EFFECT OF MAIZE FLOUR AND ITS MAJOR COMPONENTS ON BREADMAKING PROPERTIES OF WHEAT FLOUR

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ABSTRACT

Mukulumwa, Address Michello. M.Sc., The University of Manitoba, October, 1976.

Effect of Maize Flour and Its Major Components on Breadmaking Properties of Wheat Flour. Major Professor: Dr. Walter Bushuk

The breadmaking properties of composite flours comprising wheat flour and maize flour and its major components (starch, protein and oil) were investigated. Maize flour was used to replace 5, 10, 20, and 40% (flour basis) of wheat flour, and equivalent proportions of the maize components were added to wheat flour.

Generally, the proximate composition of composite flours was directly related to the proportion of constituent flours in the composite.

Maize flour and maize starch isolate produced changes in breadmaking properties suggesting a simple dilution of wheat protein. The effect of maize protein isolate suggests an interaction between the proteins of maize and wheat, while maize oil showed negligible effects on breadmaking properties. The observed effects increased as the proportion of supplement in the composite increased.

The study shows that satisfactory bread can be produced from composite flours containing wheat and up to 20% maize flour (or its

components). Minor adjustments in the breadmaking procedures would be required for composites containing up to 20% maize flour with major modifications required for high proportions.

I. INTRODUCTION

Bread is considered to be the staff of life in most developing countries. There has been a tendency, in many parts of the world, toward increased wheaten bread consumption where formerly bread was not a staple in the populations' diet. Wheat production, however, is not evenly dispersed over the world, nor is wheat equally available in all countries. The cultivation of wheat is concentrated in relatively few major areas, comprising primarily the U.S.A., Canada, Europe (including the U.S.S.R.), Australia and Argentina. These regions account for approximately four-fifths of the world's annual wheat crop, some 228 million tons out of the total 1973/74 world crop of about 341 million tons, excluding China (Bushuk, 1975). Domestic consumption, for both food and feed, amounts to some 82% of this wheat production, leaving a relatively small quantity for export to areas which contain more than 67% of the world's population.

In the other countries of the world, wheat is only sparsely grown, largely because of climatic and soil conditions that are less conducive to wheat cultivation. To satisfy the growing demand for bread products in these areas would require the importation of wheat or its flour with payments in foreign currency. This is an adverse economic factor for almost all developing countries. Hence it would be economically advantageous if the demand for bread would be met by the use of domestically grown products, instead of wheat. It is from this point of view that a whole new chapter in Cereal Chemistry and Technology was opened. World bodies, institutions and societies, in collaboration with respective governments all over the world, have joined in an attempt to solve the problem by using the so-called "composite" flours for the production of traditional baked goods.

The term 'composite flour' is used to describe a flour made by blending varying amounts of nonwheat flour with wheat flour which is used for the production of baked goods that were traditionally made from wheat. Cereal flours other than wheat flour, namely maize (corn) (*Zea mays* L.), barley (*Hordeum vulgare*), oats (*Avena sativa*), rice (*Oryza sativa*), sorghum (*Sorghum bicolor*), millet (*Pennisetum* sp.) flours, starches from roots, tubers, and pulses, and high protein flours from oil-seeds, yeast, fish, petroleum, etc. have been investigated as ingredients for composite flour production. A survey made by the ICC Working Group on Composite Flours in 1971 indicated that 22 institutes located in different countries have research programs on composite flours (Civetta, 1974). Since then, considerable literature has been accumulated and is still accumulating on composite flours.

It is now well established that nonwheat flours can be blended with wheat flour to produce baked goods of acceptable quality. It is also reasonably well-known that different nonwheat flours, when used in composite flours for bread, affect the breadmaking and rheological properties of wheat flour differently. For any given nonwheat flour, there exists a maximum level that can be used to obtain baked goods of acceptable quality; increasing the level beyond this maximum leads to processing problems or gives unacceptable baked products. Furthermore, it is well documented that the major constituents of the nonwheat flours differ qualitatively and quantitatively. For example, maize, cassava (Manihot utilissima Pohl.) and rice flours contain much more starch than protein, whereas soybean and legume flours contain much more protein than starch, and so forth. However, little is known about the substance(s) in the nonwheat flours that cause undesirable or deleterious effects on the rheological (processing) and breadmaking properties of wheat flour.

Background information for the present study was derived mainly from the results of the work of two institutions. The first was the milling and baking study carried out at the Grain Research Laboratory, Winnipeg (Tipples, 1974). Results of this study suggested that it should be feasible to make bread acceptable to Zambian consumers from wheat flour containing up to 20% of Zambian maize flour. The study suggests that in order to facilitate maximum utilization of maize, it is important to use maize and wheat flours of appropriate quality and to optimize the milling and baking processes. Thus, a high grade, high quality maize product, such as breakfast meal reduced to flour, an optimized baking formula (e.g., addition of sodium stearoyl lactylate or S.S.L.) and breadmaking procedure (e.g., four-piece moulding; Chorleywood Process) can greatly improve the over-all bread quality.

The second study was carried out by the National Milling Company, Lusaka, Zambia (1975). A series of tests were performed to evaluate the effect on bread quality of the addition of various maize meals, namely roller meal, breakfast food, maize flour and sieved No.3

meal. The maize meals (10%) were used to replace a standard wheat flour. The results showed that No.3 meal, when sieved through a No.24 wire sieve, produced the best all-round loaf characteristics which compared favourably with the control loaves baked from 100% wheat flour.

The objective of the present study was to extend the observations of the two preliminary studies mentioned above. Specifically, the study examined the effects of various levels of maize flour and its major components (starch, protein and lipid) on the breadmaking properties of a selected wheat flour which was used as the carrier for the nonwheat additives.

II. LITERATURE REVIEW

This literature review is organized as follows. The first part covers the literature on composite flours containing maize flour and its components. The published reports are reviewed in chronological order. The remaining portion of the review covers the literature on composite flours containing various other nonwheat flours or concentrates. Again the publications are reviewed in chronological order.

The first reported study of bread production from composite flour was that of Noznick _et al_. (1946) who made bread from mixtures of gluten and starch. The starch used comprised mixtures of wheat starch and various quantities of waxy maize starch. Complete substitution of wheat starch by waxy maize starch gave loaves that had highly compressible crumbs and showed excessive shrinkage after baking. Crumb compressibility and crumb swelling capacity, measured three hours after baking, were increased with substitution of waxy maize starch for wheat starch. On storage, crumb compressibility of loaves containing maize starch decreased at about the same rate as that of loaves from mixtures of gluten and wheat starch.

Ballschmeiter and Vliestra (1963; 1965; 1968) carried out experiments on the use of maize flour in leavened wheat bread. Bread containing 25% (flour basis) maize flour was improved by the addition of ascorbic acid or potassium bromate and 1% baking fat. Optimized quantities of these ingredients were required for a good bread quality. Granular (coarse) maize flour was more suitable than fine flour. Wheat starch was found to be necessary for the baking of gluten-containing maize bread but it could be replaced by potato starch without affecting bread volume significantly.

In 1965, Feldberg prepared a variety of bakery products using maize gluten added to wheat flour up to 3% level. These studies indicated that maize gluten, at low levels, improved the color, moistness, moisture retention, and tenderness of the crumb, and the storage stability of the bread.

Pomeranz and Hayes (1968) studied the effect of hydrogenated maize oils on bread baked from flours of single wheat varieties. Seven hydrogenated oils, varying in iodine value and melting points, were added individually at a rate of 3 g per 100 g flour. The 16 flours used varied widely in protein content, rheological properties and breadmaking potentialities. Loaf volume and crumb grain of the bread baked from each flour were improved substantially by adding the maize oils. Subsequently, studies were made of the effects of shortening, refined maize oil and wheat lipids (total, nonpolar and polar) on rheological properties of dough (Tao and Pomeranz, 1968). The fats were added to seven hard red winter wheat flours of comparable milling extraction and protein content but varying widely in protein quality. The effects of maize oil were as follows: Mixogram characteristics were little affected; there was no change in farinograph absorption; and peak amylograph viscosity was slightly lowered.

Pringle *et al*. (1969) studied the production of bread by mechanical development of doughs from composite flours containing wheat flour and maize starch. They found that mechanical development of doughs, using the Chorleywood Bread (CB) process of Axford *et al*. (1963), produced bread that was significantly superior to the bread produced by the standard no-time and the conventional fermentation processes for all composites. The CB process displayed good tolerance and permitted significant variations in ingredient levels. They concluded that the CB process offered distinct advantages in simplicity, control and ability to utilize nonwheat flours from indigenous crops of many developing countries.

Two processed maize meals and one uncooked maize meal were compared at various levels of replacement by wheat flour in bread doughs and as ingredients in suspensions for beverage or porridge (Matthews *et al*., 1970a). Processed maize meals had greater water absorption capacity than uncooked meal in mixtures with wheat flour. At the 5 and 15% levels of wheat flour replacement, doughs made from processed maize meal of lesser degree of starch gelatinization, as shown by consistency and amylograph measurements, showed better mixing tolerance than doughs made from processed maize meal of greater degree of starch gelatinization. At the 25% level of wheat flour replacement, the extent of starch gelatinization of processed maize meals had little effect on mixing tolerance of dough.

Bushuk and Hulse (1974) used a simple, low-power sheeting development dough-making process in the production of bread from a variety of composite flours, including maize flour. The results obtained with this simple breadmaking process were comparable to those obtained with the more sophisticated CB process. The quality of bread deteriorated gradually as the amount of the nonwheat flour in the composite increased. Satisfactory bread was obtained from composite flours containing up to 20% (flour basis) nonwheat flour. Bread of acceptable grain but low loaf volume was obtained from flours containing higher proportions of nonwheat flour. The addition of sodium stearoyl lactylate (S.S.L.), at the 0.5% level, generally produced a small improvement in loaf volume and a notable improvement in crumb grain and apparent crumb color.

Molina et al. (1975) studied pasta products prepared from semolina containing 20, 40 and 60% maize flour. Resistance to disintegration and organoleptic evaluation tests indicated that satisfactory pasta products can be obtained from the composite flours and that heat treatment of the maize flour induced a significant improvement in the quality of the product.

The effect of adding maize starch to wheat flour for use in breadmaking was studied by Seyam and Kidman (1975). In this study, the doughs were produced by the activated dough development (A.D.D.) process. Farinograph measurements on doughs from these flours showed a decrease in farinograph absorption from 68 to 65.2% on the addition of 25% maize starch. At this level, maize starch produced an increase of 40 BU in mixing tolerance index. Overall farinograph score was decreased as were the extensigraph and amylograph scores. The addition of maize starch also decreased loaf volume.

Recently, Molina et al. (1976) used several physico-chemical tests to evaluate the pasta making properties of heat-treated and untreated maize flour, wheat semolina containing maize flour, and wheat semolina containing maize flour mixed with defatted soybean flour. Heat treatment of maize flour significantly increased the level of damaged starch, lowered the sedimentation values and raised the maximum amylograph viscosity. A high correlation was obtained between the maximum amylograph viscosity and the solids-in-cooking water value, and the organoleptic score of the pasta products. The results indicated a desirable effect of partial starch gelatinization in maize flour used for pasta production.

With strong wheat flours, it is possible to incorporate high levels of rice flour and obtain good quality bread (Borasio, 1931). The rice flour should be milled from the whole grain to retain the major nutritive substances which stimulate the action of yeast enzymes. Breadmaking with rice composite flours presents no problem. Various types of bread can be made by standard procedures with minor modifications.

Many investigators (Ofelt et al., 1954a; 1954b; Finney et al., 1963; Tsen et al., 1971; Tsen and Hoover, 1971; Tsen and Tang, 1971) have shown that the breadmaking performance of wheat-soybean composite flours can be improved by raising absorption, decreasing mixing time, increasing oxidant (bromate) treatment, reducing fermentation period and adding dough conditioners. For best results, each factor must be optimized for a specific flour.

Lentil and gram flours added to wheat flour at levels above 5% adversely affected grain and volume of bread (Bains and Tara, 1967). Better loaf volume was obtained by adding groundnut flour to the composite flour; the texture and grain were improved by adding 0.25% sodium stearoyl fumarate to the composite flour.

The suitability of using cassava, yam (Dioscorea spp.), sago and arrow-root (Abstroemeria ligtu) for making bread when mixed with protein concentrates obtained from soybean, peanut, cottonseed and fish meal was investigated (Jongh et al., 1968; Kim and deRuiter, 1968; 1969). Detailed study was made on mixtures of cassava and soybean flours in an attempt to develop formulae and procedures that could be used for the production of well-aerated bread under widely varying climatic and environmental conditions. Satisfactory results were obtained with mixtures of cassava and peanut flours. These studies were under the auspices of the Food and Agricultural Organization (F.A.O.) and with the financial assistance of the Netherlands Government, and the Institute for Cereal, Flour and Bread at Wageningen.

Perten (1969) studied the effects of adding cassava starch and millet flours to wheat flour in the production of French-type bread by mechanical dough development. He showed that acceptable bread could be made with the Tweedy dough mixer and developer. Hearth-baked bread was more suitable for diluted wheat flour than large-tin bread. Weak wheat flours tolerated a dilution with cassava starch and millet flour of up to 30%, and strong flours up to 50% dilution. Addition of glycerol monostearate (G.M.S.) and oxidising agents (potassium bromate) was essential for the cassava starch composite flour but less important for the millet composite. Doughs from millet composite flour can be mixed in conventional mixers, when using chemical dough development, with good results. The conventional method (straight dough; long fermentation) gave poorer quality bread. Full-fat soybean flour, used at a 5% level, improved the quality of the bread. Unprocessed soybean flour, with full enzymatic activity, gave a softer bread crumb and a lighter crumb color. The flavour of bread containing millet flour was superior to that containing cassava starch. The cassava bread had a lighter crumb color. The keeping quality of both types of bread was considered satisfactory.

Matthews et al. (1970b) investigated the effects of adding oilseed flours (cottonseed, peanut, safflower and full-fat soybean) to wheat flour in breadmaking. Bread made with the conventional straight-dough method had poor loaf volume at the 25% level of substitution. Changes in formulation or mixing time of doughs or both usually improved loaf volume. The oilseed flours increased absorption and usually decreased mixing tolerance of doughs in direct relation with the increase in substitution level.

According to Sammy (1970), sweet potato flour can be used with wheat flour without difficulty at a rate not exceeding 15% in bread and 30% in pastry. Baking properties were similar for flours from peeled and unpeeled tubers. Glycerol monostearate and glycerol monopalmitate at 1% level improved the baking properties only slightly.

Bookwalter et al. (1971) used extrusion-cooked soybean flour to produce high-protein bread. They found that loaf volume decreased less with extruded full-fat soybean flour than with the nonextruded flour. As the proportion of the soybean flour increased from 5 to 10%, loaf volume reduced gradually; it decreased sharply at 15%.

In a study by Dendy et al. (1971), different wheat flours were diluted with various proportions of cassava starch. The blends were processed into bread by three different breadmaking methods. Mechanical dough development (Chorleywood Bread Process) gave the best bread and allowed for incorporation of 10% more nonwheat flour than other methods. Cottonseed, groundnut, leaf and coconut proteins were also tested as supplements as well as tropical cereals such as sorghum, rice and millet. It was also found that 20% yam flour could be used without serious adverse effects.

Farinograph results by Hamed et al. (1972) showed that the addition of sweet potato flour to wheat flour increased water absorption, weakened the dough strength, and decreased dough development time, dough stability and valorimeter index. There was a decrease in extensibility of dough and an increase in proportional number (ratio figure) as measured by the extensigraph. An increase in the weight of bread and a decrease in its volume were generally obtained when sweet potato flour was added to wheat flour.

According to Tanaka (1972), replacement of wheat flour with rice flour causes a decrease in loaf volume, but various surfactants can restore dough and loaf characteristics to normal levels. The addition of small amounts of bacterial alpha-amylase with high heat resistance was also beneficial. Coarse rice flour performed better than fine, parched or puffed rice flour. At a 10% level of substitution, extension of the final proofing time resulted in a loaf of the same volume as that from 100% wheat flour.

Luh and Maneepun (1973) prepared lima bean protein concentrate by extraction, and lima bean flour by freeze drying. These preparations, in combination with wheat flour, were tested for breadmaking potential. Both supplements increased water absorption of the dough and water retention in the loaf, reduced loaf volume and produced a slightly yellow crumb. Noticeable loss of organoleptic quality occurred at additions in excess of 3% lima bean protein concentrate and 10% lima bean flour.

