
74
72
70
68
6.9
6.6
6.0
5.3
4
5
6
7
8
9
Mix time (min.)

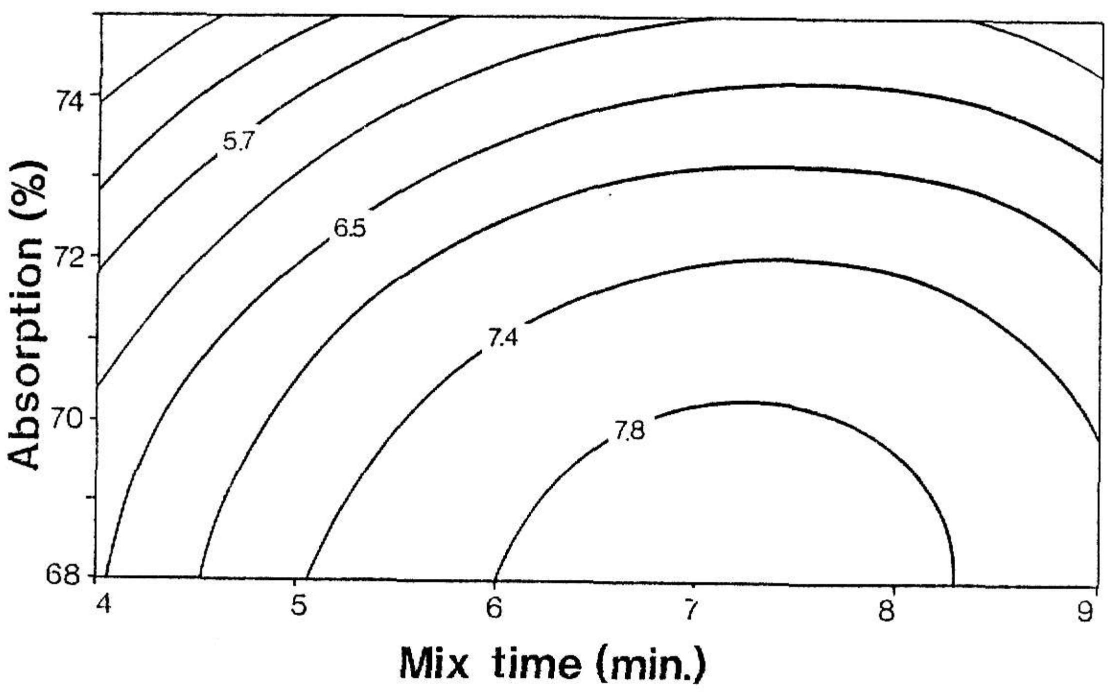
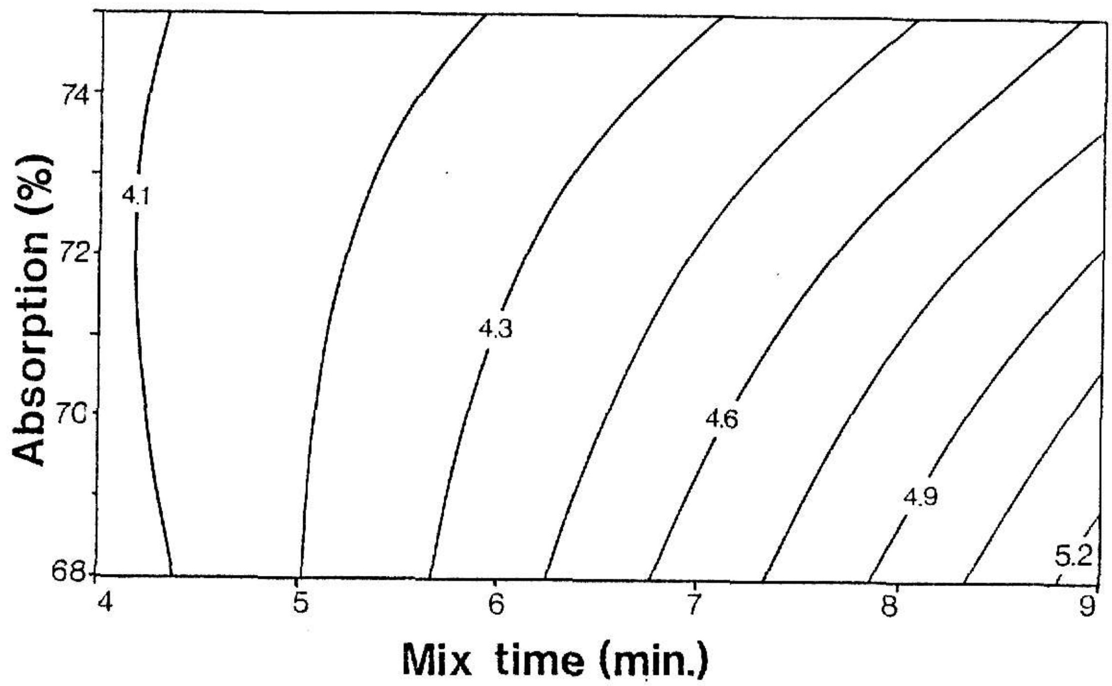
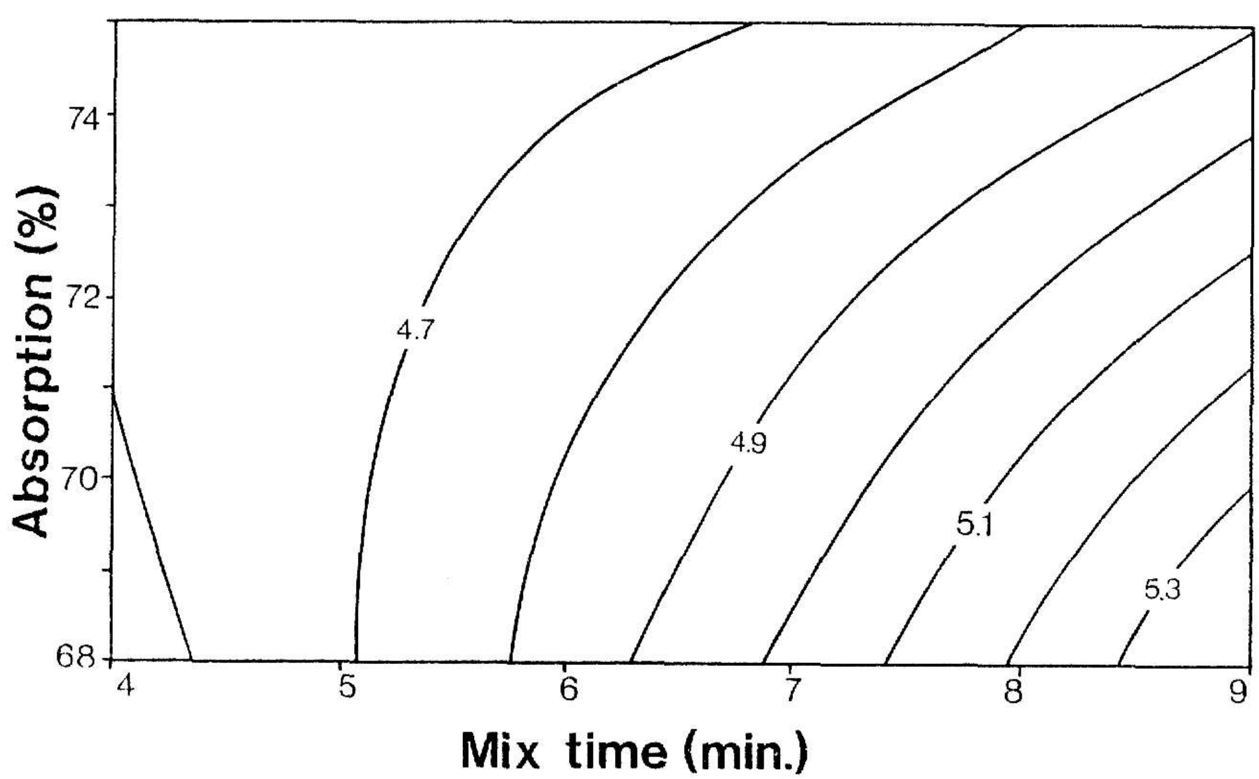

Absorption (%)
74
72
70
68
5.7
6.5
7.4
7.8
4
5
6
7
8
9
Mix time (min.)

Fig. 6. Contour plot of specific volume (cc/g.) for absorption and mix time of coarse whole wheat flour mixed in pin-type mixer (0% shortening, 0.5% DATA, and 15 ppm $KBrO_3$).

Fig. 7. Contour plot of specific volume (cc/g.) for absorption and mix time of coarse whole wheat flour mixed in pin-type mixer (6% shortening, 0.5% DATA, and 15 ppm $KBro_3$).


4.1
4.3
4.6
4.9
5.2
74
72
70
68
4
5
6
7
8
9
Absorption (%)
Mix time (min.)


4.7
4.9
5.1
5.3
74
72
70
68
4
5
6
7
8
9
Absorption (%)
Mix time (min.)

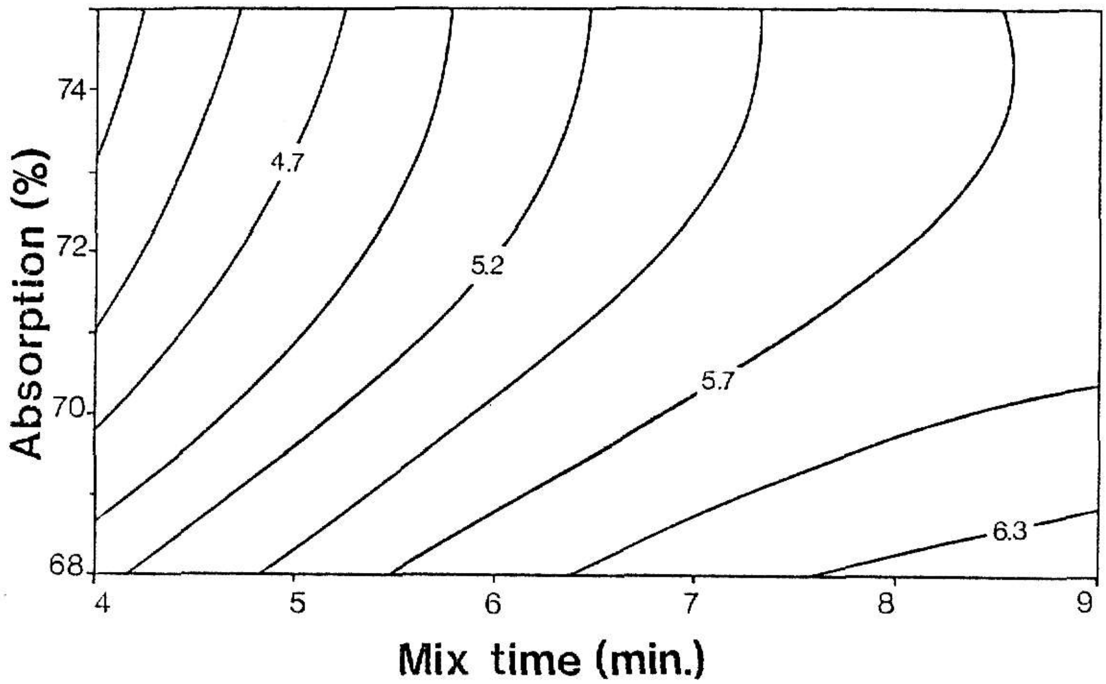
volume in the coarse granulation whole wheat breads. Again, the shortening level was varied, and again we see that the values of the contours shifts as a result. However, unlike the previous plots, the apparent optimum appears to lie outside the range of mix times and absorptions tested. From the shape and orientation of these contours, however, it can be seen that the same general trend that was observed for the effect of shortening on the fine granulation breads is also seen with those of the coarse granulation breads.

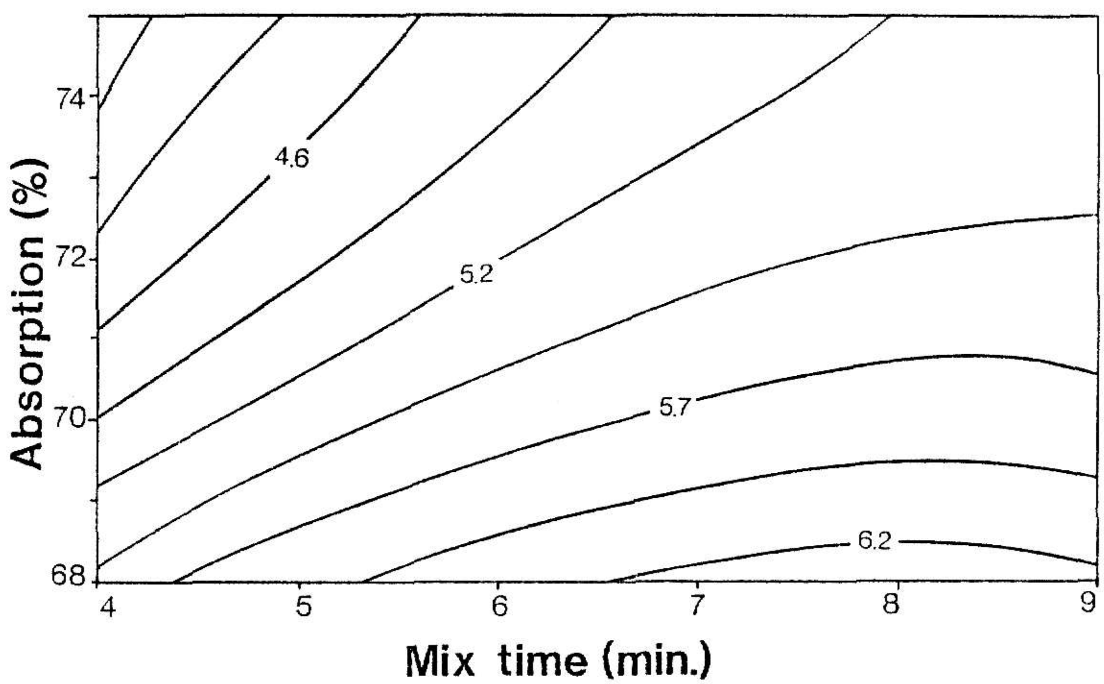
At this point, it should be noted that the RSM experimental design prescribes that the variable levels to be tested lie mainly near the center of the specified ranges. For this reason, the model equations best predict responses in this area, while less confidence can be placed in the region of the contour plot which lies near the perimeter. This should be considered in the evaluation of such plots as Figures 6 and 7. In fact, subsequent bakes showed that the optimum levels of absorption and mix time for these sets of conditions do lie within the tested range (at 4.5% shortening, optimum absorption was 69.5% and optimum mix time was 8 minutes.).

Referring now to Figures 8 and 9, the effect of absorption and mix time on the grain score of coarse granulation whole wheat bread is shown. The shape of these plots differs from the shape of the specific volume contours (Figures 6 and 7). Whereas the specific volume contours are primarily vertical, those which represent grain score are more oriented in a horizontal direction. This vertical alignment indicates that specific volume is more dependent upon mix time that it is on absorption. The different orientation of the grain score contours indicates that

Fig. 8. Contour plot of grain score for absorption and mix time of coarse whole wheat flour mixed in pin-type mixer (0% shortening, 0.5% DATA, and 15 ppm $KBrO_3$).

Fig. 9. Contour plot of grain score for absorption and mix time of coarse whole wheat flour mixed in pin-type mixer (6% shortening, 0.5% DATA, and 15 ppm $KBrO_3$).


4.7
5.2
5.7
6.3
Absorption (%)
74
72
70
68
4
5
6
7
8
9
Mix time (min.)


4.6
5.2
5.7
6.2
Absorption (%)
74
72
70
68
4
5
6
7
8
9
Mix time (min.)

while higher absorptions may not adversely affect specific volume, they may result in bread with poorer grain. It is interesting to note that this trend was not observed in the fine granulation breads. In those breads specific volume and grain score were affected in a similar way by both absorption and mix time.

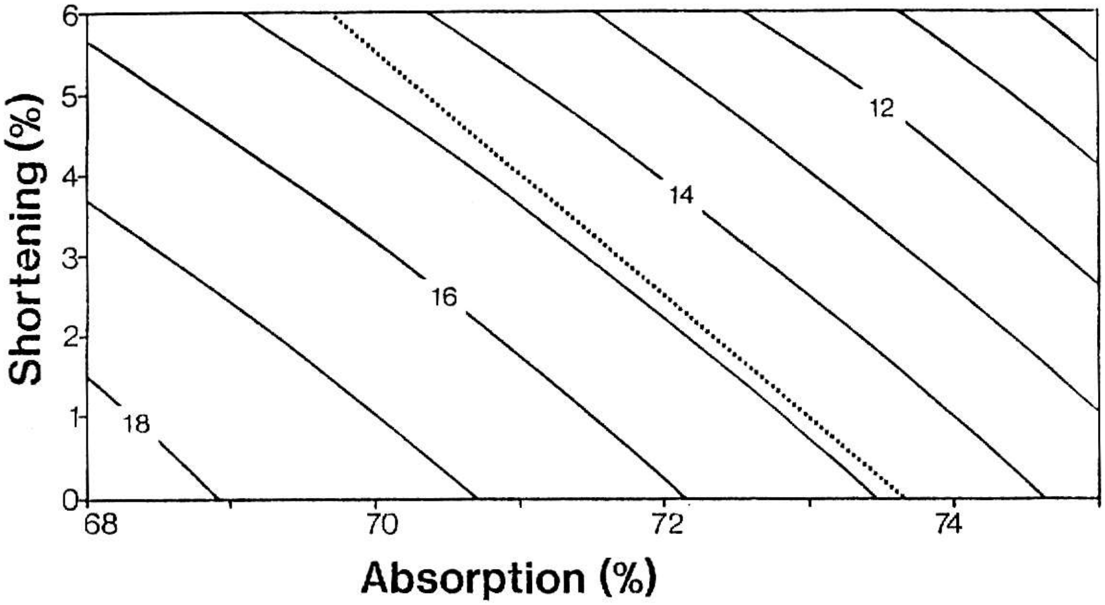
In an attempt to elucidate the nature of the relationship between shortening and absorption, these variables were plotted with the response variable of work input (watthours/Kg of dough). These plots appear in Figures 10 and 11 representing the fine and coarse granulations of the whole wheat flour. In generating these plots, the fine granulation mix time was set at 6 minutes while the coarse granulation was fixed at 8 minutes. These levels represent near to optimum mix times for each of the flours. In Figure 10 (fine granulation) a dotted line was drawn to indicate the points where optimum specific volume and grain score were achieved.

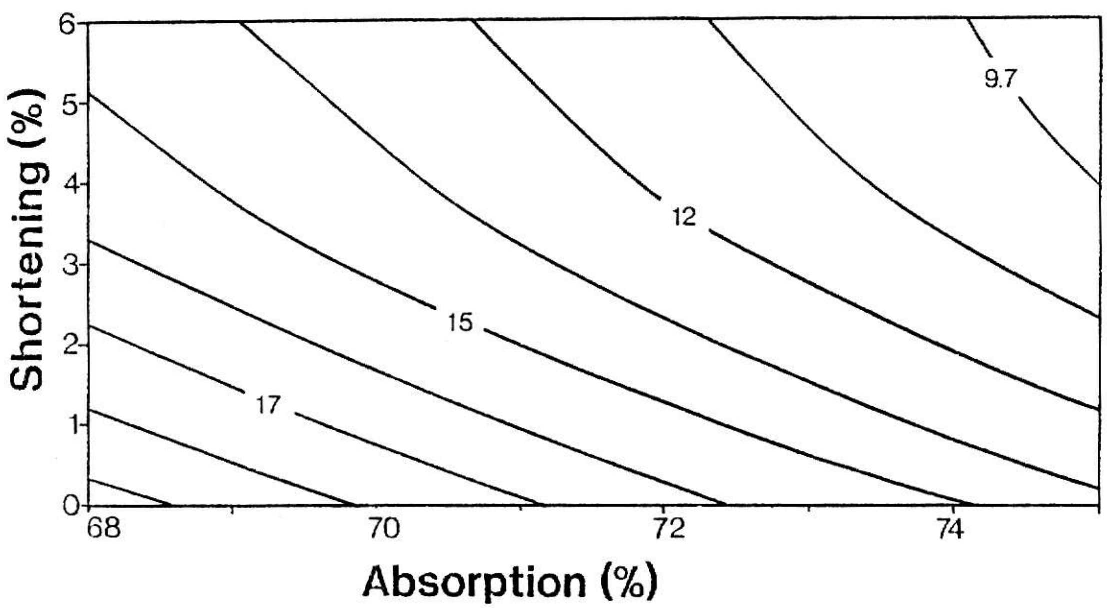
This line follows closely the work input contours at a level of about 15 watthours/Kg. This result suggests that the addition of shortening does not change the work requirement for optimum development of dough made from the fine granulation flour.

Subsequent bakes indicated that coarse whole wheat flour also requires about the same work level to produce an optimum loaf as does the fine whole wheat flour. From this, it may be inferred that the longer mix time which is required by the coarse flour does not indicate a difference in work requirement, but rather suggests that the coarser particles need more time to hydrate, and during this time there is more

Fig. 10. Contour plot of work input (watthours/kg) for shortening and absorption of fine whole wheat flour mixed in pin-type mixer (6 min. mix time, 0.5% DATA, and 15 ppm $KBrO_3$).

Fig. 11. Contour plot of work input (watthours/kg) for shortening and absorption of coarse whole wheat flour mixed in pin-type mixer (8 min. mix time, 0.5% DATA, and 15 ppm $KBrO_3$).


6
5
4
3
2
1
0
Shortening (%)
18
16
14
12
68
70
72
74
Absorption (%)


6
5
4
3
2
1
0
Shortening (%)
17
15
12
9.7
68
70
72
74
Absorption (%)

free water available for binding by dough constituents. It may therefore act as lubricant and delay the imparting of energy by the mixing pins.

Figure 12 shows two power curves for the mixing of doughs containing fine and coarse granulation whole wheat flours. Both doughs contained 72% absorption, 4.5% shortening, no DATA, and 15 ppm potassium bromate. The arrows on these curves indicate the times at which optimum breads were achieved. In both curves, we see that optimum bread was obtained by doughs mixed at less than the peak level of mixing. This finding is consistent with the general belief that whole wheat doughs should be slightly undermixed for optimum results (Cain 1966, Becker 1975). With this in mind, researchers should be cautious in the interpretation of mixograph, farinograph, and power meter curves. The point of maximum consistency (minimum mobility) in dough mixing curves is often interpreted as the point of optimum dough development, but many studies have surfaced which note exceptions to this notion. Frazier et al. (1975) reviews these studies and cites that the Chorleywood breadmaking process has been shown to require work input at the mixer of only half the work needed to reach peak consistency. The present study indicates that the work requirements of whole wheat doughs in the National Mixer also require substantially less work than is required to attain maximum consistency.

The sheeting method resulted in contour plots which are distinctly different from those obtained from the pin-type mixing. Figures 13 and 14 show the effect of varying absorption and number of passes on the specific volume of the fine granulation loaves. With no shortening (Figure 13) we see a diagonal maximum which covers a region from 68 to

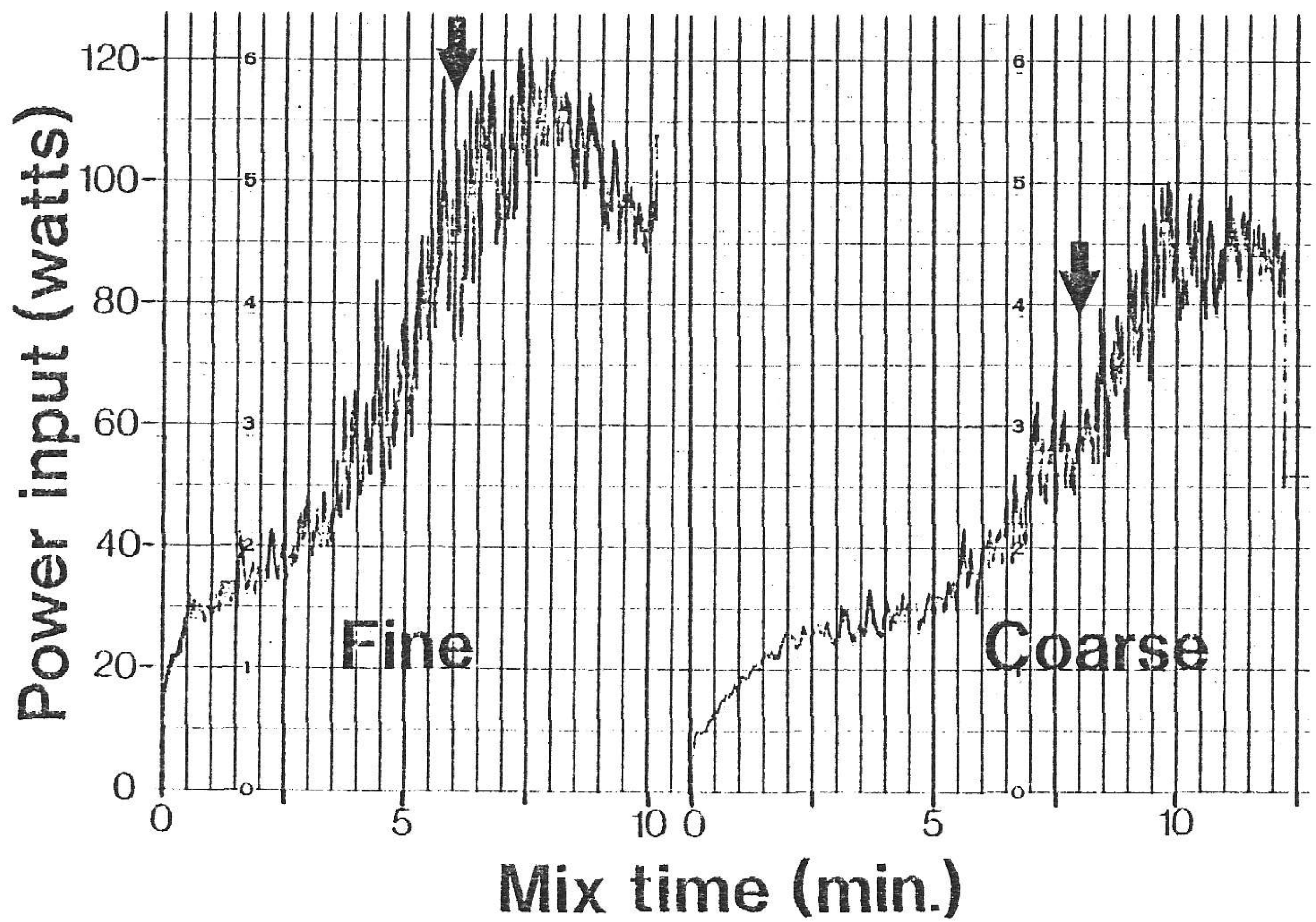
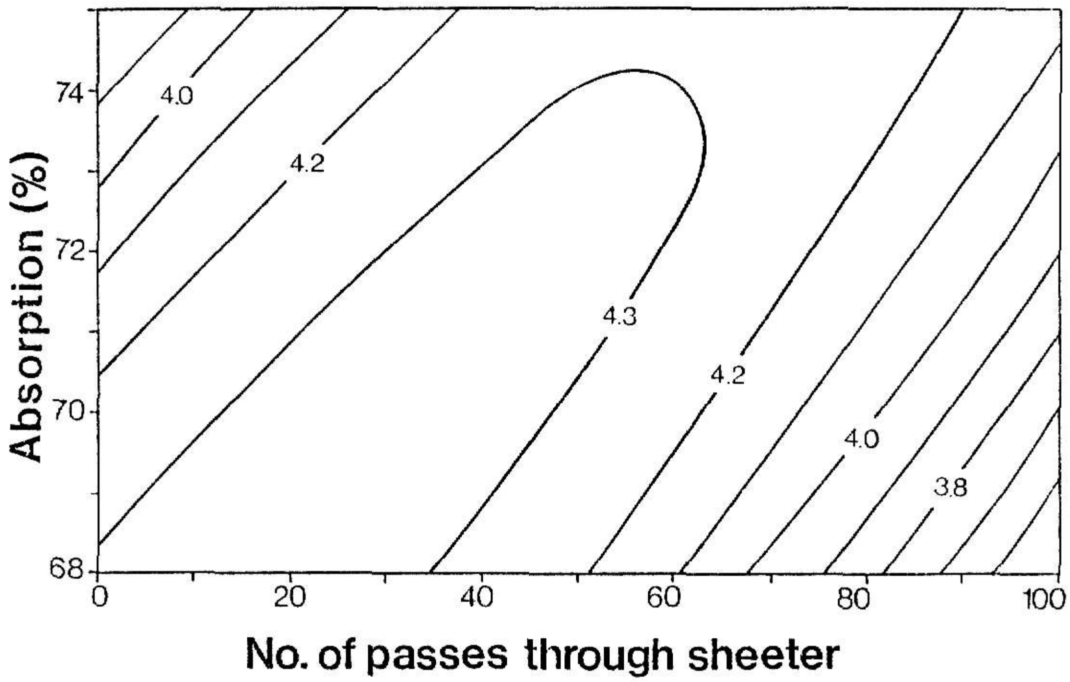