The addition of soybean flour to wheat flour adversely affected the rheological properties of dough for breadmaking (Tsen and Hoover, 1973). The stability of doughs containing 12 to 28% soybean flour was increased by the addition of 0.25 to 2.0% S.S.L. All flours containing 12 to 28% soybean flour produced bread with unacceptable loaf volume and grain score. Both characteristics were improved substantially by the addition of 0.5% S.S.L.

A satisfactory high-protein bread can be made from a composite of wheat flour and faba bean (Vicia faba L.) protein concentrate (McConnell et al., 1974). There was a progressive decrease in loaf volume and a deterioration in crumb grain, even in the presence of S.S.L., as the level of faba bean flour increased. The addition of faba bean protein concentrate at the rate of 9% to wheat flour gave a composite flour containing 20% protein. This composite flour produced bread whose color, grain and volume scores were comparable to those of bread from wheat flour control.

According to Badi and Hoseney (1975), millet and sorghum composite flours do not produce acceptable cookies prepared according to the standard procedures used for testing soft wheat flour. The cookies showed little or no spread, and were hard and gritty with a mealy texture and had an undesirable taste. Replacement of the millet or sorghum lipids with wheat flour lipids produced cookies with increased spread and good top grain. Replacement with soybean oil improved the cookie spread only. Attempts to improve the results were made by treating the millet and sorghum flours with diastatic malt syrup. After drying, the treated flours were blended up to 50% with wheat flour. The resulting composite flours produced cookies comparable to those made from 100% wheat flour.

D'Appolonia (1975) investigated the rheological and baking characteristics of flours obtained from various legumes blended with wheat flour. The legumes used were faba beans, pinto beans, navy beans, mung beans and lentils. As the proportion of the legume flour in the composite increased, farinogram mixing time and stability decreased. Addition of S.S.L. increased dough strength. Extensigram data showed certain effects that can be attributed to characteristics of the legume flour used. Loaf volume of bread decreased as the proportion of the legume flour in the composite increased. There was an improvement in crumb color when up to 10% legume flour was added to wheat flour.

Khan et al. (1975) used a high fiber coconut residue to blend with wheat flour to make white pan bread and cookies. Acceptable bread could be made from wheat flour containing 7.5% coconut residue. The bread contained about 60% of the crude fiber of whole wheat.

Generally, bread made from wheat flour containing horsebean (*Vicia faba* M.) flour is more sweet, beany, bitter, and less wheaty and sour than bread made from wheat flour containing horsebean protein isolate (Patel *et al*., 1975). Based on the effects of the two supplements on various breadmaking properties as well as on the appearance and eating quality of the bread, it was concluded that bread from flours containing up to 20% protein isolate would be more acceptable than bread from the flour composite of equivalent protein content.

The above review shows that a wide range of materials have been used to formulate composite flours for bread production. These materials include cereals, other than wheat, tubers, oilseed, and legume flours. Although this entire area of research has been reasonably well surveyed, much remains to be done on the details that are necessary to use composite flours successfully in developing countries.

III. MATERIALS

The wheat flour (WF) used in this study was supplied by Soo Line Mills of Winnipeg. It was an unbleached and untreated commercial flour, of 13.0% protein, milled from Canadian red spring wheat. The maize breakfast meal (BFM), which was ground into flour (MF), was supplied by the National Milling Company Ltd., Lusaka, Zambia. The breakfast meal was commercially milled from white maize. The main difference between white and yellow maize commonly grown in North America, is the content of xanthophyll pigments. The gluten and oil from yellow maize are brightly colored and even the starch has a yellowish tinge. In contrast, gluten from white maize is light brown and the starch is pure white in color.

Commercial maize starch (MS), under the trade name Durham Corn Starch, used as a standard for starch determination and microscopy, and maize oil (MO), under the trade name Mazola Corn Oil, were purchased from a local supermarket. They were used without further processing. Maize starch isolate (MSI) was extracted from a defatted sample of maize flour. Maize protein isolate (MPI) was extracted from a defatted, relatively low-starch sample of maize flour.

All the materials were stored at 5°C during the study and samples were withdrawn as required. The materials are identified in Table 1.

Table 1. Identification of Materials

MATERIALS	ABBREVIATION
Breakfast Meal	BFM
Maize Flour	MF
Maize Starch	MS
Maize Starch Isolate	MSI
Maize Protein Isolate	MPI
Maize Oil	MO
Wheat Flour	WF

IV. METHODS

A. Sample Preparation

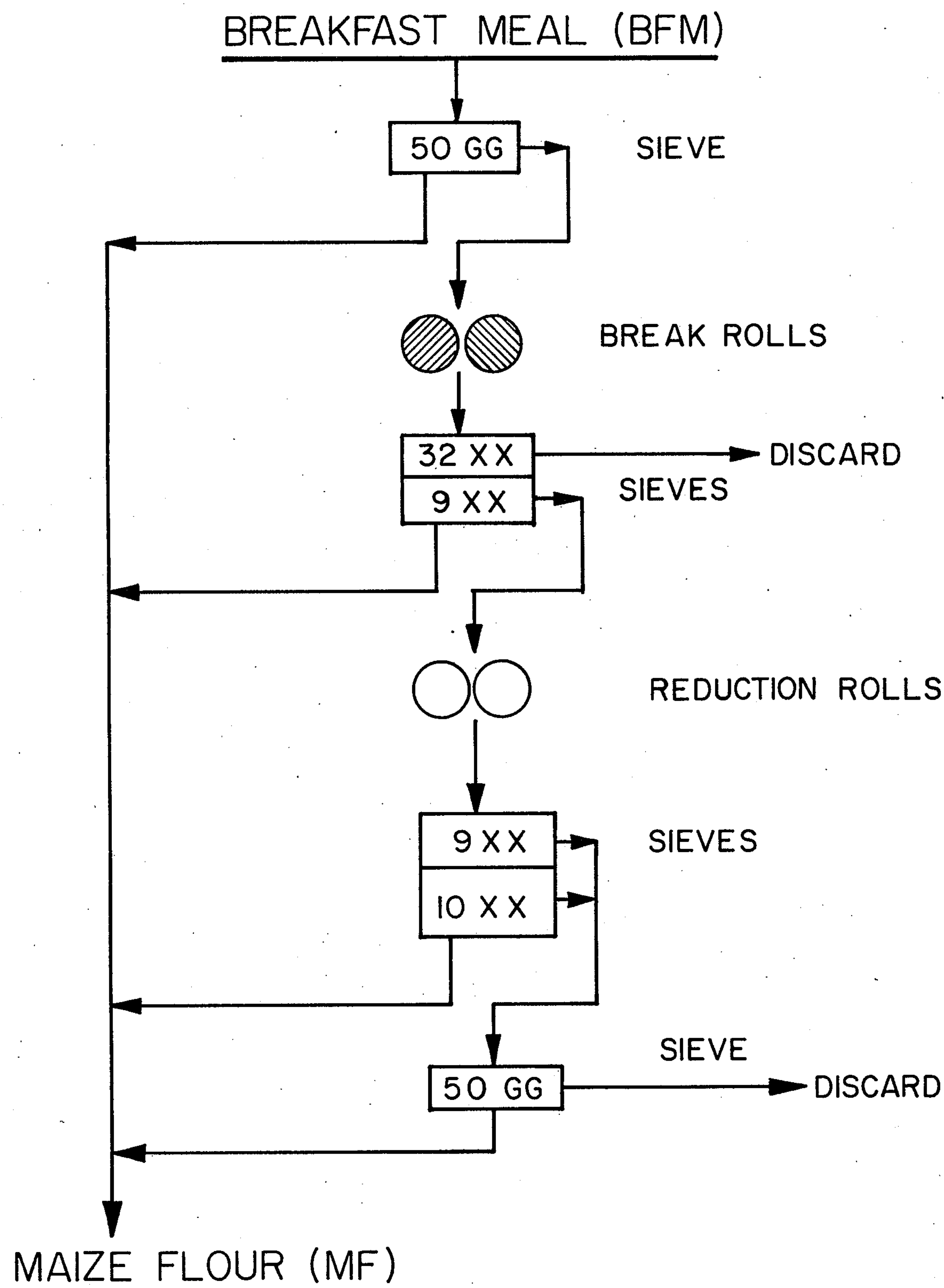
1. Preparation of Maize Flour

A small sample of the BFM received from Zambia was kept for further reference and use. The bulk of the sample was ground and sifted on the Buhler laboratory mill (MLU-202) to produce MF of acceptable granulation as outlined in Fig. 1.

2. Preparation of the Maize Starch Isolate

Three hundred g of MF was mixed in a Waring Blendor with 500 ml of clear Skellysolve F (petroleum ether, b.p. 36 to 58°C) under a fume hood for 10 to 15 min. After mixing, the slurry was allowed to settle completely. The yellow ether layer was then decanted very carefully into a clean 500 ml beaker. The above procedure was repeated until the ether layer was clear. The ether-extracted flour was air-dried and then returned to the Waring Blendor. Six hundred ml of 1% NaCl solution was added to the flour and the slurry was mixed for 15 to 20 min and passed through a 200-mesh stainless steel sieve to separate the protein from the starch. The starch passed through the sieve as a white suspension. The extraction and sieving steps were repeated until the suspension passing through the sieve was no longer white (that is, until it was free of starch). The residue

Figure 1. Scheme for grinding breakfast meal into flour.


BREAKFAST MEAL (BFM)
50 GG
SIEVE
BREAK ROLLS
32 XX
9 XX
DISCARD
SIEVES
REDUCTION ROLLS
9 XX
10 XX
SIEVES
SIEVE
50 GG
DISCARD
MAIZE FLOUR (MF)

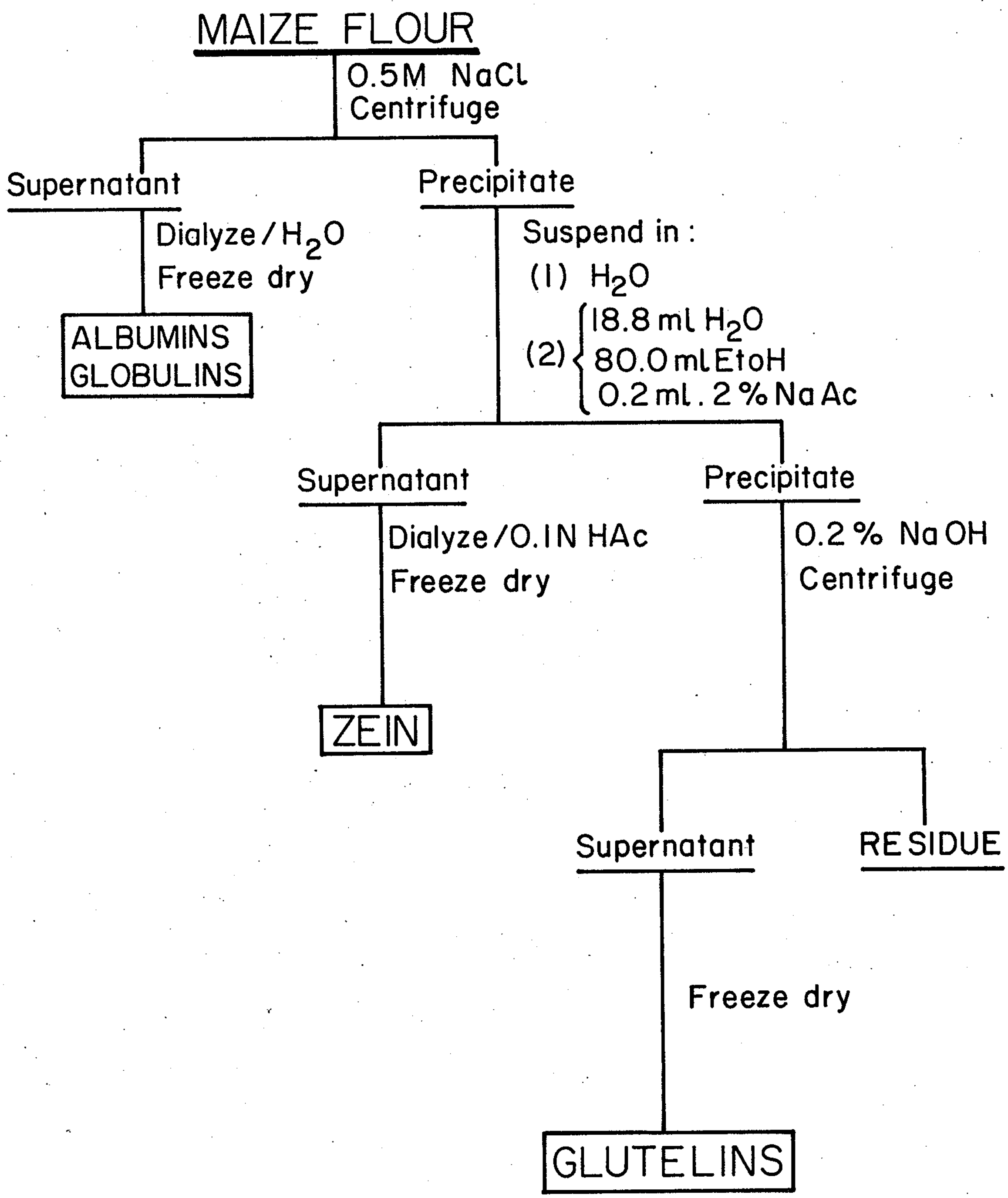
remaining on top of the sieve was air-dried and stored in a cold room (at 5^{o}C) until used to prepare maize protein isolate. The suspensions were combined and centrifuged to concentrate the prime starch. The tailings starch was scraped off the top of the precipitate after decanting the supernatant. The prime starch layer was resuspended in 500 ml 1% NaCl solution and centrifuged. To remove the remaining protein from the starch, it was extracted with 250 ml of 0.05N NaOH solution for about two hours. Finally, the starch precipitate was washed twice with 500 ml of distilled water, twice with 250 ml of 95% alcohol and once with 200 ml of ether. It was air-dried at room temperature, carefully pulverised in a mortar and pestle, and stored in a cold room (at 5^{o}C) until required.

Several batches were prepared and combined to provide sufficient starch for entire study.

3. Preparation of Maize Protein Fractions

The defatted, relatively starch-free maize flour remaining after preparing starch, was used to prepare maize protein fractions. The fractions were fractionated according to the method of Skoch _et al._ (1970) shown in Fig. 2. Two minor modifications were added. First, the samples were extracted by stirring with a magnetic stirrer for periods ranging from 24 to 36 hours at 4^{o}C instead of longitudinal rotation at room temperature, and second, 0.5M (2.9%) NaCl was used instead of 5% NaCl solution for the extraction of water- and salt-soluble protein fractions. The residue (15 g) was stirred for 24-36 hours in 250 ml of 0.5M NaCl solution, centrifuged and the supernatant

Figure 2. Scheme for extracting maize protein fractions.



MAIZE FLOUR
0.5M NaCl
Centrifuge
Supernatant
Precipitate
Dialyze/H_2O
Freeze dry
ALBUMINS
GLOBULINS
Suspend in:
(1) H_2O
(2) 18.8 ml H_2O
80.0 ml EtoH
0.2 ml. 2% NaAc
Supernatant
Precipitate
Dialyze/0.1N HAc
Freeze dry
ZEIN
0.2% NaOH
Centrifuge
Supernatant
RESIDUE
Freeze dry
GLUTELINS

was decanted. Two similar extractions followed. The supernatants were combined and extensively dialyzed against distilled water. The dialysate was freeze-dried to obtain the combined water-soluble (albumins) and salt-soluble (globulins) protein fraction. The residue (precipitate) remaining after salt extraction was suspended in distilled water to remove residual salt and then extracted twice with 250-ml portions of solution comprising 18.8 ml water, 80 ml ethanol and 0.2 ml of 0.2% sodium acetate solution per 100 ml solution. This mixture was centrifuged and the supernatant dialyzed against 0.1N acetic acid to remove the alcohol, and freeze-dried to obtain the alcohol-soluble (zein) fraction. The residue remaining after the alcohol extraction was extracted twice with 200-ml portions of 0.2% (w./v.) sodium hydroxide solution. The suspensions were centrifuged and the supernatants combined and freeze-dried to obtain alkali-soluble (glutelins) fraction. The four fractions of several preparations were combined and stored at $5^{o}C$ (cold room) until required.

The combined protein fractions will be referred to as the maize protein isolate (MPI).

B. Analytical Methods

Proximate analyses were made on the two basic flours (wheat and maize) and the various maize fractions used in this study to obtain information that might be useful in explaining the effects of the non-wheat components on the breadmaking properties of the base wheat flour.

1. Moisture Content

Determinations of moisture content were made according to the Approved Method (44-15A) of the American Association of Cereal Chemists (A.A.C.C., 1969).

2. Protein Content

Determinations of protein content were made using the boric acid modification of the Kjeldahl procedure according to the Approved Method (46-12) of the A.A.C.C. (1969). One-g flour samples at 0% moisture were used. The titrating acid was 0.142N sulfuric. This procedure gives values based on the 6.25 nitrogen-to-protein conversion factor. The data were multiplied by 0.784 to convert them to protein content on a 5.7 nitrogen-to-protein conversion factor at 14% moisture.

3. Amino Acid Composition

Amino acid compositions of MF and MPI were determined on a Beckman, model 121, automatic amino acid analyzer using the standard (6N HCl; vacuum; 24 hr.; 110°C) hydrolysis procedure. Concentrations of individual amino acids were computed against the Beckman standard.

4. Fat (Ether-extract) Content

Petroleum ether (Skellysolve F; b.p. 36-58°C) was refluxed for 12 hours through 5-g samples using a Soxhlet extractor. After solvent evaporation and drying of the oil in a 250-ml conical flask, the weight of the extracted fat was determined and reported as a percentage of the initial sample weight.

5. Fatty Acid Composition

Fatty acid composition of maize oil was determined according to the method of Hougen and Bodo (1973).

6. Ash Content

Determinations of ash content were made according to the Approved Method (08-01) of the A.A.C.C. (1969).

7. Starch Content

Determinations of starch content were made using the gluco-amylase method proposed by the Starch and Pentosan Collaborative Group of the A.A.C.C. recorded in Appendix A.

8. Starch Damage

Determinations of starch damage were made according to the Approved Method (76-30A) of the A.A.C.C. (1969) and expressed in Farrand units.

9. Gassing Power

Determinations of gassing power were made by the Pressure-meter Method (22-11) of the A.A.C.C. (1969).

10. Zeleny Sedimentation Value

The Zeleny Sedimentation Test was made according to the Approved Method (56-61A) of the A.A.C.C. (1969).

C. Dough Mixing and Rheological Measurements

1. Alveograph

Doughs from 250-g (14% moisture basis) flour were mixed in the alveograph mixer for six minutes and extruded in form of sheets. Disks were cut from these sheets according to standard practice. Alveograph curves were obtained after resting the disks for 22 min.

2. Amylograph

Starch pasting curves were obtained with a Brabender VISCO/Amylo/GRAPH according to the Approved Method (22-10) of the A.A.C.C. (1969). Curves were obtained using 65 g of flour dispersed in 460 ml of tap water at 30^{o}C. The temperature was increased at a rate of 1.5^{o} per minute to 95^{o}C and held until a 45-minute preset cycle elapsed.

3. Extensigraph

Extensigraph curves were obtained with a Brabender extensigraph according to the Approved Method (54-10) of the A.A.C.C. (1969). Doughs were made from 200-g (14% moisture basis) flour, 50 ml of 2% NaCl solution, and sufficient water to give an absorption of two percentage units less than the farinograph absorption. The dough was mixed for 2½ minutes in a GRL mixer to make about 300 g of dough. The dough was divided into two 150-g pieces which were rounded, shaped and rested. Extensigrams were obtained after 90- and 135-minute rest periods. Since the two curves were essentially the same, the data reported in this thesis are the average of the data for the two curves.

4. Farinograph

Farinograph curves were obtained according to the Constant Flour Weight Procedure of the A.A.C.C. (1969) Approved Method (54-21). Fifty g. flour (14% moisture basis) was used and water was added with a small buret to produce curve with maximum consistency centered on the 500 B.U. line.

5. Mixograph

Mixograph curves were obtained according to the Approved Method (54-40) of the A.A.C.C. (1969) with a Swanson Mixograph using 35-g (14% moisture basis) flour and water equivalent to farinograph absorption. A spring setting of nine was used for all measurements.

D. Baking Procedures

Baking properties of the composite fours were determined by two baking methods. The G.R.L. Remix experimental baking procedure by Irvine and McMullan (1960), recorded in Appendix B, was used to make pup loaves from 100-g (14% moisture basis) flour.

The Chorleywood Bread (CB) process of Axford et al. (1963) was used to make dough from 1000-g (14% moisture basis) flour. The formula used is given below. A two-speed Morton mixer, connected to a watt-hour meter to control the work input into the dough during mechanical development, was used to mix flour and ingredients. The mixer was run at "low" speed for 30 seconds, stopped and sides of the bowl of the mixer were scraped down. It was restarted and run at "high" speed until the pre-set work input was reached and the mixer stopped automatically. The dough was removed from the bowl and its temperature was recorded. It was scaled into five 160-g dough pieces (equivalent to dough made from 100 g flour). Each dough piece was rounded by hand seven times, put on a plastic sheet and given a 10-minute rest period in a proofing cabinet (30^{o}C; 100% R.H.). After resting, the dough was sheeted, moulded, panned and proofed (30^{o}C; 100% R.H.) for 55 minutes.

CB Process Formula

Baking Absorption	2% higher than farinograph abs.	
Flour (14% m.b.)		1000 g
Yeast, compressed	4%	40 g
Sugar	2.5%	250 ml
Salt	0.1%	
Malt syrup (250^{o}L)	0.3%	10 ml
Ammonium phosphate, monobasic	0.1%	10 ml
Potassium bromate	15 ppm	
Fat (Crisco)		10 g
Ascorbic acid	75 ppm	10 ml
Water, distilled		variable

With both baking procedures used in this study, the bread was baked at 221^{o}C for 25 minutes. The loaf volume data reported are average volumes of five loaves (for the CB) and two loaves (for the Remix) measured by rapeseed displacement after a cooling period of about 30 minutes. The best loaf from each set of five loaves (CB) and from each pair (Remix) was chosen for photographing.

V. RESULTS AND DISCUSSION

A. Proximate Analyses and Other Measurements Related to Breadmaking Properties of Base Materials

Proximate analyses of the samples used in this study are presented in Table 2. Amino acid compositions of MF and MPI are presented in Table 3. Literature values of the amino acid composition of wheat flour are included in this table for comparison. Fatty acid composition of MO is presented in Table 4. Figure 3 shows scanning electron photomicrographs of MS and MSI at 600x, 1200x, and 2400x magnifications.

1. Moisture Content

There is a difference in moisture contents of the two starting materials, wheat flour and breakfast meal; BFM had a lower moisture content than WF. Moisture content of MF (11.5%) was higher than the moisture content of BFM (10.3%). There was a small difference between the moisture content of MSI and that of MF. The moisture content of MPI was about four percentage units lower than that of MF.

2. Protein Content

Protein content (13.0%) of WF is a typical value for a medium-quality wheat flour milled commercially from a Canadian hard red spring wheat sample. Protein contents of BFM (7.0%) and MF (6.2%)

Table 2. Proximate Analysis and Other Data for Base Flours

PARAMETER	WF	BFM	MF	MSI	MPI
Moisture, %	13.3	10.3	11.5	11.0	7.6
Protein (N x 5.7), %[1]	13.0	7.0	6.2	1.96	38.3
Fat (Ether Extract), %[1]	1.84	3.80	3.50	1.11	0.69
Ash, %[1]	0.43	0.75	0.35	0.78	1.50
Color, Kent-Jones and Amos Units	1.4	5.8	2.9	nd[2]	nd
Starch, %[1]	66.05	nd	74.59	81.62	nd
Starch Damage, Farrand Units	22	3	42	0	nd
Gassing Power, mm. Hg.	385	375	600	140	6.35
Zeleny Sedimentation Value, ml.	70.0	12.0	10.0	5.5	59.0

1 14.0% moisture basis

2 nd - not determined

are typical values for breakfast meal and maize flour milled from Zambian white maize; both of the values reported in this thesis are similar to the values reported in a study by Tipples (1974). MSI had a relatively low protein content (1.96%) for a laboratory prepared sample of maize starch. The protein content (38.3%) of MPI, although relatively high, indicates that this fraction contained a major proportion of non-protein material which is probably starch.

3. Amino Acid Composition

Amino acid composition of maize flour and maize protein isolate used in this study are given in Table 3. Literature values (Bushuk and Wrigley, 1971) of the amino acid composition of wheat flour, of 12.8% protein content (14% moisture) milled on an experimental mill from a sample of Marquis wheat, are included in Table 3.

MPI contained relatively low proportions of lysine and methionine compared to the compositions of these amino acids in MF. Both MF and MPI contained relatively high proportions of glutamic acid and proline, typical of cereal proteins. Both had higher proportions of aspartic acid, alanine, and leucine and lower proportions of glutamic acid than wheat flour. The amino acid composition of maize flour shown in Table 3 compares well with the composition of Colombian maize reported by Maner (1972).

Table 3. Amino Acid Composition of Maize Flour, Maize Protein Isolate and Wheat Flour (g. amino acid/100 g. Nitrogen)

AMINO ACID	MF	MPI	WHEAT FLOUR[1]
Lysine	2.58	1.20	2.32
Histidine	5.50	4.98	3.28
Ammonia	13.33	14.15	19.70
Arginine	6.78	5.62	6.92
Aspartic Acid	4.14	3.23	2.72
Threonine	2.57	2.35	1.99
Serine	3.41	3.82	4.02
Glutamic Acid	12.83	12.66	21.40
Proline	8.35	8.50	9.44
Glycine	4.02	3.25	4.20
Alanine	7.91	7.50	2.82
Valine	3.82	3.42	2.96
Methionine	0.91	0.88	0.90
Isoleucine	2.48	2.29	2.26
Leucine	10.22	10.45	4.65
Tyrosine	1.35	2.12	1.46
Phenylanine	2.79	2.69	2.62
N recovery, %	92.99	89.11	94.20

[1] Bushuk and Wrigley (1971)

4. Fat Content

The two original materials, WF and BFM, contained widely different amounts of fat (ether extract). The 1.84% ether extract for WF compares well with the literature value (1.88%) for a commercial clear flour milled from hard red spring wheat (Mecham, 1971). The fat content of MF (3.50%) was slightly lower than that of BFM (3.80%) indicating that grinding and sieving of BFM into MF probably removed some germ particles that contain substantially more fat than the endosperm particles. Both MSI and MPI contained relatively low amounts of fat compared to the fat content of MF.

5. Fatty Acid Composition

The fatty acid composition of MO (Table 4) shows that maize lipid (oil) contains a high proportion of unsaturated fatty acids (86.4%), and a relatively low proportion of saturated fatty acids (13.6%). More than half of the fatty acid composition of maize oil comprises linoleic acid (59.6%). The other major acids are oleic acid (25.1%) and palmitic acid (11.7%). Only trace quantities of fatty acids with chain lengths longer than 18 carbon atoms were detected. The fatty acid composition data of MO compare quite well with the published data (Reiners and Gooding, 1970) which are also included in Table 4 for comparison.

6. Ash Content

Wheat flour had an ash content of 0.43% and a color grade of 1.4 units, as expected for this type of flour. BFM had a higher ash content (0.75%) and color grade (5.8 units) than MF (0.35% ash and

Table 4. Fatty Acid Composition of Maize Oil

	%	
FATTY ACID	THIS STUDY	REINERS and GOODING (1970)
Palmitic (C16:0)	11.7	11.1
Stearic (C18:0)	1.9	2.0
Oleic (C18:1)	26.1	24.1
Linoleic (C18:2)	59.6	61.9
Linolenic (C18:3)	1.6	0.7
Docosenoic (C22:1)	Trace	----
Others (C > 22:1)	0.1	----

2.9 units color grade) indicating that some purification of the maize endosperm occurred in the conversion of the meal into flour. The relatively high ash content of MPI (1.50%) indicates that most of the mineral components of maize flour are associated with its protein component.

7. Starch Content

The starch content (66.05%) of WF falls within the starch content range of 65 to 71% for a commercially milled sample of hard red spring wheat (D'Appolonia _et al_., 1971). MF had a lower starch content (74.59%) than MSI (81.62%); this shows a 91% recovery of starch from maize flour. MPI was not analyzed for starch content.

8. Starch Damage

The two starting flours, WF and BFM, had quite different amounts of damaged starch (22 Farrand Units for WF compared with 3 Farrand Units for BFM). The high level of damaged starch (42 Farrand Units) in MF indicates that the grinding of breakfast meal into maize flour caused considerable physical damage to maize starch granules. MSI had no damaged starch; presumably, during the preparation of MSI, all of the damaged starch was removed in the washwater. MPI was not analyzed for damaged starch.

9. Gassing Power

The gassing power of WF (385 mm. Hg.) was essentially the same as that of BFM (375 mm. Hg.). The two flours contain comparable amounts of fermentable sugars. The high gassing power of

MF (600 mm. Hg.) compared with that of BFM is consistent with the damaged starch data. The high gassing power of MF compared with that of WF indicates that maize flour has more fermentable sugars than wheat flour. The gassing power of MSI (140 mm. Hg.) was lower than that of MF; again, this is consistent with the damaged starch data. The extremely low gassing power of MPI (6.35 mm. Hg.) indicates that the maize protein isolate is essentially free of fermentable sugars.

10. Zeleny Sedimentation Value

As expected, WF had the highest sedimentation value (70 ml). The Zeleny sedimentation value of BFM was 12.0 ml, slightly higher than the value for MF (10.0 ml). MSI had a comparatively lower sedimentation value (5.5 ml) than MF. The sedimentation value (59.0 ml) of MPI was relatively high indicating that maize proteins have a relatively high swelling capacity as measured by the rate of sedimentation in the Zeleny Sedimentation Test.

11. Scanning Electron Microscopy of Starch Samples

Figures 3a, 3b, and 3c compare scanning electron photomicrographs of a commercial maize starch (MS) and maize starch isolate at three magnifications, 600x, 1200x, and 2400x, respectively. Both samples showed the typical granule shape of maize starches. The granules varied both in shape and size. The small granules, in both samples, were essentially spherical with relatively smooth surfaces. The large granules appeared to have many sides. Similar photomicrographs were obtained for maize starch granules by Hoseney et al. (1971). The present study showed that the granule surface

Figure 3a. Scanning electron photomicrograph of commercial maize starch and maize starch isolate (600x).

1 - Commercial Maize Starch (MS)

2 - Maize Starch Isolate (MSI)

1

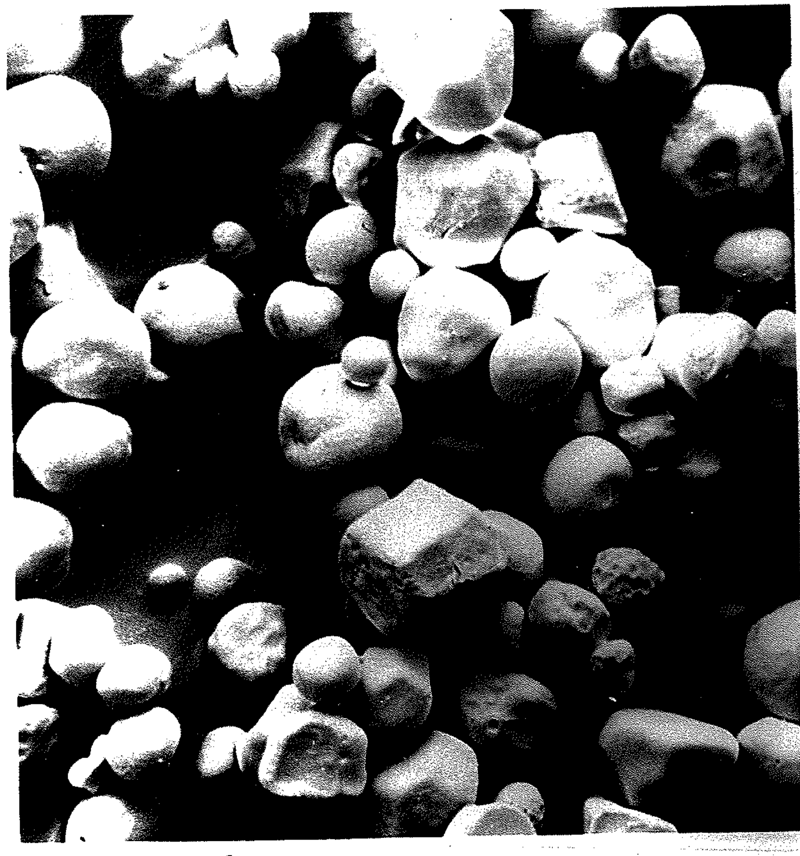
2

Figure 3b. Scanning electron photomicrographs of commercial maize starch and maize starch isolate (1200x).