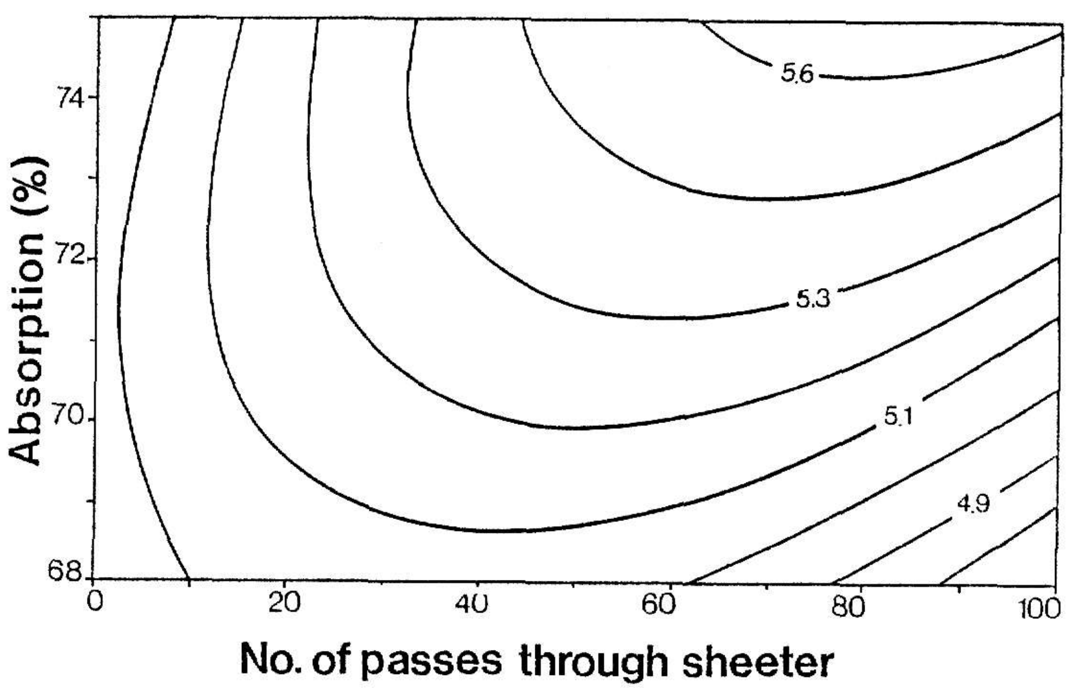
Fig. 12. Power meter mixing curves for fine and coarse whole wheat flours.

Fig. 13. Contour plot of specific volume (cc/g.) for absorption and # of passes of fine whole wheat flour mixed in sheeter (0% shortening, 0.5% DATA, and 15 ppm $KBrO_3$).

Fig. 14. Contour plot of specific volume (cc/g.) for absorption and # of passes of fine whole wheat flour mixed in sheeter (6% shortening, 0.5% DATA, and 15 ppm $KBrO_3$).



4.0
4.2
4.3
4.2
4.0
3.8
74
72
70
68
0
20
40
60
80
100
Absorption (%)
No. of passes through sheeter



5.6
5.3
5.1
4.9
74
72
70
68
0
20
40
60
80
100
Absorption (%)
No. of passes through sheeter

74% absorption and from 0 to 60 passes through the sheeter. Investigation of the grain score response for the same variable (Figure 15) shows that the maximum grain score covers a similar large area on the plot.

When the shortening level was increased to 6% we see a dramatic change in the specific volume contours (Figure 14). Instead of the expected shift of lowered optimum absorption with increased shortening, the plot suggests that the optimum has shifted towards greater absorptions. Grain score, on the other hand, does exhibit the expected shift with the higher level of shortening (Figure 16).

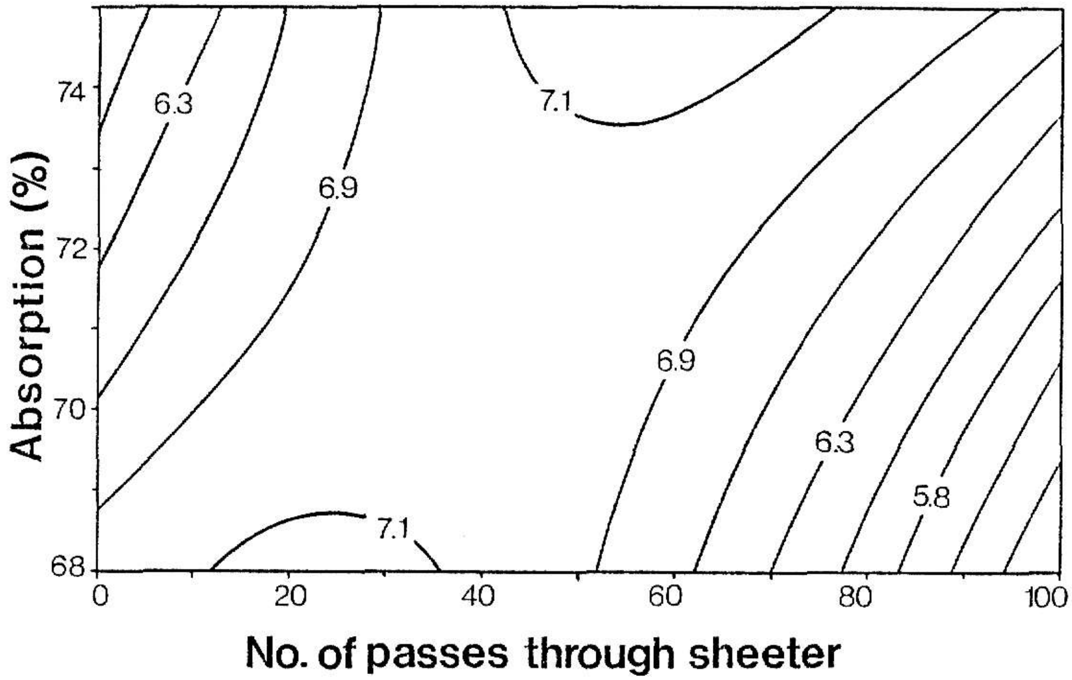
Regarding the plots which show the effect of absorption and number of passes on specific volume of the coarse whole wheat bread, (Figures 17 and 18), we see that this coarse granulation also exhibits an unexpected shortening response. With the addition of 6% shortening, a fewer number of passes was required to fully develop the dough, instead of the expected response of an increased amount of sheeting.

It is also important to note that with both flours, the optimum absorptions were between 4 and 6% greater than with doughs mixed on the pin-type mixer. This increased absorption may be attributed to one or both of the following factors.

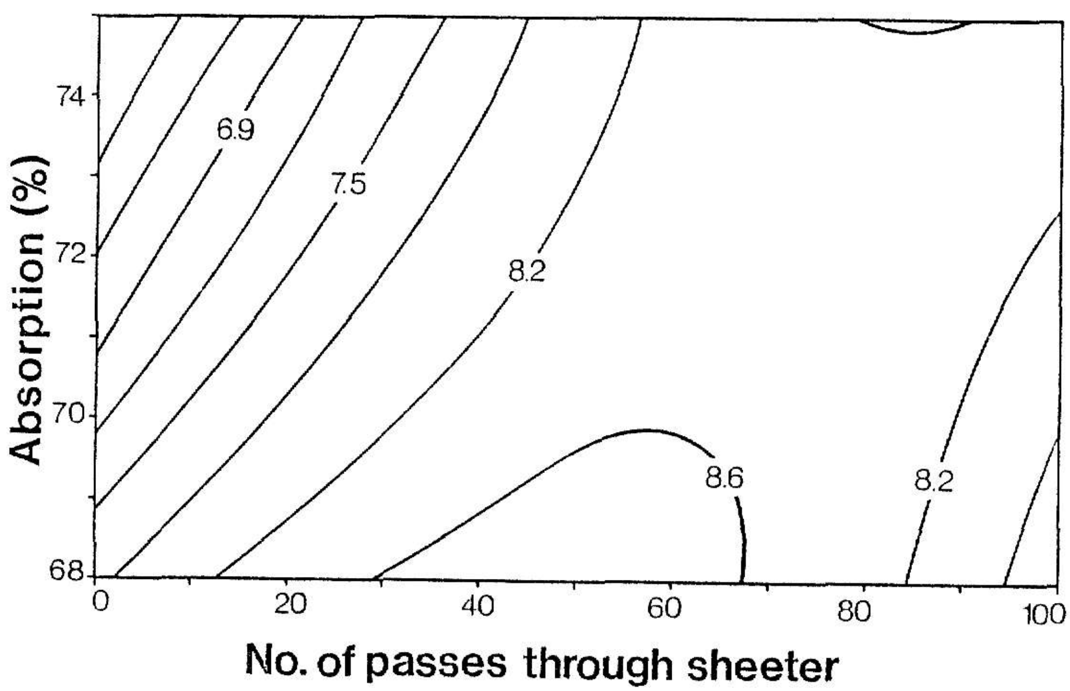
Conceivably, while doughs are being sheeted a substantial amount of moisture may be lost due to evaporation from the relatively large surface area of the sheeted dough, or, water may be absorbed by the surface of the conveyor belt of the Rondo Sheeter.

Fig. 15. Contour plot of grain score for absorption and # of passes of fine whole wheat flour mixed in sheeter (0% shortening, 0.5% DATA, and 15 ppm $KBrO_3$).

Fig. 16. Contour plot of grain score for absorption and # of passes of fine whole wheat flour mixed in sheeter (6% shortening, 0.5% DATA, and 15 ppm $KBrO_3$).



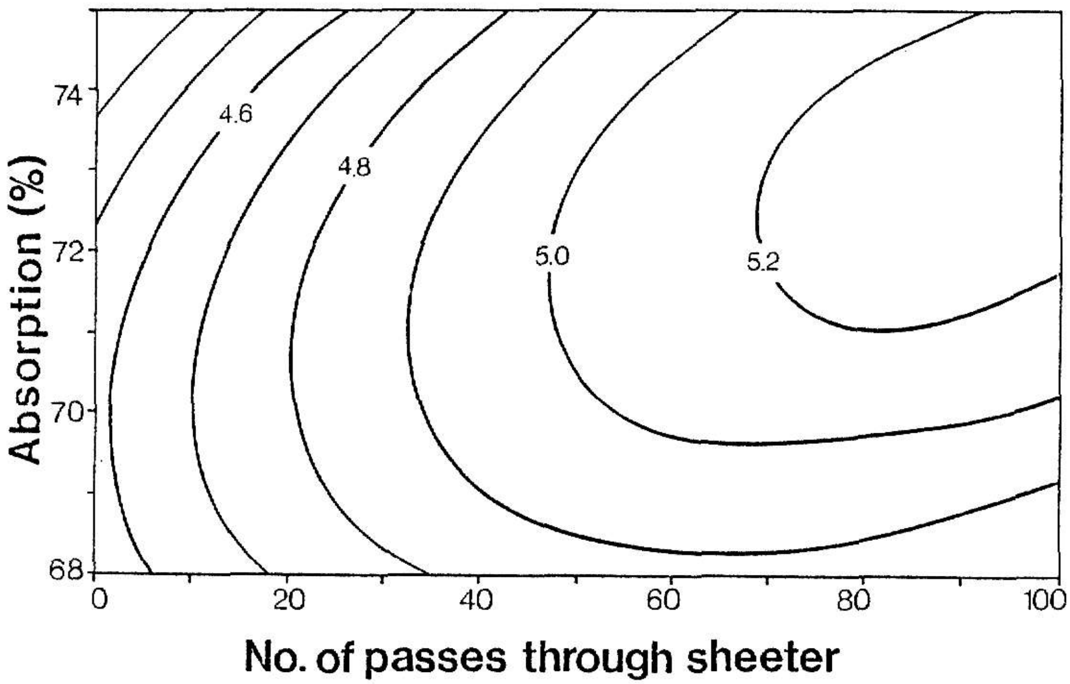
74
72
70
68
Absorption (%)
6.3
6.9
7.1
6.9
6.3
5.8
7.1
0
20
40
60
80
100
No. of passes through sheeter



74
72
70
68
Absorption (%)
6.9
7.5
8.2
8.6
8.2
0
20
40
60
80
100
No. of passes through sheeter

Fig. 17. Contour plot of specific volume (cc/g.) for absorption and # of passes of coarse whole wheat flour mixed in sheeter (0% shortening, 0.5% DATA, and 15 ppm $KBrO_3$).

Fig. 18. Contour plot of specific volume (cc/g.) for absorption and # of passes of coarse whole wheat flour mixed in sheeter (6% shortening, 0.5%DATA, and 15 ppm $KBrO_3$).


4.6
4.8
5.0
5.2
Absorption (%)
74
72
70
68
0
20
40
60
80
100
No. of passes through sheeter

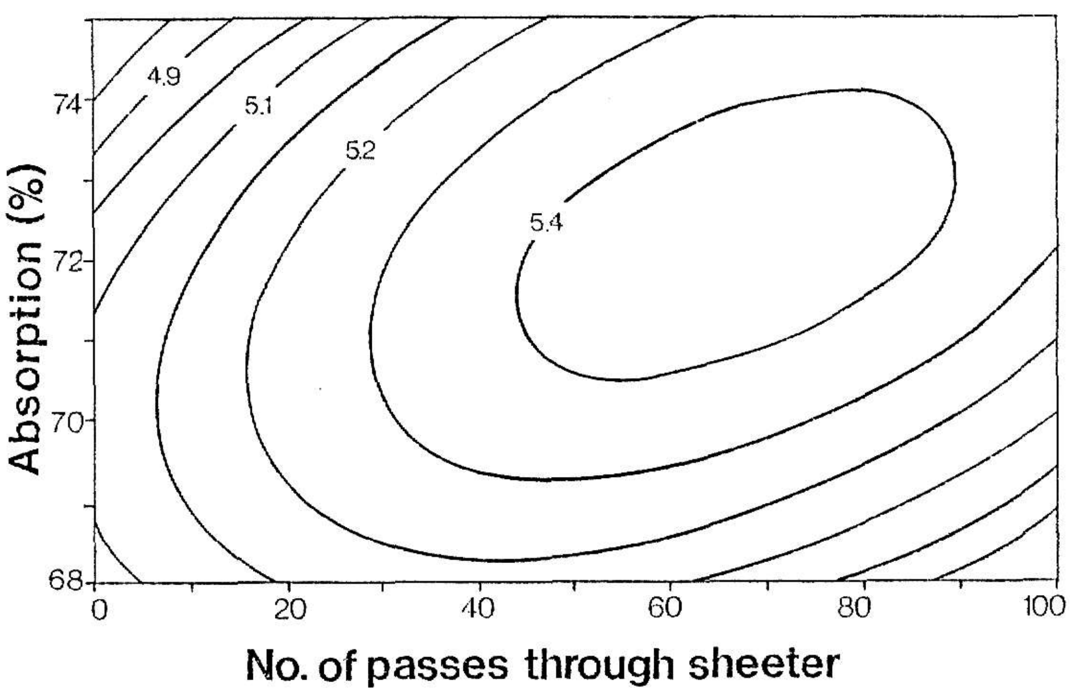
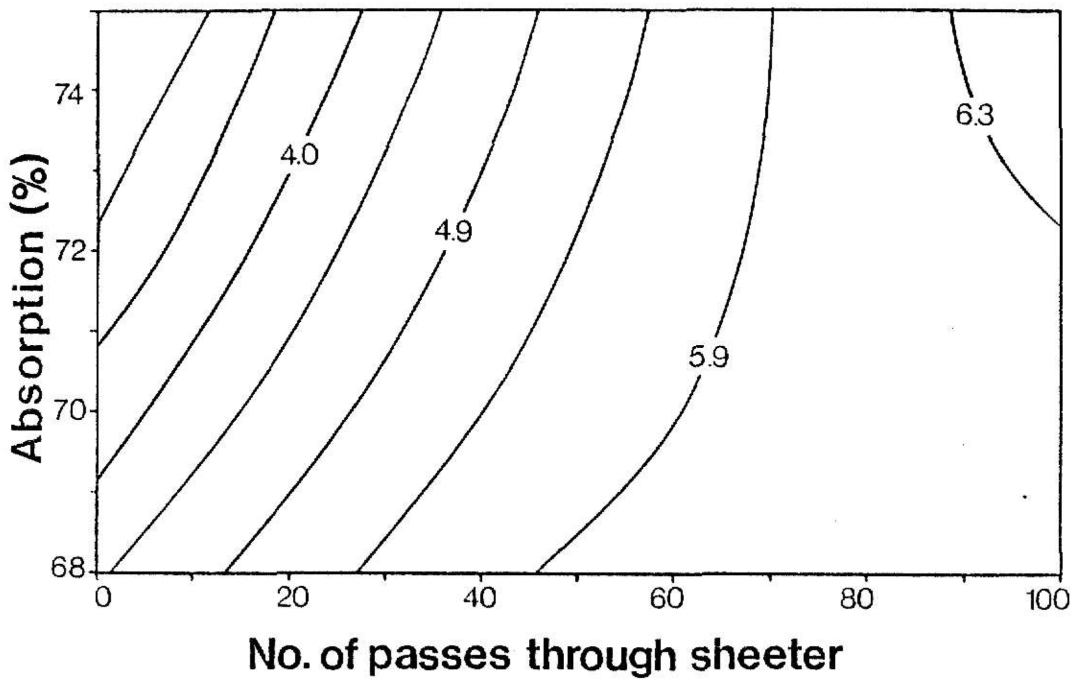
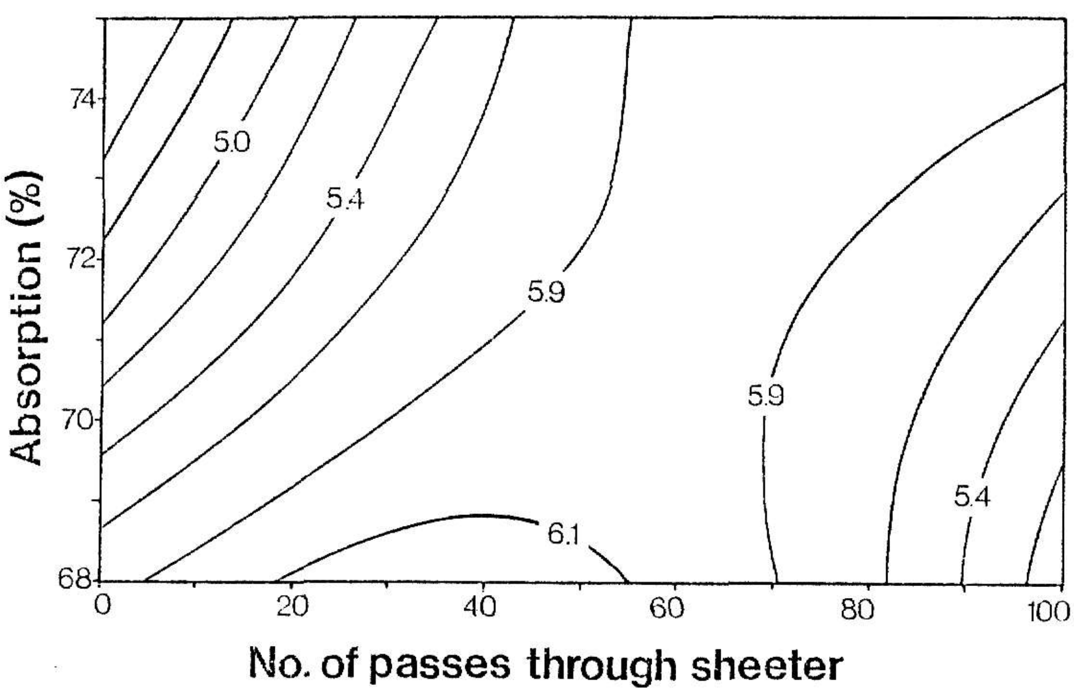

4.9
5.1
5.2
5.4
Absorption (%)
74
72
70
68
0
20
40
60
80
100
No. of passes through sheeter

Fig. 19. Contour plot of grain score for absorption and # of passes of coarse whole wheat flour mixed in sheeter (0% shortening, 0.5% DATA, and 15 ppm $KBrO_3$).

Fig. 20. Contour plot of grain score for absorption and # of passes of coarse whole wheat flour mixed in sheeter (6% shortening, 0.5% DATA, and 15 ppm $KBrO_3$).


Absorption (%)
74
72
70
68
0
20
40
60
80
100
No. of passes through sheeter
4.0
4.9
5.9
6.3


Absorption (%)
74
72
70
68
0
20
40
60
80
100
No. of passes through sheeter
5.0
5.4
5.9
6.1
5.9
5.4

Another possible explanation is that the sheeted doughs are capable of containing more water because of the repeated sheeting and folding which they undergo. These actions may, in effect, allow more water to be mixed in the dough without sacrificing optimum volume and grain, than may be used in doughs mixed with the pin-type mixer. Why this may be true is unclear.

In actual bakeshop conditions the optimum level of absorption may greatly depend on the desired handling characteristics of the dough. In order for the dough piece to be fed through the dough brake without sticking, a stiffer dough with a relatively low absorption may be required. There was, however, no difficulty in sheeting doughs in this study even at the highest levels tested, but it should be noted that in preliminary experiments some difficulty was encountered in sheeting larger (about 1000 grams) dough pieces through the Rondo sheeter.

Shortening and Emulsifiers (DATA)

One of the functions of mixing is to incorporate air into the dough. Junge and Hoseney (1981) have demonstrated that when smaller and more air cells are incorporated into the dough, a finer grain will result. They also showed that while shortening does not allow more air to be incorporated into the dough, it does encourage the formation of smaller and more cells. Shortening also acts to delay the setting of the bread crumb in the oven possibly by coating the starch granules and thereby inhibiting their gelatinization. As was mentioned earlier in this thesis, it is quite possible that starch gelatinization plays a particularly critical role in determining the quality of whole wheat bread. Moder (1980) supports this contention with his results which show that shortening has a greater improving effect on whole wheat bread than on white bread.

The results of this present study demonstrate that shortening does, in fact, improve the grain and volume of whole wheat breads. It also suggests that shortening may be functioning differently in doughs made with the fine whole wheat flour than in those made with the coarse flour.

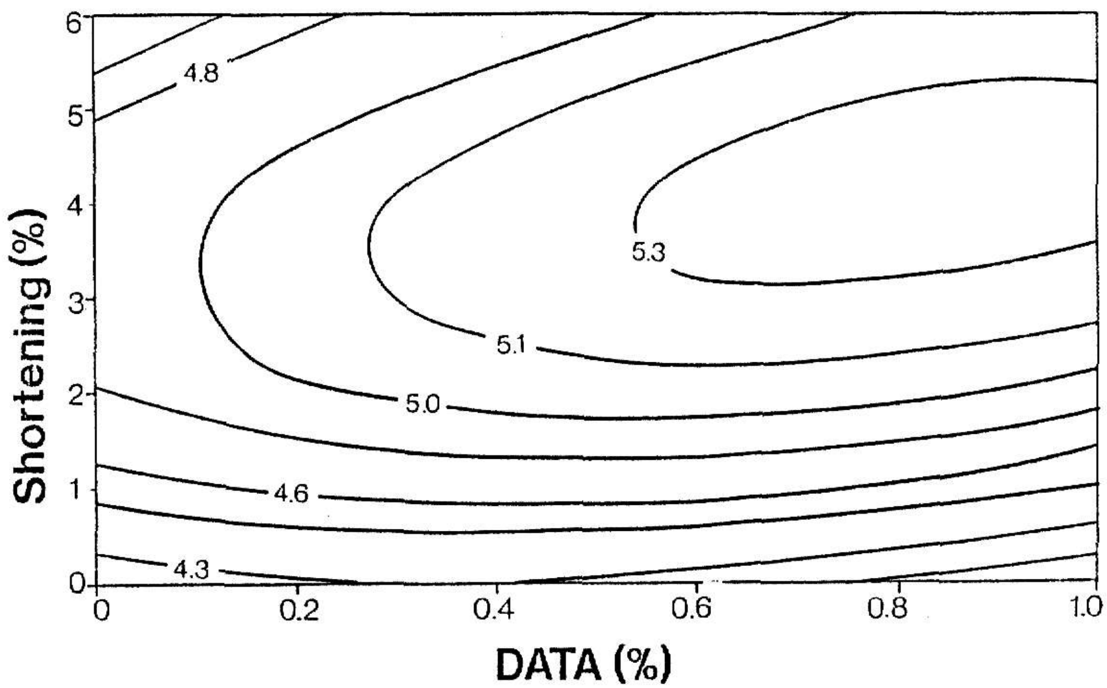
Table 13 shows that shortening had a greater improving effect on breads made from the fine whole wheat flour than it did on those made from the coarse flour. Maximum predicted responses for grain score and specific volume reveal that in both mixing methods finer granulation breads showed far greater increases in both specific volume and grain score with increased shortening than did the coarser granulation. In fact, predicted grain scores actually showed decreases for the breads made with the coarse flour in both mixing methods. The specific volume of those breads increased only to a slight (probably not significant) degree.

Moder (1981) demonstrated that whole wheat breads which contained 1% DATA exhibited greater volume than did breads containing 3% shortening. The present study did not find this same degree of effectiveness.