1 - Commercial Maize Starch (MS)

2 - Maize Starch Isolate (MSI)

1



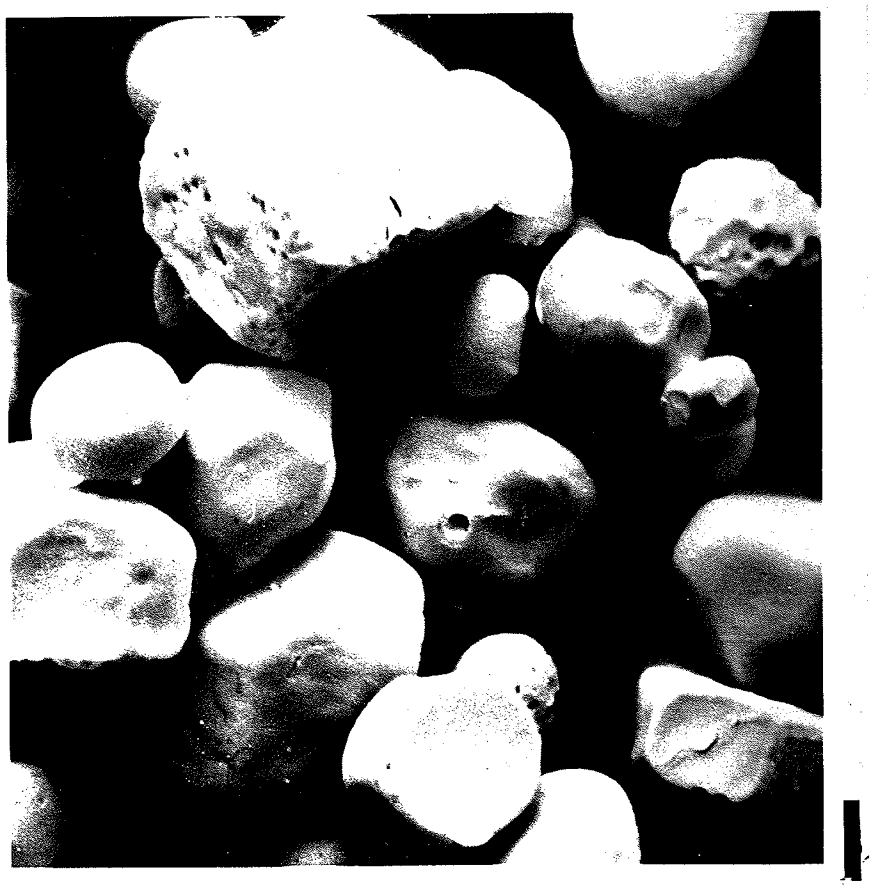
2

Figure 3c. Scanning electron photomicrographs of commercial maize starch and maize starch isolate (2400x).

1 - Commercial Maize Starch (MS)

2 - Maize Starch Isolate (MSI)

2



of the isolated maize starch sample (MSI) was different from the granule surface of the commercial starch sample. The surface of the commercial starch was smooth, while the surface of the isolated starch appeared to have adhering material. This suggests that some of the proteinaceous impurities in MSI is probably protein adhering to the granules. A few of the small granules of the commercial starch showed surface holes suggesting that the sample had suffered some damage due to native amylases or chemicals during the isolation and purification. The granules of the MSI sample showed no signs of physical damage; this is consistent with the damaged starch data.

B. Proximate Analyses and Other Measurements Related to Breadmaking Properties of Wheat-Maize Composite Flours

1. Moisture Content

Moisture contents of the two base flours and flour composites are given in Table 5. There is no relationship between composition and moisture content. Some moisture gain must have occurred during the blending of the composite flours containing 5 and 10% MF.

2. Protein Content

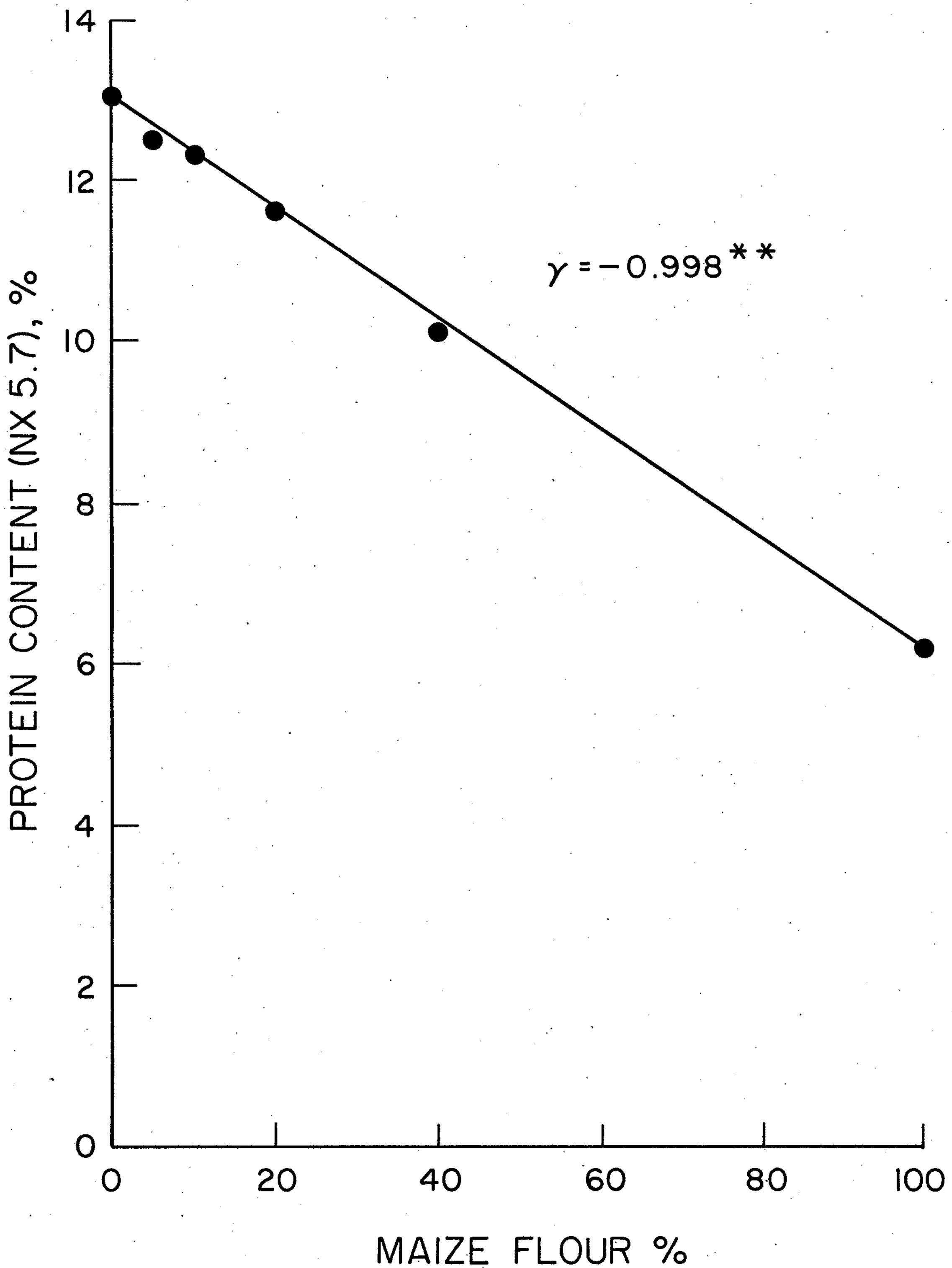
Protein content decreased with increasing proportion of MF in the composite (Table 5). The correlation between flour composition and protein content was negative and significant at the 1% level ($r = -0.998$) as shown in Fig. 4. Accordingly, the protein content of the composite flour can be calculated from the protein contents of the composites.

Table 5. Proximate Analysis and Other Data for Wheat-Maize Composite Flours

	MAIZE FLOUR, %					
PARAMETER	0	5	10	20	40	100
Moisture	13.3	13.5	13.7	12.7	12.9	11.5
Protein (N x 5.7), %[1]	13.0	12.5	12.3	11.6	10.1	6.2
Fat (Ether Extract), %[1]	1.84	1.46	2.05	2.12	2.44	3.50
Ash, %[1]	0.43	0.43	0.42	0.41	0.38	0.35
Starch Damage, Farrand Units	22	23	24	26	30	42
Gassing Power, mm. Hg.	385	445	485	545	640	600
Zeleny Sedimentation Value, ml.	70	68	58	50	38	10

[1] 14.0% moisture basis

Figure 4. Relationship between protein content and proportion of maize flour.



14
12
10
8
6
4
2
0
PROTEIN CONTENT (NX 5.7), %
γ = −0.998**
0
20
40
60
80
100
MAIZE FLOUR %

3. Fat Content

Fat contents of the base and composite flours are given in Table 5. The composite flour containing 5% MF had the lowest fat content (1.46%). The apparent lack of additivity of fat content of the composite flours is probably due to the low precision of the method used to analyze for this component.

4. Ash Content

Ash contents of the base and composite flours (up to 20% MF) were essentially the same; the ash content (0.38%) of the composite flour containing 40% MF was slightly lower than the value determined for this composite by calculation from the values of the two base flours.

5. Starch Damage

The level of damaged starch increased with the proportion of MF added to WF (Table 5). The damaged starch levels for the composites agreed with the values that can be calculated from the values for the two base flours.

6. Gassing Power

The gassing power of the composites increased essentially directly with the proportion of MF added to WF (Table 5). These results are consistent with the damaged starch data.

7. Zeleny Sedimentation Value

The sedimentation value decreased as the proportion of MF added to WF increased (Table 5). The relationship between proportion of MF in the blend and sedimentation value, however, was nonlinear indicating that there is an interaction between the two base flours in so far as their effect on the sedimentation value is concerned. The nature of this interaction was not investigated.

8. Alveograph

Alveograph data for the composite flours are given in Table 6. Alveograms obtained for the composites are shown in Fig. 5.

Stability of dough, as indicated by the P value (height of alveogram), increased as the proportion of MF in the composite increased. On the other hand, dough extensibility (L value) and dough strength (S and W values) decreased as the proportion of MF in the composite increased. These results indicate that addition of maize flour to a base wheat flour, produces a gradual change in the rheological properties of the dough from the composite flour as measured on the alveograph. Accordingly, for optimum processing, appropriate adjustments would have to be made for each composite. The fact that the change in alveograph properties is proportional to the amount of MF in the composite, suggests that it should be possible to estimate the magnitude of adjustments in processing (absorption, mixing time, fermentation time and proofing time) from the composition of the composite flour.

9. Amylograph

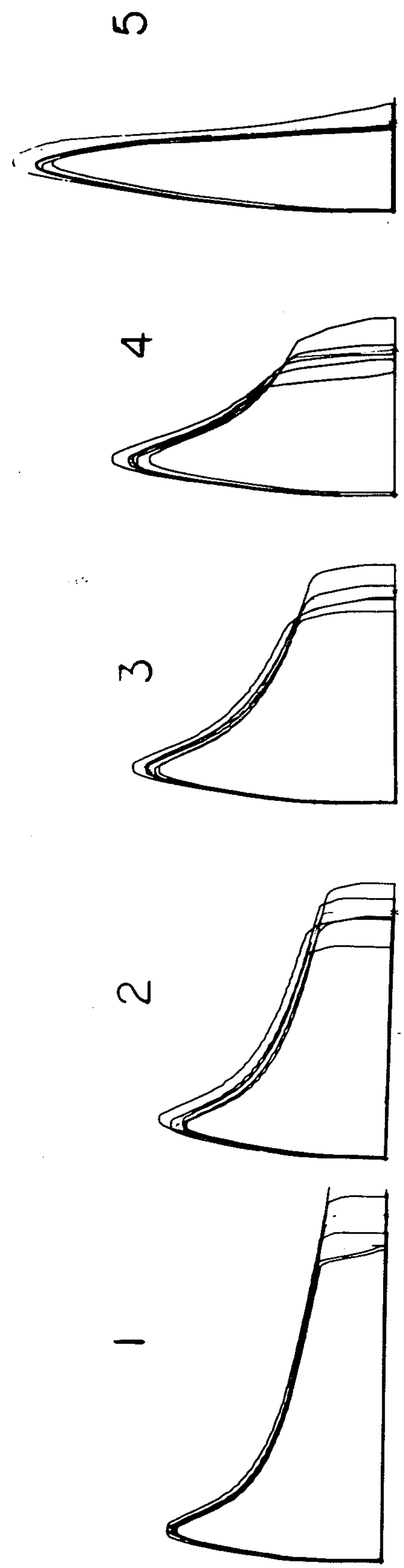
Amylograph data of the composite flours are presented in Table 6. Figure 6 shows the amylograph curves (amylograms) for the control (wheat) and the composite flours.

Table 6. Dough Mixing and Rheological Data of Wheat-Maize Composite Flours

PARAMETER	MAIZE FLOUR, % 0	5	10	20	40
ALVEOGRAM					
Height (P), mm.	94.6	94.6	111.1	117.7	161.7
Length (L), mm.	143	102	88	60	37
Area (S), cm^2	66.5	53.2	51.6	42.5	38.1
Work Value (W), $x10^3$ ergs	348	284	273	233	206
AMYLOGRAM					
Peak Viscosity, B.U.	420	430	480	540	660
Time to Peak, min.	42.0	42.5	42.0	41.5	41.5
EXTENSIGRAM					
Resistance to Extension, cm.	6.45	6.15	5.90	5.80	9.60
Extensibility, cm.	23.0	20.8	20.0	16.7	11.3
Ratio Figure	0.28	0.30	0.30	0.35	0.85
FARINOGRAM					
Absorption, % (14% m.b.)	61.4	61.2	60.0	60.4	56.2
Dough Development Time, min.	4.3	4.0	3.8	3.5	2.6
MIXOGRAM					
Maximum height, cm.	5.9	5.9	5.6	5.0	3.4

Figure 5. Alveograms for composite flours containing increasing proportions of maize flour:

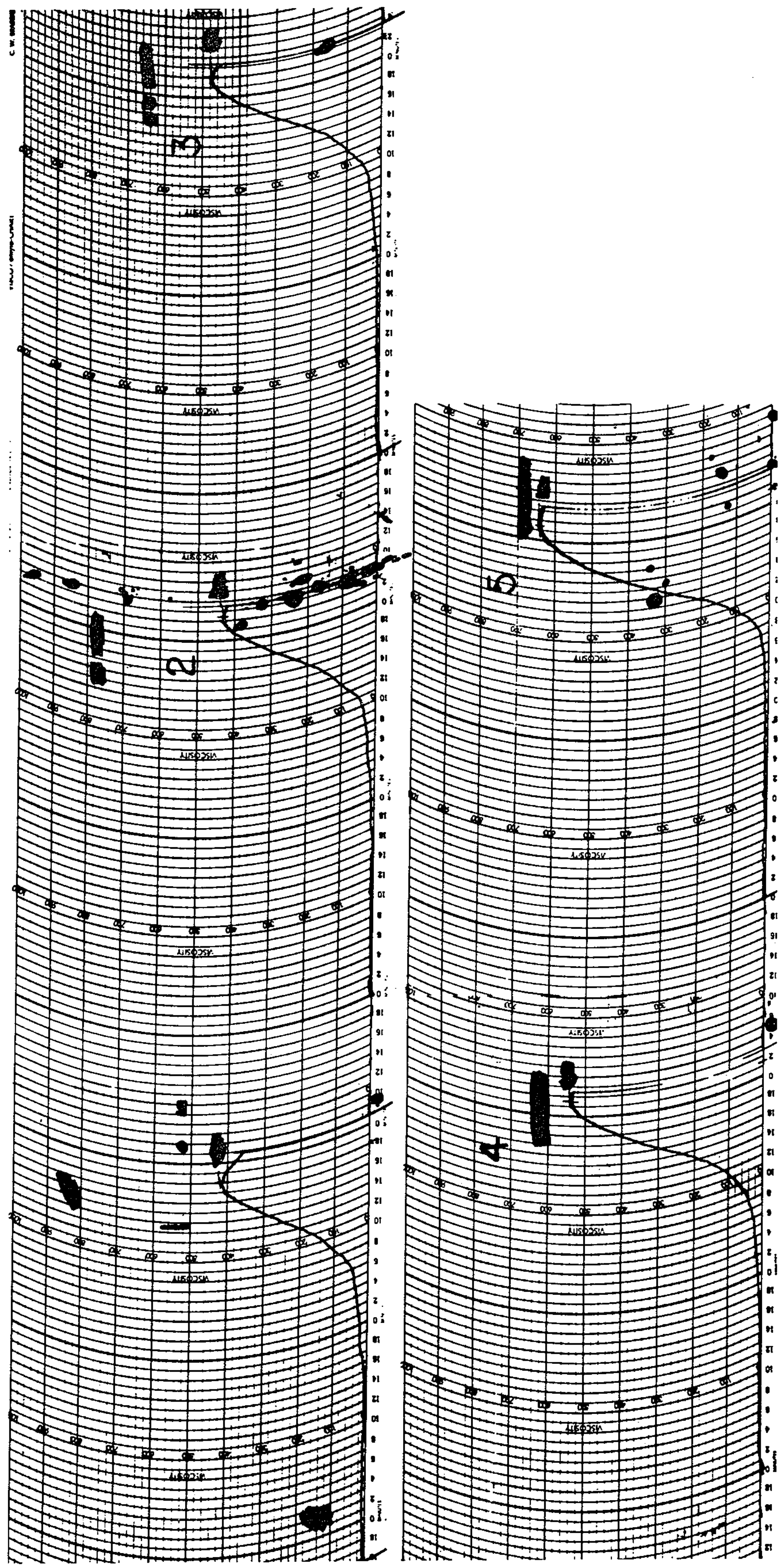
1 - 0%; 2 - 5%; 3 - 10%; 4 - 20%; 5 - 40%.