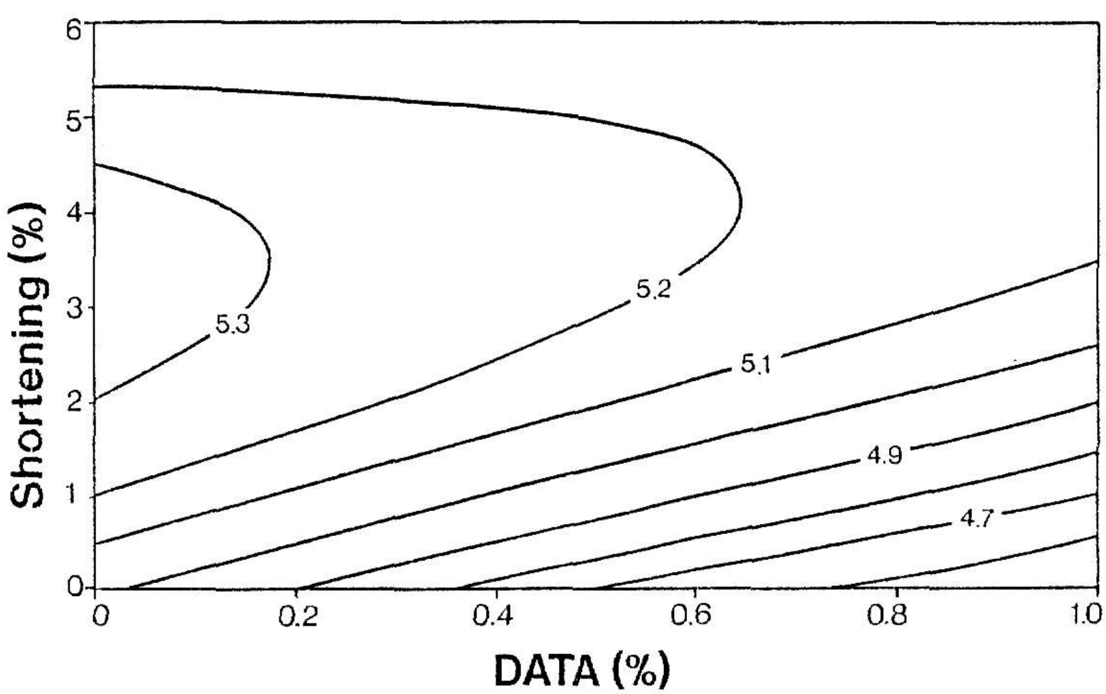
Contour plots were generated which show how shortening and DATA influence specific volume and grain score of the test breads. Figures 21 and 22 exhibit the effects of these variables on specific volume for breads made with fine and coarse granulation flours. It is clear that

Fig. 21. Contour plot of specific volume (cc/g.) for shortening and DATA of fine whole wheat flour mixed in pin-type mixer (6 min. mix time, 71.5% absorption, and 15 ppm $KBrO_3$).

Fig. 22. Contour plot of specific volume (cc/g.) for shortening and DATA of coarse whole wheat flour mixed in pin-type mixer (8 min. mix time, 71.5% absorption, and 15 ppm $KBrO_3$).



Shortening (%)
DATA (%)
0
1
2
3
4
5
6
0
0.2
0.4
0.6
0.8
1.0
4.8
5.3
5.1
5.0
4.6
4.3



Shortening (%)
DATA (%)
0
1
2
3
4
5
6
0
0.2
0.4
0.6
0.8
1.0
5.3
5.2
5.1
4.9
4.7

Table 13. The Effect of Shortening on Maximum Predicted Responses For Whole Wheat Breads. (Optimum absorption, 0.5% DATA, and 15 ppm $KBrO_3$)

Mixing Method	Granulation	Shortening %	Maximum predicted specific volume (cc/g)	Maximum predicted grain score
National	Fine	0	4.36	7.08
National	Fine	6	5.25	8.03
(Difference)			(0.89)	(0.95)
National	Coarse	0	5.29	6.35
National	Coarse	6	5.49	6.39
(Difference)			(0.20)	(0.04)
Sheeter	Fine	0	4.34	7.28
Sheeter	Fine	6	5.66	8.74
(Difference)			(1.32)	(1.46)
Sheeter	Coarse	0	5.22	6.57
Sheeter	Coarse	6	5.40	6.18
(Difference)			(0.18)	(-0.39)

in all cases, 1% DATA and no shortening would yield breads with poor volume. In fact, DATA exhibits little or no effect on the volume response for levels of shortening less than 3%, and, in the case of bread made with coarse granulation flour, this effect is detrimental. Figures 23 and 24 show the effect of these variables on the grain score of the breads. For the fine granulation we see nearly identical contours, compared to those of specific volume. The coarse granulation plot on the other hand, shows a striking difference. This indicates the absence of any shortening effect and the influence of DATA distinctly detrimental to the grain score response.

Figures 25 and 26 present contour plots which show the effect of shortening and DATA on specific volumes of fine and coarse whole wheat breads for the sheeting method. Responses with the fine granulation sheeted doughs yield plots similar to those of the pin-type mixed dough for the same conditions. Again, no improving effect is apparent with the addition of DATA to the dough. The coarse flour also fails to show any real improving effect with this emulsifier in the system tested. Tables 27 and 28 present the grain scores of the breads. Again, we see no apparent influence of this emulsifier on these whole wheat breads.

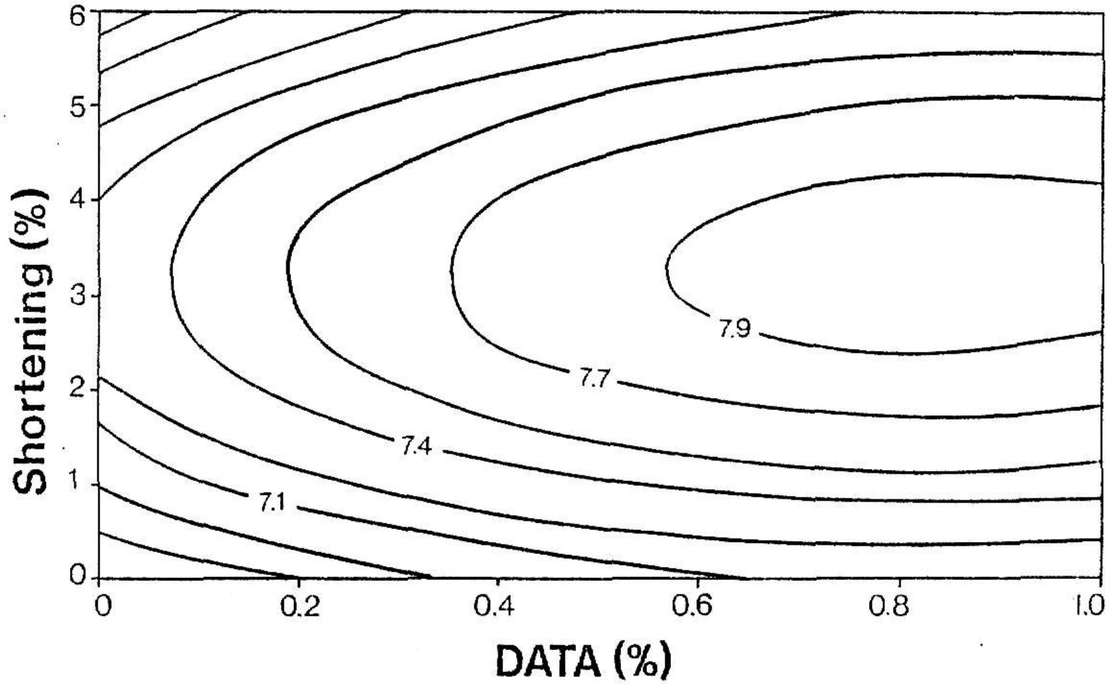
Since the improving effect of DATA is well established, it is some what surprising to observe its behavior in this study. Further research is needed to ascertain the reasons behind these unexpected findings.

Potassium Bromate

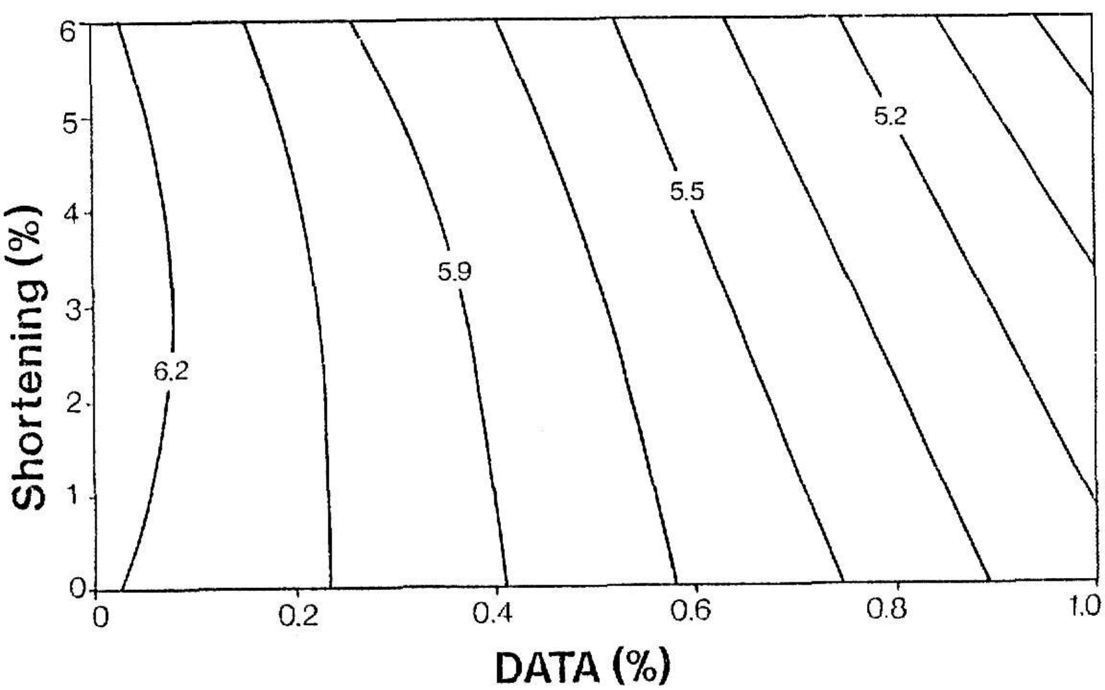
It is of interest to investigate the role of oxidation in a comparison

Fig. 23. Contour plot of grain score for shortening and DATA of fine whole wheat flour mixed in pin-type mixer (6 min. mix time, 71.5% absorption, and 15 ppm $KBrO_3$).

Fig. 24. Contour plot of grain score for shortening and DATA of coarse whole wheat flour mixed in pin-type mixer (8 min. mix time, 71.5% absorption, and 15 ppm $KBrO_3$).



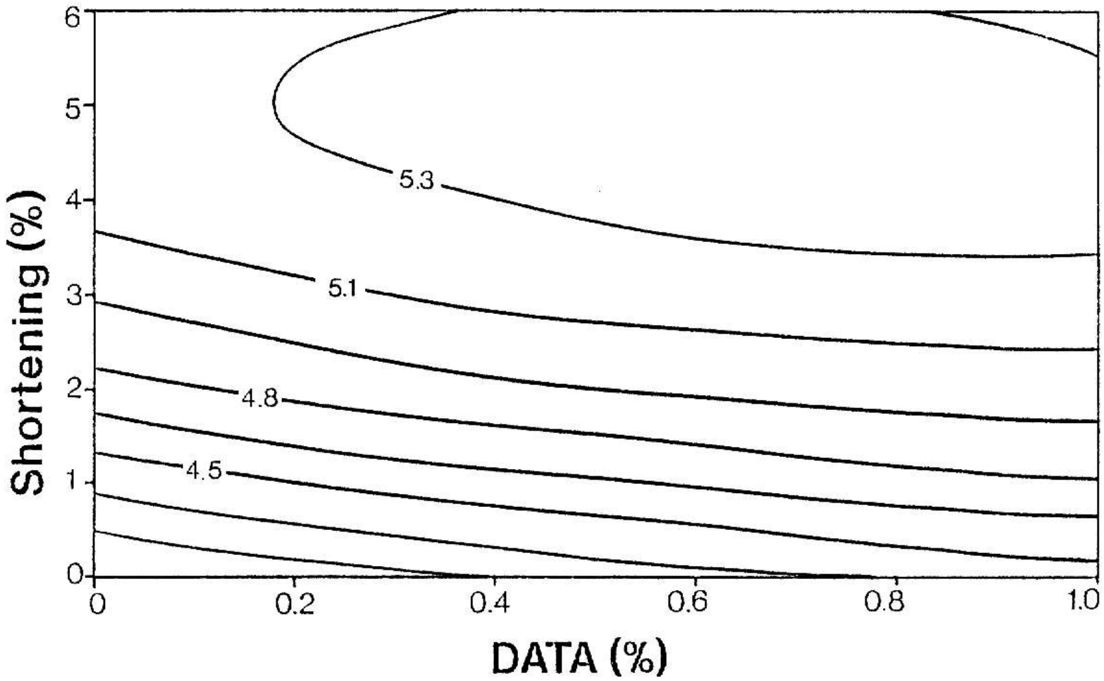
Shortening (%)
DATA (%)
7.9
7.7
7.4
7.1
0
1
2
3
4
5
6
0.2
0.4
0.6
0.8
1.0



Shortening (%)
DATA (%)
6.2
5.9
5.5
5.2
0
1
2
3
4
5
6
0.2
0.4
0.6
0.8
1.0

Fig. 25. Contour plot of specific volume (cc/g.) for shortening and DATA of fine whole wheat flour mixed in sheeter (75 passes, 71.5% absorption, and 15 ppm $KBrO_3$).

Fig. 26. Contour plot of specific volume (cc/g.) for shortening and DATA of coarse whole wheat flour mixed in sheeter (75 passes, 71.5% absorption, and 15 ppm $KBrO_3$).


6
5
4
3
2
1
0
Shortening (%)
5.3
5.1
4.8
4.5
0
0.2
0.4
0.6
0.8
1.0
DATA (%)

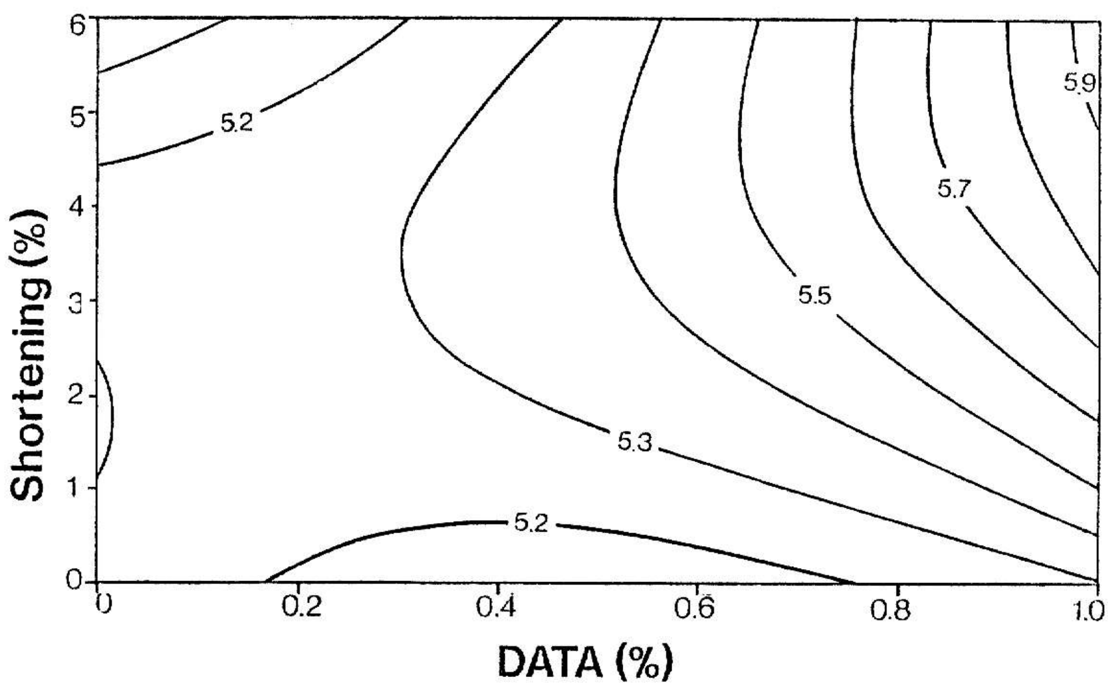
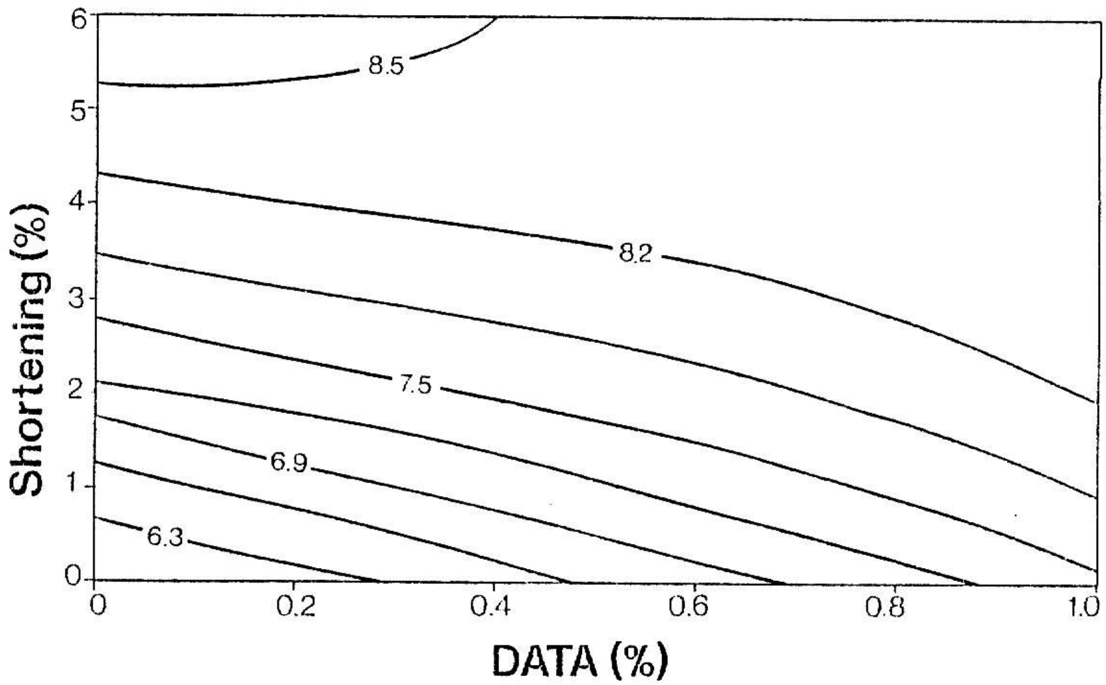
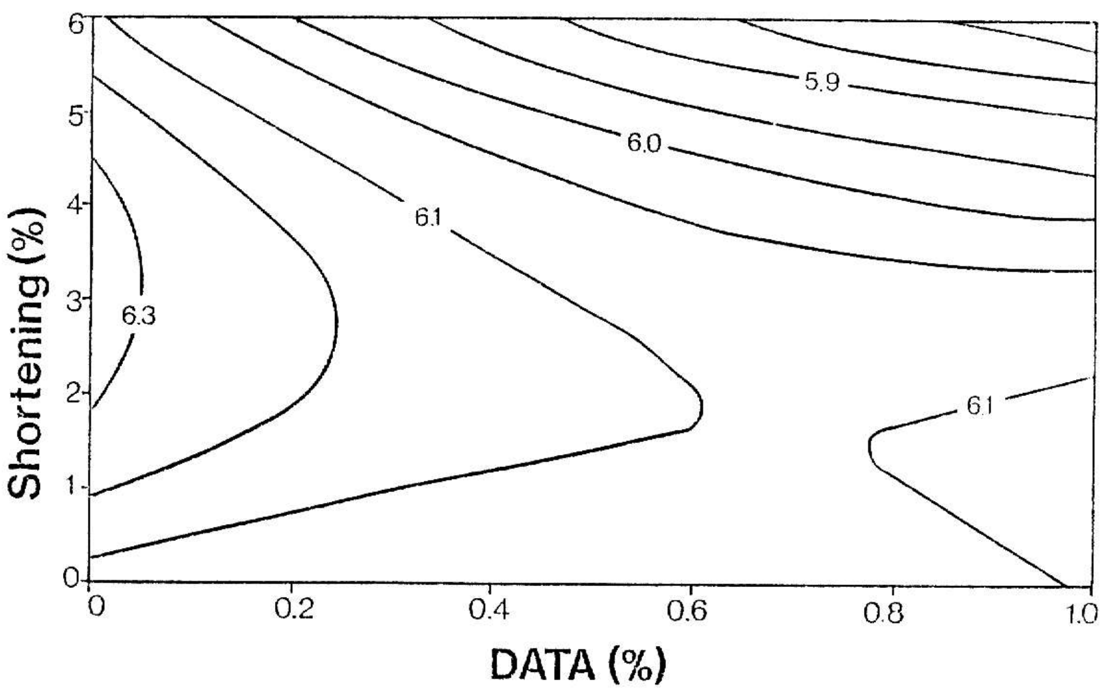

6
5
4
3
2
1
0
Shortening (%)
5.2
5.3
5.2
5.5
5.7
5.9
0
0.2
0.4
0.6
0.8
1.0
DATA (%)

Fig. 27. Contour plot of grain score for shortening and DATA of fine whole wheat flour mixed in sheeter (75 passes, 71.5% absorption, and 15 ppm $KBrO_3$).

Fig. 28. Contour plot of grain score for shortening and DATA of coarse whole wheat flour mixed in sheeter (75 passes, 71.5% absorption, and 15 ppm $KBrO_3$).



Shortening (%)
DATA (%)
8.5
8.2
7.5
6.9
6.3
0
1
2
3
4
5
6
0.2
0.4
0.6
0.8
1.0



Shortening (%)
DATA (%)
5.9
6.0
6.1
6.3
6.1
0
1
2
3
4
5
6
0.2
0.4
0.6
0.8
1.0

of fine and coarse granulation whole wheat breads, and in the comparison of sheeting and pin-type mixing.

Bran and germ contain reducing agents such as glutathione and thioctic acid. These compounds have a weakening effect upon the dough and may contribute towards a subsequent reduction in loaf volume and grain score. It is conceivable that finer granulations of whole wheat flour release more of these compounds into the dough and thereby require more oxidation. This suspicion was not supported by this study since it appears (Figures 29 and 30) that the coarse flour requires slightly more potassium bromate (about 25 ppm) than does the fine flour which requires about 20 ppm for an optimum loaf.

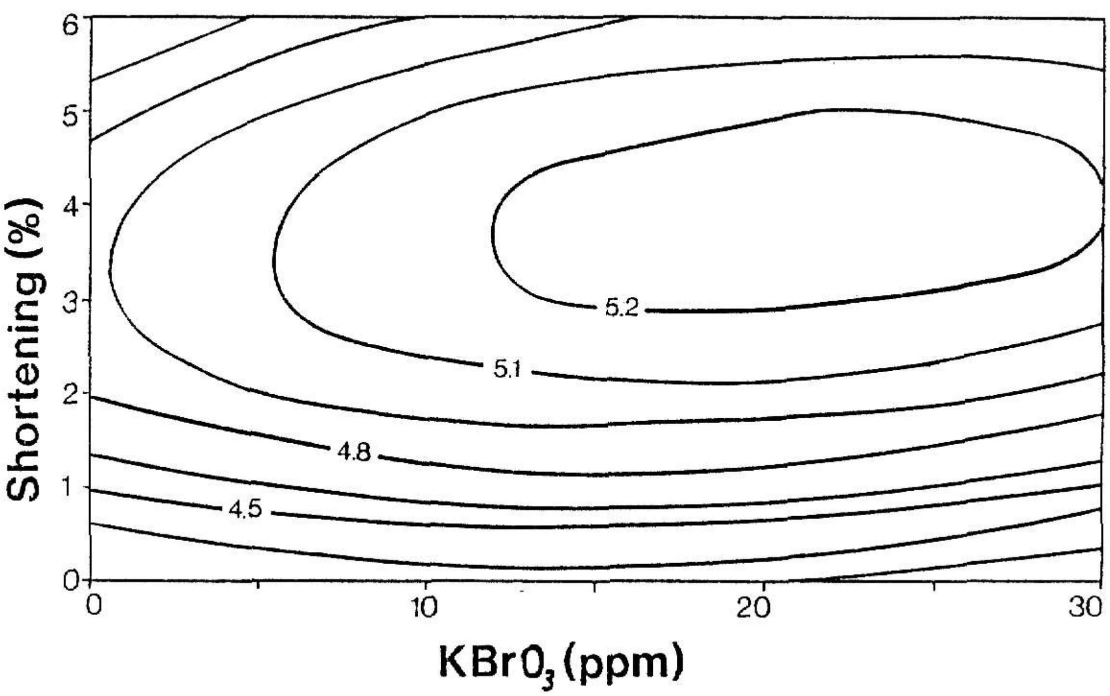
Bohn and Machon (1933) reported that coarser granulations of whole wheat flour showed a greater response to bromate, but their observation was also not supported by the present study. In fact, Figures 30 and 32 show that bread made from coarse whole wheat flour exhibits less response to added bromate than does the finer granulation.

In addition, it was postulated that, since air may be incorporated differently in the pin-type mixed doughs compared to the sheeted doughs, the requirement for added oxidant may therefore be different. Figures 31 and 32 present plots which show the influence of shortening and $KBrO_3$ on the specific volume of the sheeted whole wheat breads.

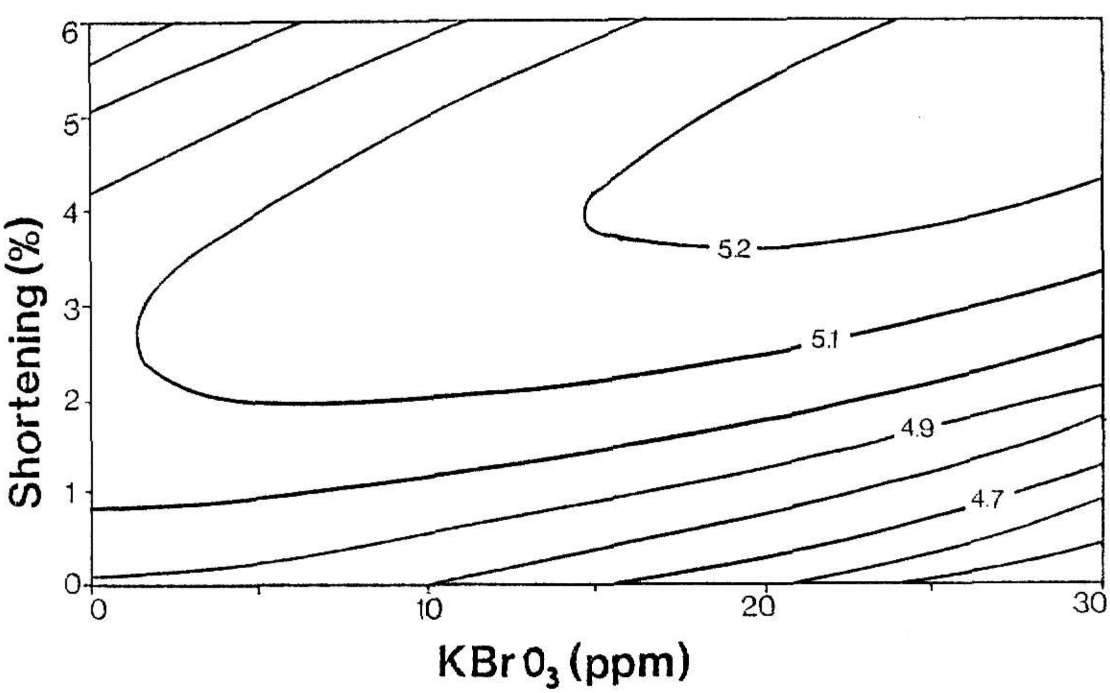
Again, we see that the optimum bromate levels differ slightly between fine and coarse granulation breads. But, in comparing the breads made with the two methods, the oxidation requirements seem to differ slightly, with the sheeting method requiring less potassium bromate than did the pin-type mixing method. Also apparent in the sheeted breads, coarse whole wheat breads seem to exhibit less of a bromate response than do those made from the fine whole wheat flours.