5
4
3
2
1

Figure 6. Amylograms for composite flours containing increasing proportions of maize flour:

1 - 0%; 2 - 5%; 3 - 10%; 4 - 20%; 5 - 40%.



Peak viscosity (maximum height of the amylogram in Brabender units) increased slightly as the proportion of MF in the composite increased. The increase in viscosity can be attributed to the increase in starch content with the increase in the amount of MF in the composite. This factor apparently is sufficient to overcome the opposite effects of increasing level of starch damage and increasing amylase activity (indicated by the gradual increase in gassing power).

The correlation coefficient ($r = +0.993$) between proportion of MF and peak viscosity was significant at the 1% level.

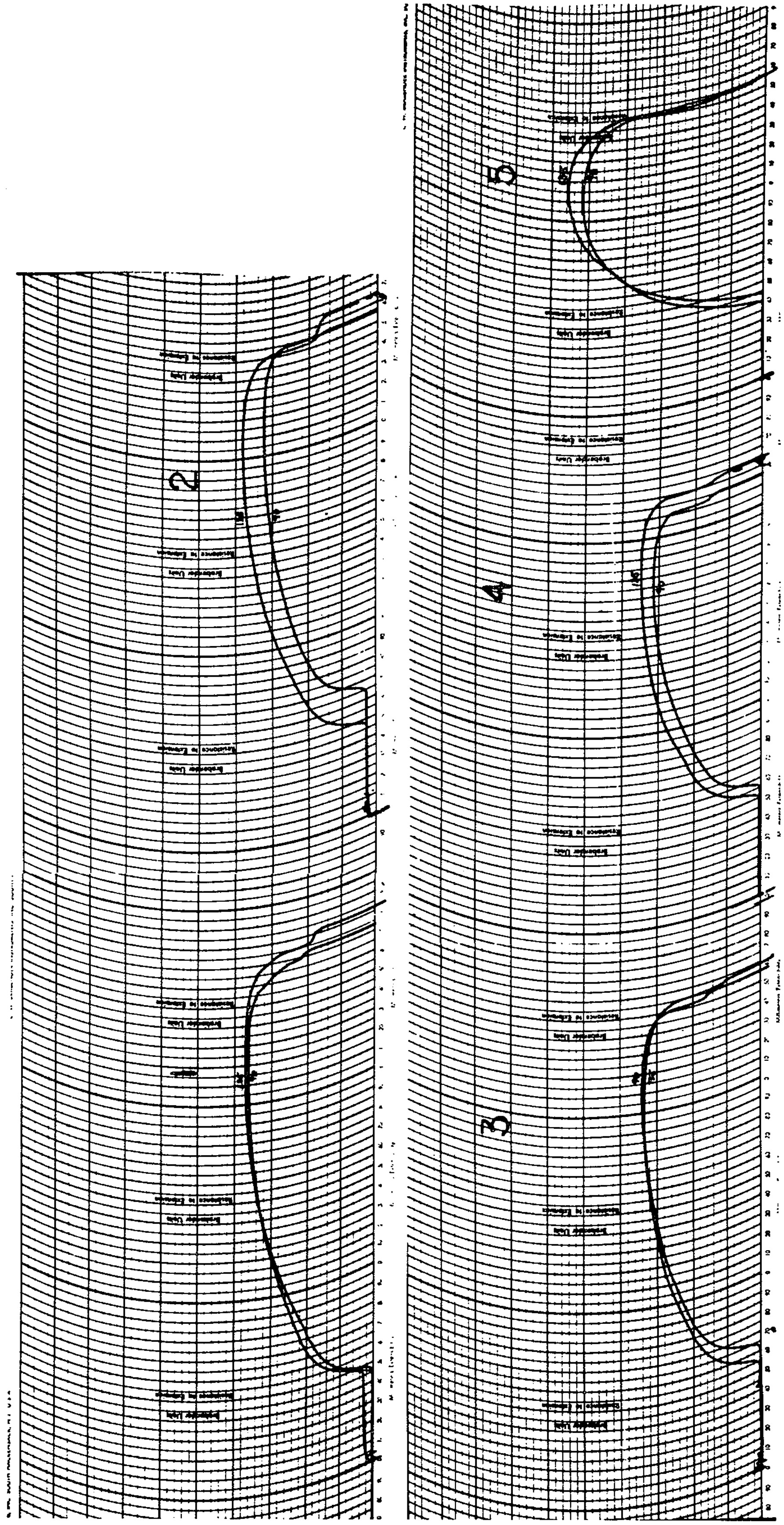
10. Extensigraph

Extensigraph results (Table 6 and Fig. 7) showed that the resistance to extension (dough elasticity) and extensibility decreased slightly as the proportion of MF in the composite increased to 20%. The extensigraph properties of doughs of these composites were analogous to those of the wheat flour control. In contrast, the dough from the 40% MF composite behaved distinctly differently in the extensigraph test. It showed a "short" dough characteristic typical of biscuit doughs. The same conclusion about dough properties can be drawn from the ratio figures given in Table 6. The extensigraph results obtained here indicate that only minor adjustments in the dough handling procedures (for bread) would be required for the composites containing 20% MF or less. Production of bread from composites containing 40% MF or more would probably require major modifications in the breadmaking procedures .

The ratio figure was directly proportional to the proportion of MF ($r = +0.859$; significant at the 5% level).

Figure 7. Extensigrams for composite flours containing increasing proportions of maize flour:

1 - 0%; 2 - 5%; 3 - 10%; 4 - 20%; 5 - 40%.



11. Farinograph

Farinograph results (Table 6 and Fig. 8) showed a gradual change in dough mixing properties with increasing proportion of MF in the composite.

Water absorption and dough development time decreased as the proportion of MF added to WF increased. Though not shown in graphical form, the relationship between dough development time and flour composition is linear within experimental error. Dough stability decreased as the proportion of MF in the composite increased. As was the case with the extensigraph results, the effect of MF on the farinograph properties was gradual to the 20% addition level. A relatively drastic change in farinogram shape occurred when the proportion of MF was increased from 20% to 40%.

The farinograph results obtained in this study are similar to those obtained by Tipples (1974) and Molina et al. (1976). They indicate that the gradual change in dough mixing properties with increasing proportion of MF should not present any major difficulties at the mixing stage of the breadmaking process.

Dough development time and proportion of MF were significantly correlated ($r = -0.993$; significant at the 1% level).

12. Mixograph

Maximum height at peak of the mixograph curve (Table 6; Fig. 9) decreased at the proportion of MF in the composite increased. The decrease in the mixogram height (at constant water absorption) is analogous to the decrease in farinograph water absorption discussed

Figure 8. Farinograms for composite flours containing increasing proportions of maize flour:

1 - 0%; 2 - 5%; 3 - 10%; 4 - 20%; 5 - 40%.

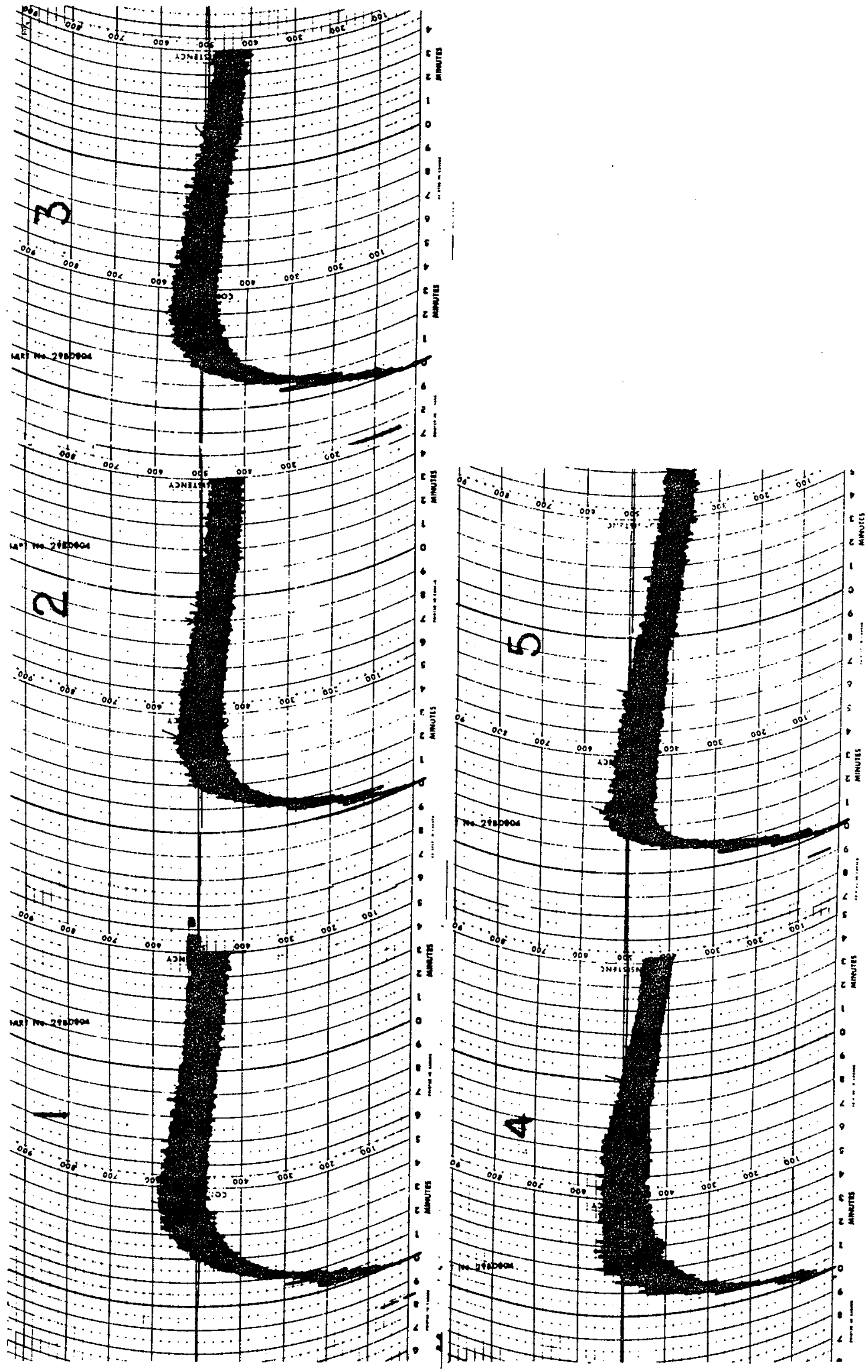
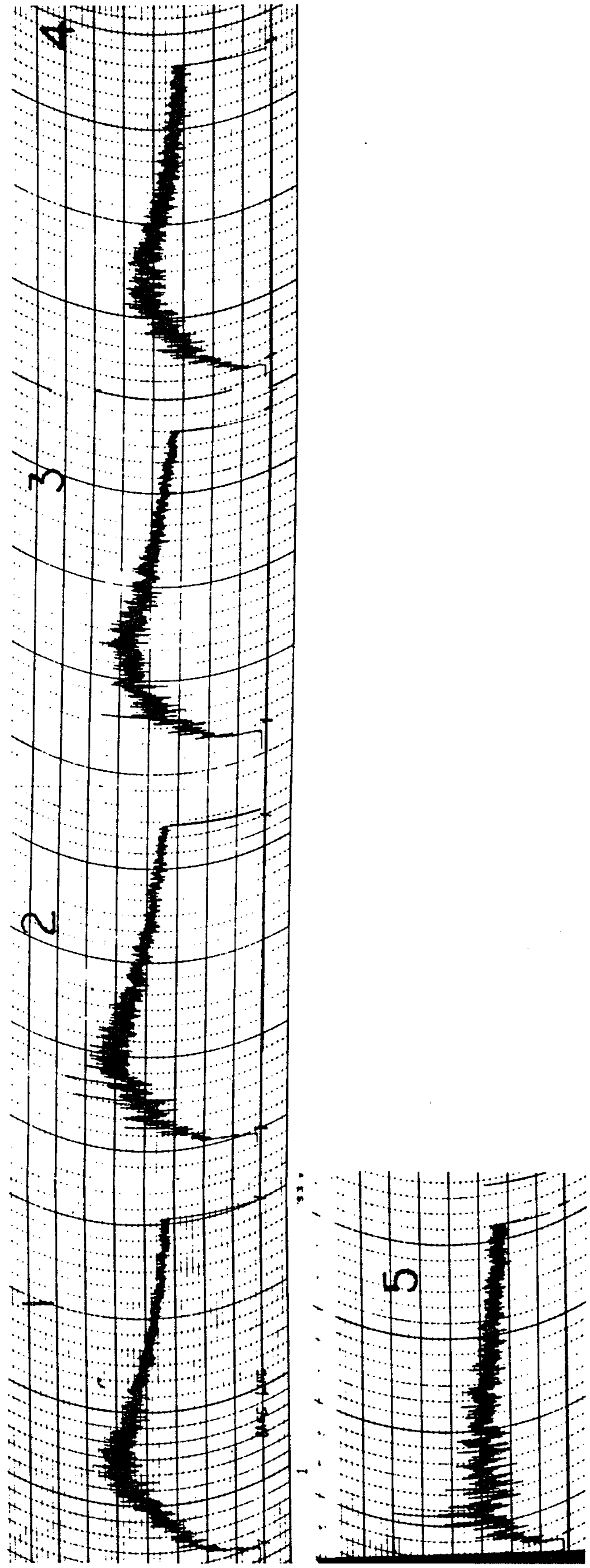


Figure 9. Mixograms for composite flours containing increasing proportions of maize flour:

1 - 0%; 2 - 5%; 3 - 10%; 4 - 20%; 5 - 40%.


4
3
2
1
5

above. The change in the mixogram with addition of MF was gradual to the 20% level of addition. A marked change in the mixing properties occurred when the proportion of MF was increased from 20% to 40%.

C. Baking Results for Wheat-Maize Composite Flours

Baking results for the wheat-maize composite flours obtained by two baking methods are given in Table 7. Internal and external characteristics of selected loaves are shown in Fig. 11.

1. GRL Remix Baking Method

The Grain Research Laboratory (G.R.L.) "Remix" baking test of Irvine and McMullan (1960) is a useful experimental baking procedure because it gives a good differentiation among flours of varying protein content and protein quality. For this reason, it was selected as the main test baking procedure for this study.