Fig. 29. Contour plot of specific volume (cc/g.) for shortening and $KBrO_3$ of fine whole wheat flour mixed in pin-type mixer (6 min. mix time, 0.5% DATA, and 71.5% absorption).

Fig 30. Contour plot of specific volume (cc/g.) for shortening and $KBrO_3$ of coarse whole wheat flour mixed in pin-type mixer (8 min. mix time, 0.5% DATA, and 71.5% absorption).



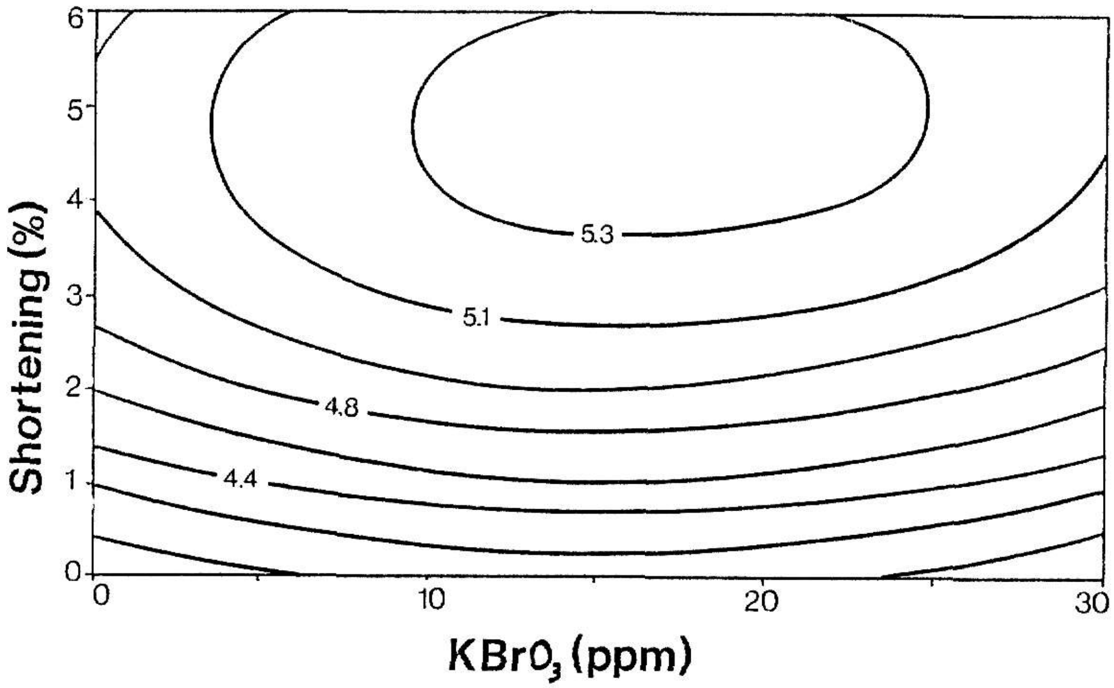
6
5
4
3
2
1
0
Shortening (%)
5.2
5.1
4.8
4.5
0
10
20
30
KBr0_3 (ppm)



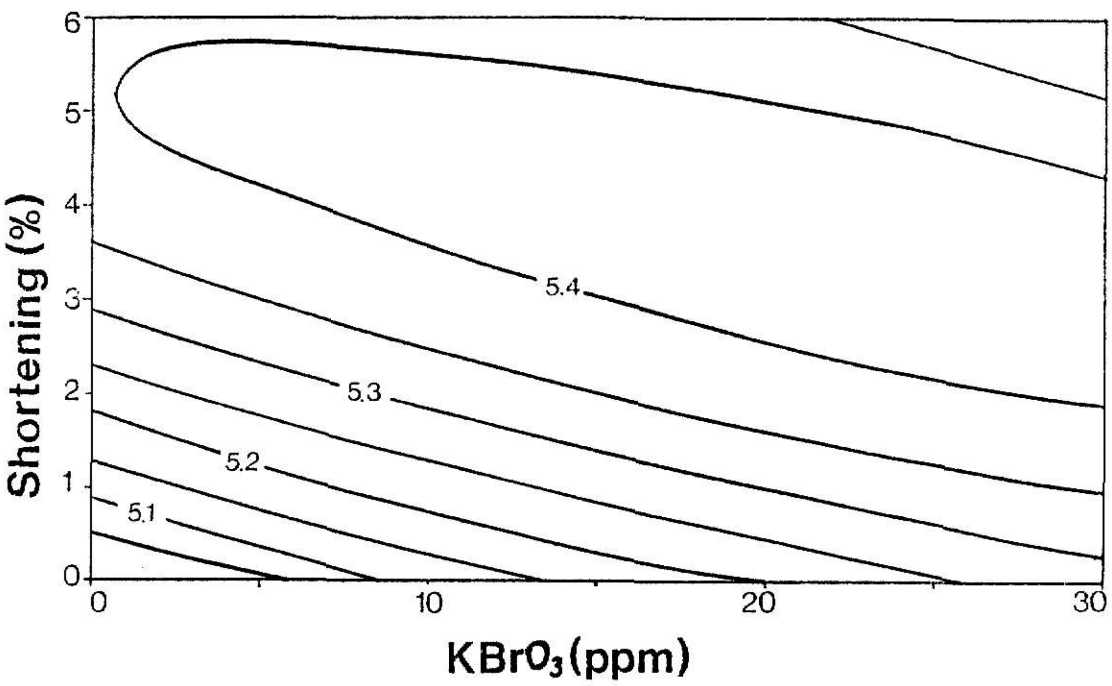
6
5
4
3
2
1
0
Shortening (%)
5.2
5.1
4.9
4.7
0
10
20
30
KBr 0_3 (ppm)

Fig. 31. Contour plot of specific volume for shortening and KBr of fine whole wheat flour mixed in sheeter (75 passes, 0.5% DATA, and 71.5% absorption).

Fig. 32. Contour plot of specific volume for shortening and KBr of coarse whole wheat flour mixed in sheeter (75 passes, 0.5% DATA, and 71.5% absorption).



Shortening (%)
6
5
4
3
2
1
0
5.3
5.1
4.8
4.4
0
10
20
30
KBrO3 (ppm)



Shortening (%)
6
5
4
3
2
1
0
5.4
5.3
5.2
5.1
0
10
20
30
KBrO3 (ppm)

CONCLUSIONS

Two methods of dough mixing, two granulations of flour, and various levels of absorption, shortening, emulsifier, and potassium bromate were investigated in the production of whole wheat bread. Response Surface Methodology was employed in the experimental design and statistical analysis of data. From these data, contour plots were generated and then used in the evaluation of variable effects.

The mixing methods included utilization of a laboratory pin-type (National) mixer as an example of a high shear mixer, and the use of a sheeter (Rondo) to typify the low shear mixing of dough brakes.

The importance of absorption in the production of whole wheat bread was investigated. Mixing method, flour granulation, and shortening level were found to influence the optimum absorption of the test breads.

The addition of shortening to whole wheat doughs was found to decrease the optimum absorption and increase the optimum mix time with all doughs mixed in the pin-type mixer. It was also noted that the grain scores of breads made with coarse whole wheat flour were more dependent on mixing time than on absorption compared to other treatments which showed similar influences from both independent variables.

It was also determined that while the addition of shortening necessitates adjustment in absorption and mix time, it does not alter the work requirement of the whole wheat doughs.

In addition, it was observed that, although coarse whole wheat flour requires more time to mix to its optimum extent than does the fine flour, it requires about the same work input as does the fine granulation.

In the examination of results from the sheeted doughs, it became obvious that these doughs react to shortening in a way different from the pin-type mixed doughs. In sheeted doughs, fine granulation whole wheat flour appeared to require a greater absorption with increases in shortening. When shortening was added to coarse flour doughs, they required less sheeting than without shortening. These results differ from those found with pin-type mixed doughs.

In general, it was observed that shortening had very little improving effect on breads made from the coarse whole wheat flour compared to the effects exhibited with the fine flour.

The sheeting method tended to produce breads with slightly better volume and improved grain compared with pin-type mixed breads. This improvement was greater in breads made with fine flour than those made with coarse flour. Also, with the fine whole wheat flour, the sheeting method allowed for a substantial increase in the improving effect of shortening.

Oxidant addition was also investigated. Contour plots showed that for both mixing methods, coarse whole wheat doughs required slightly more bromate than did those made with fine flour for an optimum quality loaf.

The bromate response, however, was found to be greater in breads made with fine flour compared to those made with coarse flour.

This study clearly shows that the sheeting method of dough mixing results in whole wheat bread of equal or superior quality compared with breads made from doughs mixed in a pin-type mixer. These results are consistent with previous studies (Kilborn et al. 1972, 1981; Moss 1980; Tweed 1979; and Bushuk and Hulse 1974) which demonstrated the superior quality of breads produced by various sheeting methods. In view of the success of these studies and the extensive use of the dough brake in numerous regions of the world, the bakers in this country may justifiably consider this alternate method of dough mixing. Granted, more research is warranted, especially in adapting the sheeting process for large scale mechanization. However, the potential for quality improvement and energy savings may justify further interest in the sheeting method of dough development.

Appendix 1. Pin-Type Mixing

Batch #	Granulation	Mix time (min.)	Shortening %	DATA %	Absorption %	$KBrO_3$ (ppm.)	Proof time (min.)	Volume (cc.)	Specific volume (cc./g.)	Grain Score	Curve ht. (Watts)	Work WHrs/kg
1	Fine	5.25	1.5	0.25	69.75	22.5	45	2100	4.72	7.5	74	13.70
2	Fine	7.75	1.5	0.25	69.75	7.5	56	2075	4.58	7.5	100	27.78
3	Fine	5.25	4.5	0.25	69.75	7.5	49	2075	4.61	6.5	77	12.74
4	Fine	7.75	4.5	0.25	69.75	22.5	51	2275	5.07	7.5	103	26.22
5	Fine	5.25	1.5	0.75	69.75	7.5	48	2050	4.53	7.0	61	12.32
6	Fine	7.75	1.5	0.75	69.75	22.5	44	1975	4.32	7.0	103	27.27
7	Fine	5.25	4.5	0.75	69.75	22.5	44	2400	5.36	8.5	62	11.44
8	Fine	7.75	4.5	0.75	69.75	7.5	48	2350	5.21	8.0	95	22.09
9	Fine	5.25	1.5	0.25	73.25	7.5	50	2150	4.74	7.0	63	11.59
10	Fine	7.75	1.5	0.25	73.25	22.5	45	1950	4.32	7.0	90	21.45
11	Fine	5.25	4.5	0.25	73.25	22.5	45	2000	4.44	7.0	55	10.06
12	Fine	7.75	4.5	0.25	73.25	7.5	55	2350	5.21	8.0	92	18.62
13	Fine	5.25	1.5	0.75	73.25	22.5	44	2225	4.96	8.0	37	10.67
14	Fine	7.75	1.5	0.75	73.25	7.5	45	2200	4.82	7.5	100	25.27
15	Fine	5.25	4.5	0.75	73.25	7.5	56	2175	4.83	6.3	43	9.44
16	Fine	7.75	4.5	0.75	73.25	22.5	46	2400	5.37	7.0	95	20.72
17	Fine	4.00	3.0	0.50	71.50	15.0	46	2250	5.00	7.5	35	6.83
18	Fine	9.00	3.0	0.50	71.50	15.0	42	2075	4.62	6.5	88	30.21
19	Fine	6.50	0.0	0.50	71.50	15.0	48	1850	4.06	6.5	88	19.29
20	Fine	6.50	6.0	0.50	71.50	15.0	46	2300	5.27	8.0	93	14.67
21	Fine	6.50	3.0	0.00	71.50	15.0	57	2275	5.04	7.5	85	17.35
22	Fine	6.50	3.0	1.00	71.50	25.0	40	2300	5.17	8.0	89	16.82
23	Fine	6.50	3.0	0.50	68.00	15.0	45	2275	5.07	8.0	102	20.51
24	Fine	6.50	3.0	0.50	75.00	15.0	43	2275	5.09	7.0	69	13.20
25	Fine	6.50	3.0	0.50	71.50	0.0	54	2250	4.99	8.0	73	16.04
26	Fine	6.50	3.0	0.50	71.50	30.0	52	2325	5.19	8.0	74	15.62
27	Fine	6.50	3.0	0.50	71.50	15.0	44	2250	5.06	7.5	98	19.07
28	Fine	6.50	3.0	0.50	71.50	15.0	48	2450	5.53	8.0	92	17.27
29	Fine	6.50	3.0	0.50	71.50	15.0	42	2325	5.21	8.0	99	17.27
30	Fine	6.50	3.0	0.50	71.50	15.0	53	2350	5.21	8.0	88	17.27
31	Fine	6.50	3.0	0.50	71.50	15.0	57	2300	5.12	8.0	86	17.62
32	Fine	6.50	3.0	0.50	71.50	15.0	50	2425	5.45	8.0	93	18.35
33	Coarse	5.25	1.5	0.25	69.75	22.5	54	2100	4.65	5.5	40	7.78

Appendix 1. Pin-Type Mixing (concluded)