For each flour, the farinograph absorption was used as the baking absorption. As expected, the loaf volume decreased as the proportion of MF in the composite increased (Fig. 10), essentially linearly. Loaf and specific weights increased as the proportion of MF in the composite increased. A parallel deterioration was obtained in loaf appearance, crumb color, grain, and crust color as the proportion of MF increased (Fig. 11). The crumb color gradually changed from light to dark, and the crust color from yellow to dull amber. Considering all the bread characteristics, the results

Table 7. Baking Results of Wheat-Maize Composite Flours

PARAMETER	MAIZE FLOUR, % 0	5	10	20	40
BREAD - GRL REMIX METHOD					
Baking Absorption, % (14% m.b.)	61.4	61.2	60.0	60.4	56.2
Loaf Volume, cc/100 g. flour	825	760	693	575	323
Loaf weight, g.	123.01	124.6	125.01	127.61	131.45
Specific weight, g/cc	0.15	0.16	0.18	0.22	0.41
Loaf appearance	8.7	8.1	7.7	7.0	5.2
Crumb color[1]	lt	lt	lt	ld	d
Crumb grain[2]	8.2-o	7.0-o	6.8-o	6.6-o,c	5.1-o
Crust color[3]	y	y	dy	d	d
BREAD - CB PROCESS					
Baking Absorption, % (14% m.b.)	63.4	63.2	62.0	62.4	58.2
Loaf Volume, cc/100 g. flour	945	903	855	765	573
Loaf weight, g.	124.23	126.81	127.1	129.12	132.0
Specific weight, g/cc	0.13	0.14	0.15	0.17	0.23
Loaf appearance	8.5	8.4	7.4	7.6	5.8
Crumb color[1]	lt	lt	lt	ld	d
Crumb grain[2]	8.6-e	7.9-o	7.2-e	6.8-e,c	5.3-c
Crust color[3]	y	y	y	y	dy

1 lt - light
ld - light dark
d - dark

2 o - open
c - coarse
e - even

3 y - yellow
dy - dark yellow
d - dull

presented in this study compare well with the results for wheat-maize composite flours obtained by Bushuk and Hulse (1974), and Tipples (1974).

As anticipated from extensigraph, farinograph and mixograph measurements, dough behavior during mixing, sheeting, and moulding was satisfactory for composites containing up to 20% MF. Dough from the composite flour containing 40% MF was tight, solid, and dry during the make-up stages of the breadmaking process.

2. Chorleywood Bread (CB) Process

Mechanical development of dough is progressively replacing the long fermentation development used in conventional commercial breadmaking. The most successful of a number of processes using mechanical development has been the CB process of Axford et al. (1963). The main advantage of this process is that bread of a given quality can be produced from a lower quality of flour than required by the conventional process (Pringle et al., 1969; Ponte, 1971; Tipples, 1975). For this reason, it is particularly attractive for producing bread from composite flours.

The baking absorption shown in Table 7 is two percentage units higher than the farinograph absorption. Loaf volume decreased linearly as the proportion of MF added to WF increased (Fig. 10). The internal and external characteristics of the bread deteriorated as MF in the composite increased (Fig. 11). Loaf volume and specific weights increased with increasing proportion of MF. The data obtained in this study are generally comparable to the data obtained

Figure 10. Relationship between loaf volume and proportion of maize flour.

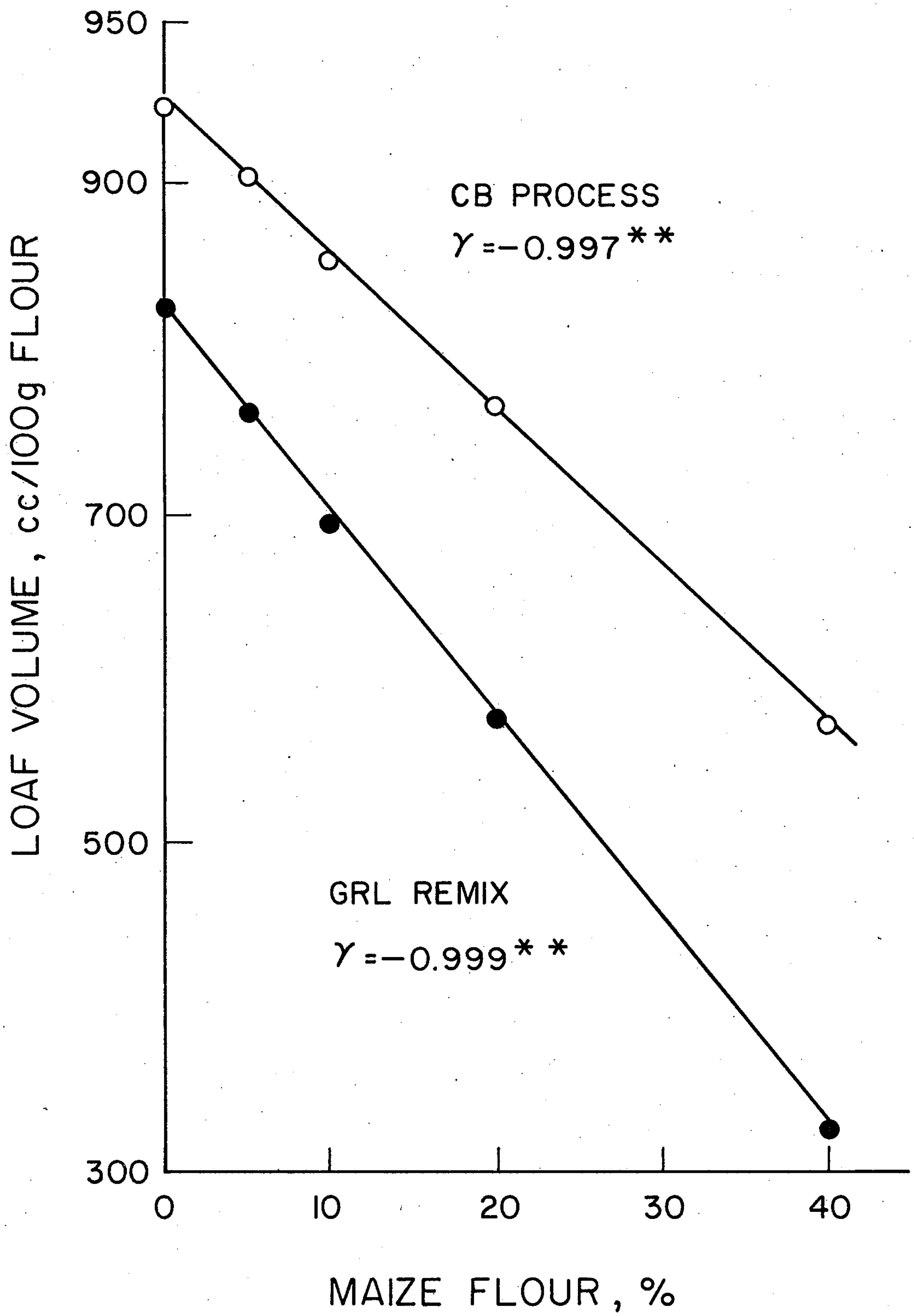
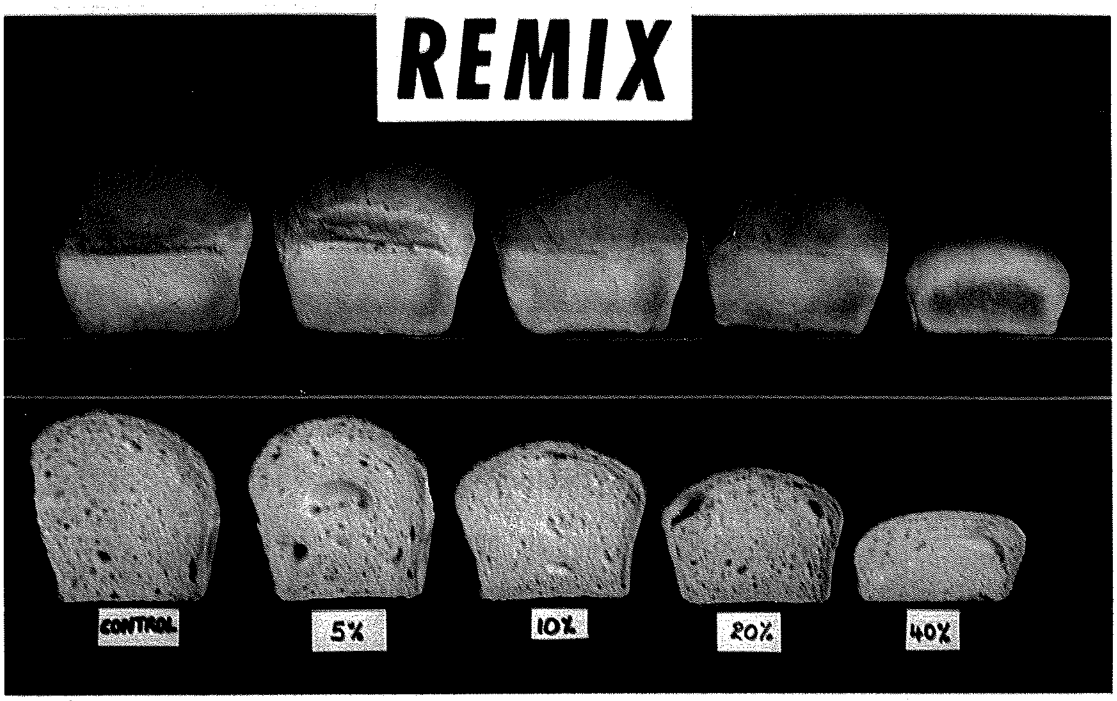
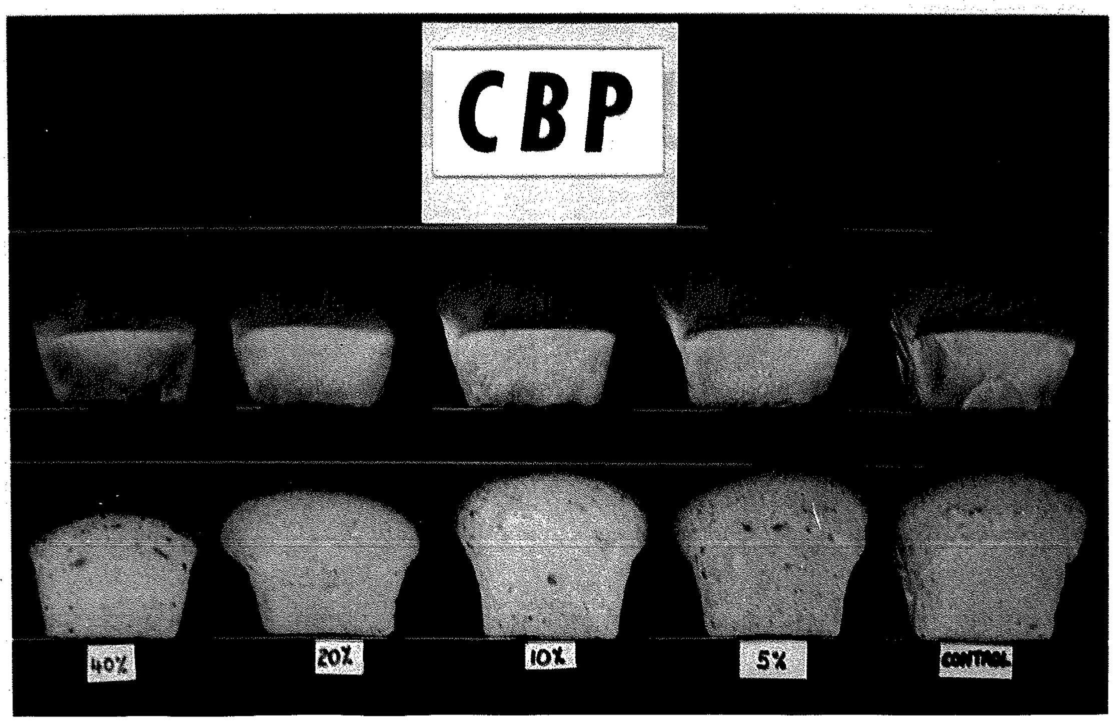

950
900
700
500
300
LOAF VOLUME, cc/100g FLOUR
CB PROCESS
γ = −0.997**
GRL REMIX
γ = −0.999**
0
10
20
30
40
MAIZE FLOUR, %

Figure 11. Bread from composite flours containing increasing proportions of maize flour


REMIX
CONTROL
5%
10%
20%
40%


CBP
40%
20%
10%
5%
CONTROL

by Bushuk and Hulse (1974) and Tipples (1974) and confirm the previously observed advantages of the CB process over the conventional breadmaking processes.

D. Proximate Analyses and Measurements Related to Breadmaking Properties of Wheat-Maize Starch Isolate Composite Flours

This section presents results of proximate analyses and rheological measurements for composite flours prepared by replacing 3.7%, 7.5%, 14.9%, and 29.8% of WF with maize starch isolate (MSI). These replacement levels are equivalent to 5%, 10%, 20%, and 40% used to replace WF with MF. The data are presented and discussed in the same order as was done in Section B for wheat-maize flour composites.

1. Moisture Content

Maize starch isolate gained moisture during blending with wheat flour since all the composite flours had a moisture content higher than that of MSI (11%). There was essentially no difference in moisture content between the composites (Table 8).

2. Protein Content

Protein content decreased linearly as the proportion of MIS increased (Table 8; Fig. 12). The correlation between protein content and proportion of MSI ($r = -0.990$) was significant at the 1% level indicating again that the protein content of the composite can be calculated from the protein contents of the constituent flours with a high degree of accuracy.

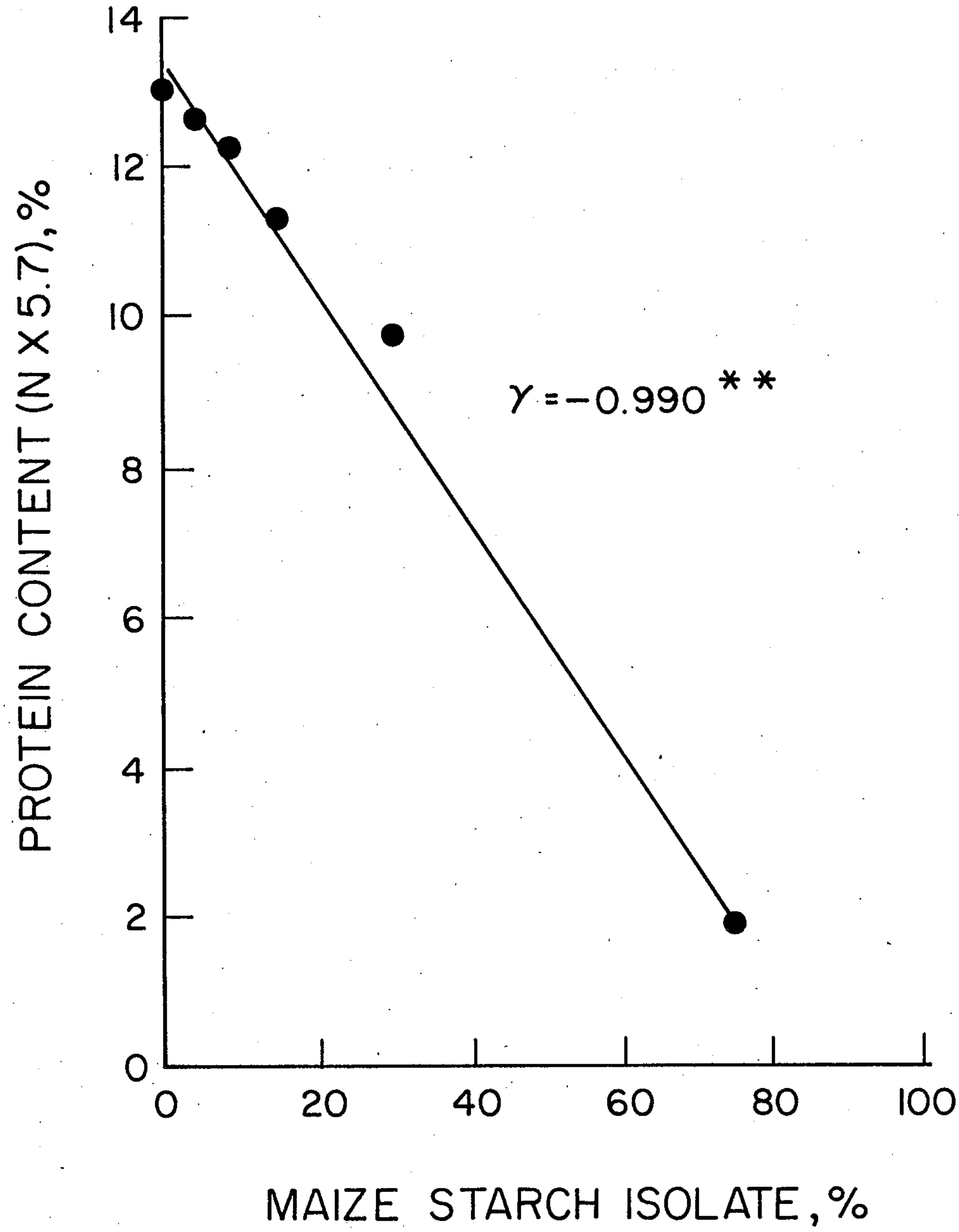
Table 8. Proximate Analysis and Other Data for Wheat-Maize Starch Isolate Composite Flours

	MAIZE STARCH ISOLATE, %[1]					
PARAMETER	0(0)	5(3.7)	10(7.5)	20(14.9)	40(29.8)	100(74.6)
Moisture, %	13.3	13.4	13.4	13.2	13.1	11.0
Protein (N x 5.7), %[2]	13.0	12.6	12.2	11.2	9.7	1.96
Fat (Ether Extract), %[2]	1.83	1.82	1.78	1.76	1.61	1.11
Ash, %[2]	0.43	0.44	0.46	0.49	0.53	0.78
Starch Damage, Farrand Units	22	22	21	21	22	0
Gassing Power, mm. Hg.	385	375	365	355	310	140
Zeleny Sedimentation Value, ml.	70	67	62.5	56.4	40.9	5.5

1 Maize flour equivalent; proportion of MSI shown in parentheses

2 14% moisture basis

Figure 12. Relationship between protein content and proportion of maize starch isolate.



PROTEIN CONTENT (N X 5.7), %
14
12
10
8
6
4
2
0
γ = −0.990 **
0
20
40
60
80
100
MAIZE STARCH ISOLATE, %

3. Fat Content

Ether extract (fat content) decreased as the proportion of MSI added to WF increased (Table 8) from 7.5% to 29.8%; little change in fat content was obtained when 3.7% MSI was added. Considering the fat content of the base flours (WF and MSI), the results of fat content are additive, within experimental error.

4. Ash Content

The ash contents of the MSI composites determined by analysis were essentially the same as the values that can be calculated from the composition and ash contents of the base components (Table 8).

5. Damaged Starch

As expected from the zero damaged starch value of MSI, the level of damaged starch in the composite flours was essentially the same as that of the base wheat flour.

6. Gassing Power

Gassing power decreased linearly as the proportion of maize starch isolate in the composite increased (Table 8) indicating that the gassing power value of the composite flour can be estimated from the gassing power values of the base flours and the known flour composition.

7. Zeleny Sedimentation Value

Zeleny sedimentation value decreased as the proportion of MSI in the composites increased. The correlation coefficient

(r = -0.997) between sedimentation value and proportion of MSI was significant at the 1% level. Accordingly, there appears to be no interaction between the base flours in the Zeleny Sedimentation test.

Sedimentation values of composites containing MSI (Table 8) were essentially the same as the values of composite flours containing MF (Table 5), except at the 7.5% and 14.9% levels of wheat flour substitution. At these two levels, the values for MSI composites were slightly lower than the values for MF composites. The deviations are not considered to be significant.

8. Alveograph

Alveograph data obtained from the curves in Fig.13 are presented in Table 9. Dough stability (P value) decreased up to 7.5% MSI addition and increased thereafter. Dough extensibility (L value) and strength (S and W values) decreased as the proportion of MSI added to WF increased indicating that maize starch has a marked effect on the visco-elastic properties of wheat flour as measured by the alveograph. With the addition of MSI, the rheological properties gradually changed in the direction of lower extensibility and higher elasticity. If such doughs are used in breadmaking, adjustments would have to be made for each level of MSI to optimize the handling (machining) properties of the dough.

Statistical analysis of the limited alveograph data showed that the P values were positively correlated (r = 0.859*) while the L and S values were negatively correlated (r = -0.968** and r = -0.910*, respectively) with the proportion of MSI. W value was negatively correlated (r = -0.840; significant at the 5% level).

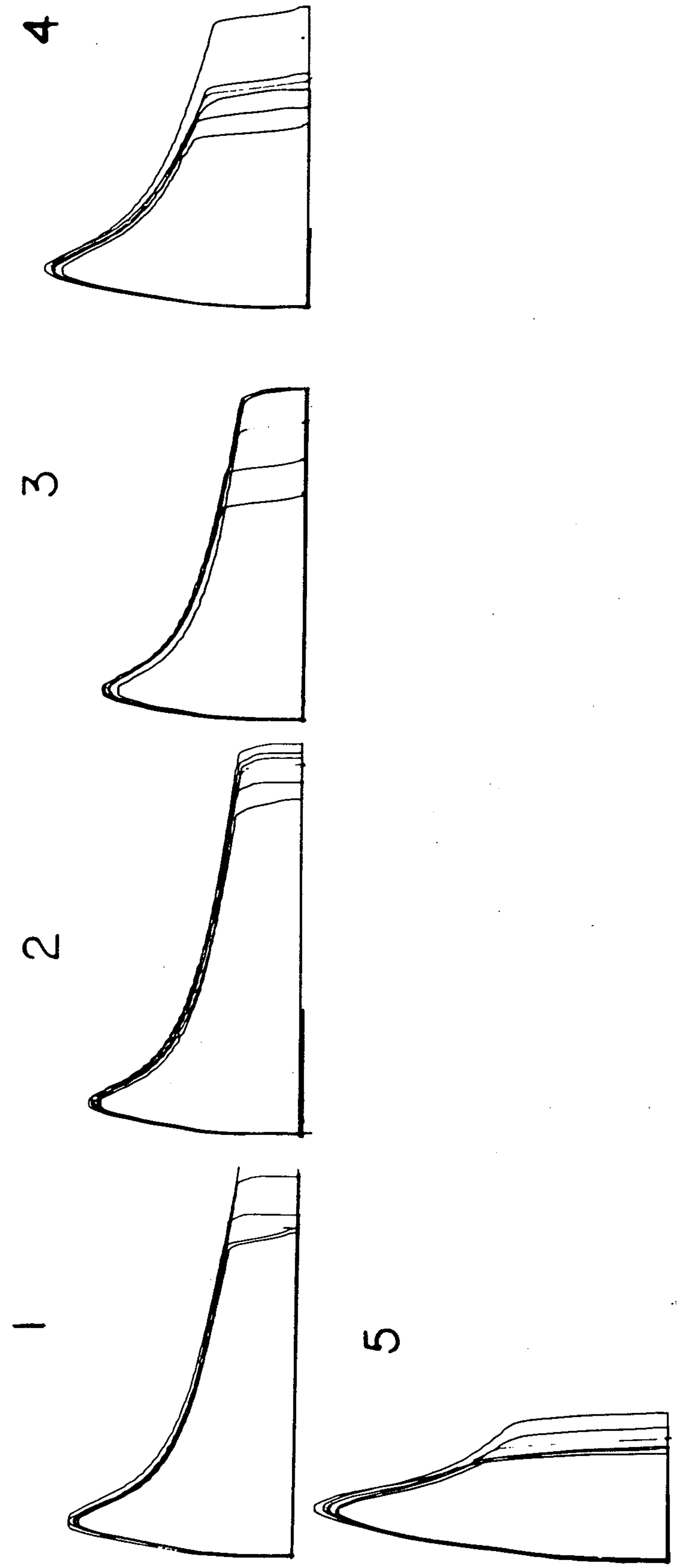
Table 9. Dough Mixing and Rheological Data of Wheat-Maize Starch Isolate Composite Flours

	MAIZE STARCH ISOLATE, %[1]				
PARAMETER	0(0)	5(3.7)	10(7.5)	20(14.9)	40(29.8)
ALVEOGRAM					
Height (P), mm.	94.6	89.1	83.6	110.0	147.4
Length (L), mm.	143	146	118	90	49
Area (S), cm^2	66.5	65.2	56.5	56.8	46.4
Work Value (W), $x10^3$ ergs	348	339	295	274	255
AMYLOGRAM					
Peak viscosity, B.U.	420	520	480	690	941
Time to Peak, min.	42.0	41.5	41.0	42.5	40.5
EXTENSIGRAM					
Resistance to extension, cm.	6.45	7.9	8.9	10.7	15.0
Extensibility, cm.	23.0	21.6	21.2	19.2	15.6
Ratio Figure	0.28	0.37	0.42	0.56	0.96
FARINOGRAM					
Absorption, % (14% m.b.)	61.4	59.8	59.2	58.2	56.8
Dough Development Time, min.	4.3	4.0	3.5	2.5	1.5
MIXOGRAM					
Maximum height, cm.	5.0	4.6	4.6	4.2	3.4

[1] Maize flour equivalent; proportion of MSI shown in parentheses

Figure 13. Alveograms for composite flours containing increasing proportions of maize starch isolate:

1 - 0%; 2 - 3.7%; 3 - 7.5%; 4 - 14.9%; 5 - 29.8%.


4
3
2
1
5

9. Amylograph

Results of amylograph measurements of wheat-maize starch isolate composite flours are presented in Fig.14 and Table 9.

As expected, the peak viscosity increased as the proportion of MSI in the composite increased. This can be attributed to the increase of starch content in the composite with increasing proportion of MSI. The effect of MSI was slightly greater than the effect of MF; this is consistent with its higher starch content. These results are in general agreement with the results obtained in a study by Seyam and Kidman (1975).

Statistical treatment showed that the amylogram peak viscosity was significatnly correlated (r = +0.966**) with proportion of MSI.

10. Extensigraph

Extensigraph data of the composites (Table 9 and Fig.15) showed that resistance to extension (dough elasticity) increased and extensibility decreased as the proportion of MSI in the composite increased. The increase in ratio figure indicates that MSI has an adverse effect on breadmaking properties of dough as measured by the extensigraph. Similar results were obtained by Seyam and Kidman (1975). At equivalent substitutions, MSI had a greater effect than MF on extensigraph measurements.

Of the three numerical parameters obtained from the extensigram, the ratio figure gave a significant correlation (r = +0.989**) with proportion of MSI.

Figure 14. Amylograms for composite flours containing increasing proportions of maize starch isolate:

1 - 0%; 2 - 3.7%; 3 - 7.5%; 4 - 14.9%; 5 - 29.8%.

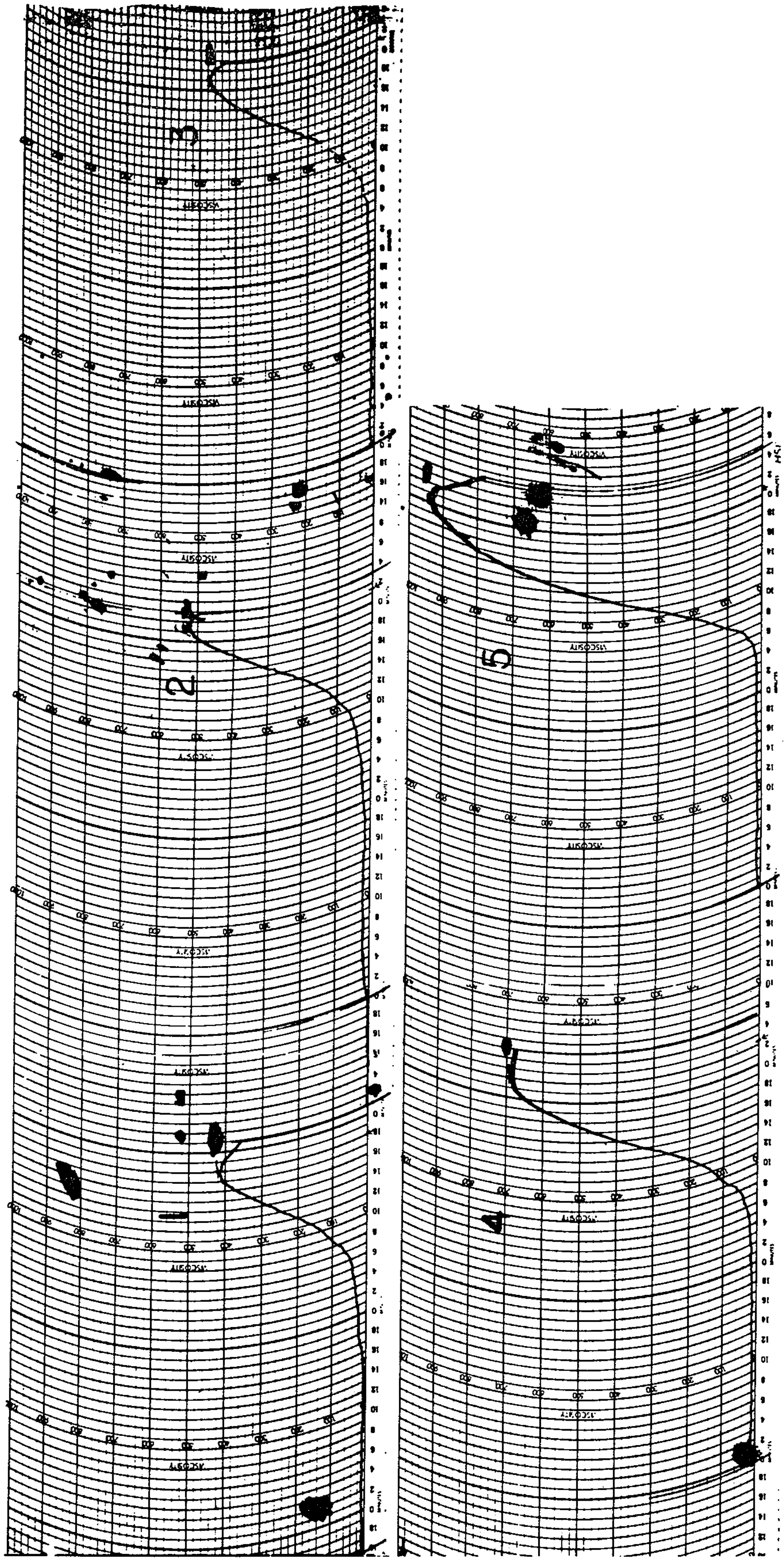
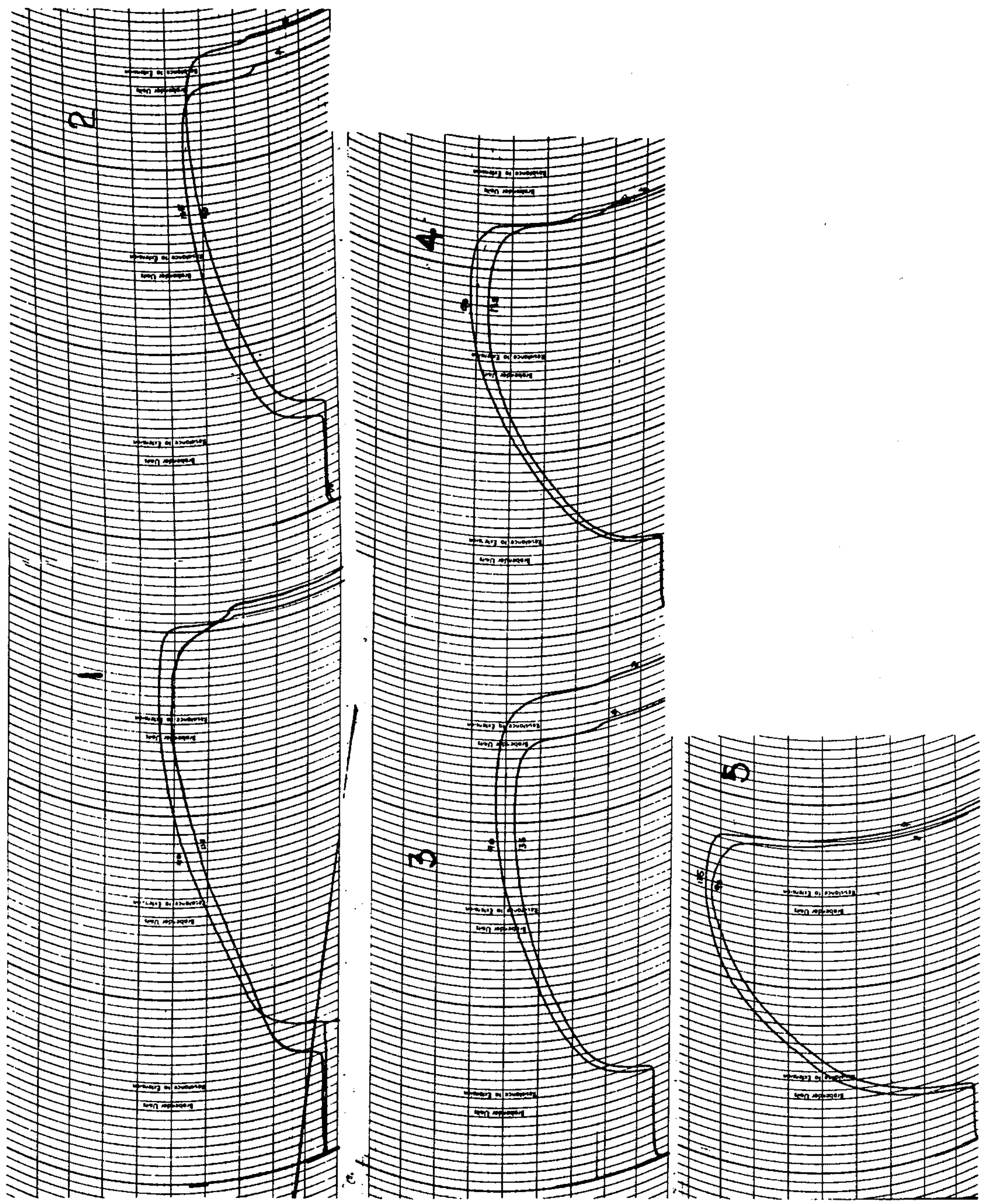


Figure 15. Extensigrams for composite flours containing increasing proportions of maize starch isolate:

1 - 0%; 2 - 3.7%; 3 - 7.5%; 4 - 14.9%; 5 - 29.8%.