Batch #	Granu-lation	Mix time (min.)	Shortening %	DATA %	Absorption %	$KBrO_3$ (ppm.)	Proof time (min.)	Volume (cc.)	Specific vol-ume (cc./g.)	Grain Score	Curve ht. (Watts)	Work WHrs/kg
34	Coarse	7.75	1.5	0.25	69.75	7.5	45	2275	5.07	5.5	69	16.89
35	Coarse	5.25	4.5	0.25	69.75	7.5	65	2050	4.55	5.0	32	7.64
36	Coarse	7.75	4.5	0.25	69.75	22.5	55	2400	5.33	6.5	59	13.65
37	Coarse	5.25	1.5	0.75	69.75	7.5	52	2150	4.77	5.5	40	8.22
38	Coarse	7.75	1.5	0.75	69.75	22.5	55	2350	5.27	6.0	62	14.74
39	Coarse	5.25	4.5	0.75	69.75	22.5	52	2325	5.17	5.5	36	7.51
40	Coarse	7.75	4.5	0.75	69.75	7.5	56	2375	5.33	5.5	58	13.76
41	Coarse	5.25	1.5	0.25	73.25	7.5	52	2100	4.72	4.0	27	6.16
42	Coarse	7.75	1.5	0.25	73.25	22.5	51	2225	4.97	6.0	55	12.87
43	Coarse	5.25	4.5	0.25	73.25	22.5	56	2200	4.87	4.5	32	7.63
44	Coarse	7.75	4.5	0.25	73.25	7.5	55	2250	5.03	5.0	38	10.89
45	Coarse	5.25	1.5	0.75	73.25	22.5	45	2025	4.46	5.0	31	6.40
46	Coarse	7.75	1.5	0.75	73.25	7.5	45	2200	4.99	5.0	61	12.97
47	Coarse	5.25	4.5	0.75	73.25	7.5	52	2150	4.79	5.0	25	6.64
48	Coarse	7.75	4.5	0.75	73.25	22.5	46	2275	5.09	5.0	49	9.67
49	Coarse	4.00	3.0	0.50	71.50	15.0	52	2100	4.70	4.5	25	5.04
50	Coarse	9.00	3.0	0.50	71.50	15.0	51	2400	5.36	6.0	63	15.83
51	Coarse	6.50	0.0	0.50	71.50	15.0	48	2000	4.42	5.5	55	11.50
52	Coarse	6.50	6.0	0.50	71.50	15.0	54	2250	5.00	5.5	36	9.08
53	Coarse	6.50	3.0	0.00	71.50	15.0	49	2275	5.06	6.0	56	11.57
54	Coarse	6.50	3.0	1.00	71.50	15.0	46	2225	5.03	5.0	32	8.59
55	Coarse	6.50	3.0	0.50	68.00	15.0	52	2250	5.02	6.0	52	10.44
56	Coarse	6.50	3.0	0.50	75.00	15.0	52	2175	4.85	5.5	29	8.34
57	Coarse	6.50	3.0	0.50	71.50	0.0	46	2250	5.00	5.5	40	9.11
58	Coarse	6.50	3.0	0.50	71.50	30.0	46	2125	4.74	5.0	34	9.58
59	Coarse	6.50	3.0	0.50	71.50	15.0	48	2325	5.18	5.0	50	11.15
60	Coarse	6.50	3.0	0.50	71.50	15.0	46	2225	4.96	6.0	38	10.07
61	Coarse	6.50	3.0	0.50	71.50	15.0	47	2350	5.27	5.0	44	8.99
62	Coarse	6.50	3.0	0.50	71.50	15.0	52	2225	4.96	5.0	36	8.63
63	Coarse	6.50	3.0	0.50	71.50	15.0	52	2165	4.81	5.5	36	8.63
64	Coarse	6.50	3.0	0.50	71.50	15.0	47	2125	4.74	6.0	37	8.99

Appendix 2. Dough-brake Mixing

Batch #	Granulation	# of passes	Time in Sheeter (min)	Shortening %	DATA	Absorption %	$KBrO_3$ (ppm.)	Proof time (min.)	Volume (cc.)	Specific volume (cc./g.)	Grain Score	Curve ht. (Watts)	Work WHrs/kg
65	Fine	25	2.83	1.5	0.25	69.75	22.5	46	2100	4.72	8.0	44	5.93
66	Fine	75	7.43	1.5	0.25	69.75	7.5	45	2125	4.71	7.0	47	6.38
67	Fine	25	2.48	4.5	0.25	69.75	7.5	53	2400	5.30	8.0	45	6.19
68	Fine	75	8.33	4.5	0.25	69.75	22.5	51	2375	5.28	8.5	39	5.03
69	Fine	25	2.53	1.5	0.75	69.75	7.5	42	2300	5.12	8.0	33	6.72
70	Fine	75	3.57	1.5	0.75	69.75	22.5	51	2275	5.06	7.5	47	6.26
71	Fine	25	2.43	4.5	0.75	69.75	22.5	42	2450	5.46	8.5	38	6.08
72	Fine	75	7.23	4.5	0.75	69.75	7.5	48	2325	5.22	8.0	41	5.07
73	Fine	25	2.50	1.5	0.25	73.25	7.5	54	2150	4.77	7.0	41	5.79
74	Fine	75	7.58	1.5	0.25	73.25	22.5	48	2200	4.86	7.5	32	4.65
75	Fine	25	2.83	4.5	0.25	73.25	22.5	48	2300	5.13	8.0	33	4.86
76	Fine	75	6.92	4.5	0.25	73.25	7.5	57	2450	5.46	8.0	32	4.57
77	Fine	25	2.47	1.5	0.75	73.25	22.5	52	2250	5.04	8.0	40	5.69
78	Fine	75	6.27	1.5	0.75	73.25	7.5	53	2250	5.06	8.0	37	4.68
79	Fine	25	2.83	4.5	0.75	73.25	7.5	49	2425	5.41	7.5	29	4.10
80	Fine	75	6.85	4.5	0.75	73.25	22.5	52	2600	5.82	8.5	34	5.18
81	Fine	0	0.00	3.0	0.50	71.50	15.0	47	2275	5.08	6.5	34	5.76
82	Fine	100	10.00	3.0	0.50	71.50	15.0	42	2150	4.80	7.5	37	5.40
83	Fine	50	4.88	0.0	0.50	71.50	15.0	56	1900	4.18	6.5	42	5.94
84	Fine	50	4.83	6.0	0.50	71.50	15.0	46	2425	5.40	8.5	36	4.89
85	Fine	50	4.72	3.0	0.00	71.50	15.0	52	2300	5.17	7.5	36	5.06
86	Fine	50	5.42	3.0	1.00	71.50	15.0	46	2325	5.18	8.5	37	5.72
87	Fine	50	5.17	3.0	0.50	68.00	15.0	49	2200	4.89	8.0	44	6.34
88	Fine	50	5.77	3.0	0.50	75.00	15.0	46	2400	5.44	8.0	30	4.17
89	Fine	50	5.17	3.0	0.50	71.50	0.0	45	2225	4.92	8.0	37	5.47
90	Fine	80	4.67	3.0	0.50	71.50	30.0	43	2200	4.95	7.5	39	5.32
91	Fine	50	4.70	3.0	0.50	71.50	15.0	47	2375	5.37	8.0	36	5.08
92	Fine	50	4.58	3.0	0.50	71.50	15.0	52	2452	5.53	8.0	42	5.40
93	Fine	50	5.15	3.0	0.50	71.50	15.0	47	2350	5.25	8.5	24	5.76
94	Fine	50	4.53	3.0	0.50	71.50	15.0	44	2400	5.38	8.5	43	6.12
95	Fine	50	4.95	3.0	0.50	71.50	15.0	48	2500	5.67	8.5	43	5.40

Appendix 2. Dough-brake Mixing (concluded)

Batch #	Granu- lation	# of passes	Time in Sheeter (min)	Shorten- ing %	DATA	Absorpt- ion %	$KBrO_3$ (ppm.)	Proof time (min.)	Volume (cc.)	Specific vol- ume (cc./g.)	Grain Score	Curve ht. (Watts)	Work WHrs/k
96	Fine	50	4.58	3.0	0.50	71.50	15.0	44	2400	5.44	3.0	39	5.76
97	Coarse	25	2.42	1.5	0.25	69.75	22.5	45	2250	4.98	6.5	30	4.44
98	Coarse	75	6.38	1.5	0.25	69.75	7.5	53	2225	4.94	6.0	28	4.13
99	Coarse	25	2.27	4.5	0.25	69.75	7.5	54	2175	4.85	5.5	27	4.00
100	Coarse	75	7.13	4.5	0.25	69.75	22.5	51	2250	4.97	7.0	24	3.59
101	Coarse	25	2.67	1.5	0.75	69.75	7.5	60	2200	4.91	5.0	28	4.48
102	Coarse	75	6.75	1.5	0.75	69.75	22.5	47	2325	5.19	6.5	25	4.42
103	Coarse	25	2.63	4.5	0.75	69.75	22.5	61	1375	5.30	6.0	25	3.21
104	Coarse	75	6.77	4.5	0.75	69.75	7.5	51	2325	5.20	6.0	26	3.62
105	Coarse	25	3.00	1.5	0.25	73.25	7.5	55	2075	4.61	4.0	20	2.90
106	Coarse	75	7.03	1.5	0.25	73.25	22.5	43	2275	5.07	6.5	22	3.57
107	Coarse	25	2.43	4.5	0.25	73.25	22.5	45	2150	4.76	5.5	24	3.47
108	Coarse	75	7.80	4.5	0.25	73.25	7.5	49	2200	4.92	6.0	23	3.16
109	Coarse	25	2.48	1.5	0.75	73.25	22.5	46	2250	5.03	5.0	18	2.13
110	Coarse	75	7.43	1.5	0.75	73.25	7.5	50	2300	5.16	6.5	25	2.88
111	Coarse	25	2.75	4.5	0.75	73.25	7.5	49	2300	5.13	5.5	25	3.50
112	Coarse	75	6.98	4.5	0.75	73.25	22.5	60	2400	5.37	6.0	22	3.45
113	Coarse	0	0.00	3.0	0.50	71.50	15.0	45	2075	4.64	4.5	28	3.96
114	Coarse	100	9.40	3.0	0.50	71.50	15.0	51	2275	5.07	6.0	24	2.88
115	Coarse	50	4.62	0.0	0.50	71.50	15.0	50	2100	4.67	5.5	23	3.34
116	Coarse	50	4.93	6.0	0.50	71.50	15.0	51	2350	5.27	6.0	26	3.84
117	Coarse	50	4.77	3.0	0.00	71.50	15.0	52	2250	5.03	5.0	24	3.25
118	Coarse	50	4.77	3.0	1.00	71.50	15.0	54	2425	6.44	6.0	30	4.30
119	Coarse	50	4.75	3.0	0.50	68.00	15.0	49	2175	4.82	6.0	29	4.47
120	Coarse	50	5.33	3.0	0.50	75.00	15.0	50	2250	4.99	6.0	22	3.13
121	Coarse	50	4.75	3.0	0.50	71.50	0.0	49	2250	5.07	5.5	27	4.01
122	Coarse	50	4.92	3.0	0.50	71.50	30.0	46	2250	5.06	6.5	25	3.91
123	Coarse	50	4.47	3.0	0.50	71.50	15.0	48	2300	5.15	6.0	23	3.24
124	Coarse	50	5.17	3.0	0.50	71.50	15.0	51	2350	5.22	5.5	24	3.24
125	Coarse	50	4.67	3.0	0.50	71.50	15.0	56	2275	5.07	6.0	22	3.60
126	Coarse	50	4.78	3.0	0.50	71.50	15.0	52	2375	5.33	6.0	23	3.24
127	Coarse	50	4.48	3.0	0.50	71.50	15.0	58	2275	5.07	6.5	27	3.60
128	Coarse	50	5.75	3.0	0.50	71.50	15.0	49	2225	4.94	6.0	22	3.24

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EFFECTS OF INGREDIENTS AND PROCESSING VARIABLES ON THE QUALITY OF WHOLE WHEAT BREAD

by

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AN ABSTRACT OF A MASTER'S THESIS

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ABSTRACT

The first part of this thesis presents a comparison between the flavor and aroma of white bread and whole wheat bread. The profile method of flavor analysis was used and these profiles were determined after one, three, and five days storage at room temperature.

Whole wheat bread was found to have strikingly different profiles compared to those of white bread. Total flavor and aroma intensities were considerably greater in the whole wheat bread. Yeasty aromatics, which were the dominant notes in white bread, were entirely absent from whole wheat bread. Other flavor and aroma differences were noted and discussed.

In Part II of this study two methods of dough mixing, two granulations of flour, and various levels of absorption, shortening, emulsifier, and potassium bromate were investigated in the production of whole wheat bread. Response Surface Methodology was employed in the experimental design and statistical analysis of data.

The mixing methods included utilization of a laboratory pin-type mixer as an example of a high shear mixer, and the use of a sheeter to typify the low shear mixing of dough brakes. Both methods produced whole wheat breads of acceptable quality, but most breads made with the sheeting method exhibited greater volume and improved grain. Breads made from fine whole wheat flour showed greater improvements with the sheeting method than did those made from coarse flour.

The importance of absorption in the production of whole wheat bread was investigated. Mixing method, flour granulation, and shortening level were found to influence the optimum absorption of test breads.

The addition of shortening to the doughs resulted in improvements in volume and grain of the whole wheat breads. Breads made from the fine flour exhibited this improvement to a greater extent than did those made from coarse flour.

The emulsifier, diacetyl tartaric acid ester of monoglyceride (DATA) was found to have only a slight improving effect in these whole wheat breads. Breads made from coarse whole wheat flour required slighter more potassium bromate addition than did those made with fine flour.

Results from this study show the potential for use of the sheeter in both commercial and research applications.