11. Farinograph

Flour absorption and dough development time decreased as the proportion of MSI in the composite increased (Table 9). Dough development time and proportion of MSI were significantly correlated (r = -0.976**). Doughs made from composites containing 7.5% and 14.9% MSI had overly long stability (curves 3 and 4, Fig.16); the other doughs had short stability.

As found for other physical measurements on dough, MSI had a greater effect on farinograph properties than MF.

Similar results on the effect of maize starch on the farinograph properties of wheat flour doughs were published by Seyam and Kidman (1975).

12. Mixograph

Strength of dough, indicated by maximum height of the mixogram, decreased as the proportion of MSI increased (Table 9, Fig.17). It appears that the sensitivity of the mixograph is not sufficient to show any difference between the doughs containing 3.7% and 7.5% MSI. The mixing behavior of the dough as reflected by the mixograph results is consistent with the results of the other rheological tests (alveograph, extensigraph and farinograph).

Figure 16. Farinograms for composite flours containing increasing proportions of maize starch isolate:

1 - 0%; 2 - 3.7%; 3 - 7.5%; 4 - 14.9%; 5 - 29.8%.

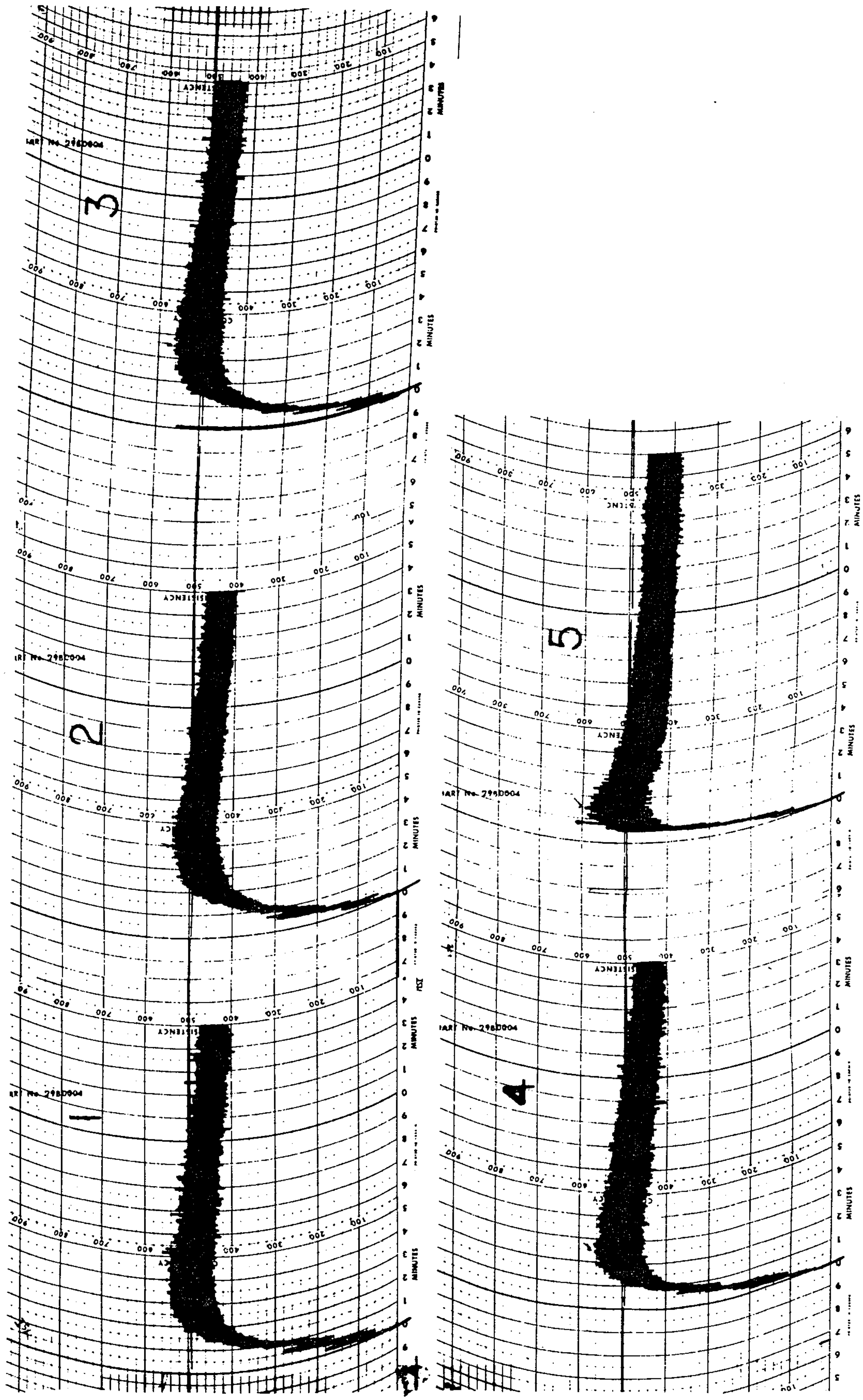
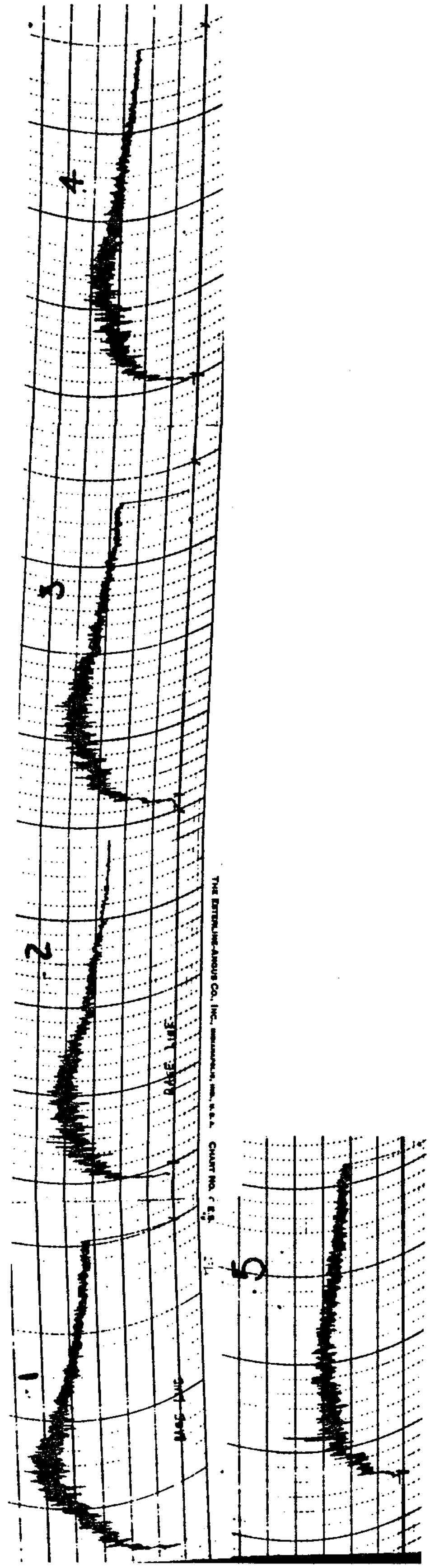

3
2
1
5
4

Figure 17. Mixograms for composite flours containing increasing proportions of maize starch isolate:

1 - 0%; 2 - 3.7%; 3 - 7.5%; 4 - 14.9%; 5 - 29.8%.



1
2
3
4
5
BASE LINE
BASE LINE

E. Baking Results for Wheat-Maize Starch Isolate Composite Flours

Baking results for MSI composite flours are summarized in Table 10. Fig.18 shows the relationship between loaf volume and flour composition, and Fig.19 shows internal and external characteristics of the bread baked from the composites.

1. GRL Remix Baking Method

The baking absorption used in the remix baking test was equal to the farinograph absorption. Loaf volume decreased while specific weight increased as the proportion of MSI in the composite increased. The relationship between flour composition and loaf volume is essentially linear (Fig.18). As expected, there was a gradual deterioration in loaf appearance, crumb color and grain, and crust color. Crumb grain ranged from even to coarse, and color of crumb or crust ranged from light or yellow to dark or very dull. The bread obtained in this study appears similar to the bread obtained in studies by Noznick et al. (1946), Kim and deRuiter (1968), Pringle et al. (1969), Hoseney et al. (1970), and Seyam and Kidman (1975).

Handling properties of dough made from MSI composites were similar to those of doughs containing MF but the loaf volumes were higher suggesting that some of volume depressing factors of MF were removed (or diluted) in the preparation of MSI.

2. Chorleywood Bread (CB) Process

As expected, loaf volume decreased and loaf density increased as the proportion of MSI substituting WF increased; loaf appearance,

Table 10. Baking Results of Wheat-Maize Starch Isolate Composite Flours

PARAMETERS	MAIZE STARCH ISOLATE, %[1]				
	0(0)	5(3.7)	10(7.5)	20(14.9)	40(29.8)
BREAD - GRL REMIX METHOD					
Baking absorption, %	61.4	59.8	59.2	58.2	56.8
Loaf volume, cc/ 100 g. flour	840	800	765	690	549
Loaf weight, g.	128.3	128.8	131.0	133.2	133.5
Specific weight, g/cc	0.15	0.16	0.17	0.19	0.24
Loaf appearance	8.8	8.2	7.9	7.1	5.5
Crumb color[2]	lt	lt	lt	ld	d
Crumb grain[3]	8.5-e	8.0-o	7.8-o	6.5-o,c	5.2-c
Crust color[4]	y	y	dy	d	vd
BREAD - CB PROCESS					
Baking absorption, %	63.4	61.8	61.2	60.2	58.8
Loaf volume, cc/ 100 g. flour	890	845	810	725	540
Loaf weight, g.	123.0	123.9	124.4	125.8	129.0
Specific weight, g/cc	0.14	0.15	0.15	0.17	0.24
Loaf appearance	8.7	8.0	7.8	7.3	5.8
Crumb color[2]	lt	lt	lt	d	d
Crumb grain[3]	8.3-o	7.9-o	7.2-o	6.7-o,c	5.1-o,vc
Crust color[4]	y	y	dy	d	vd

[1] Maize flour equivalent; proportion of MSI shown in parentheses

[2] lt - light
ld - light dark
d - dark

[3] o - open
e - even
c - coarse
vc - very coarse

[4] y - yellow
dy - dull yellow
d - dull
vd - very dull

Figure 18. Relationship between loaf volume and proportion (Maize flour equivalent) of maize starch isolate

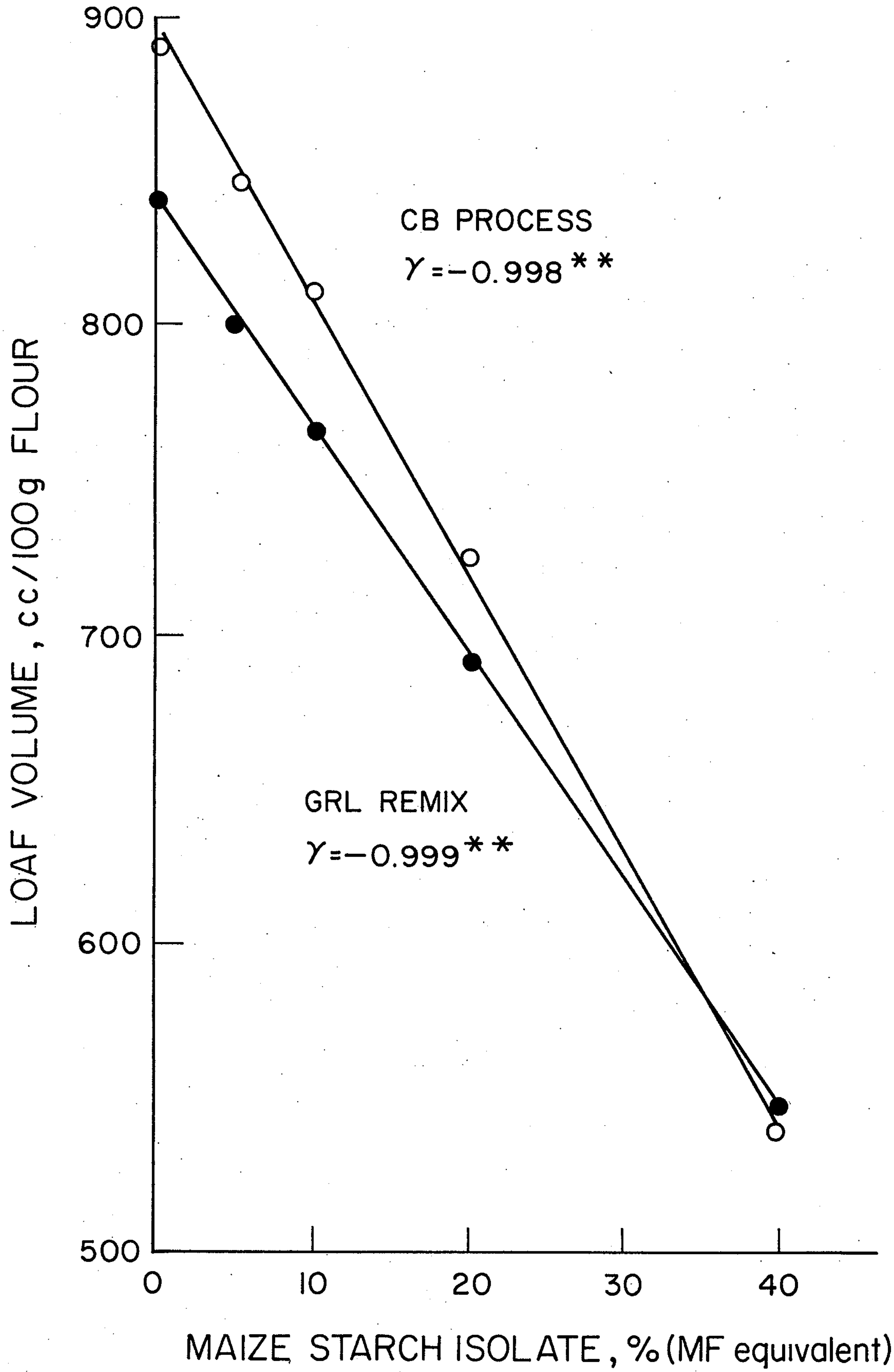
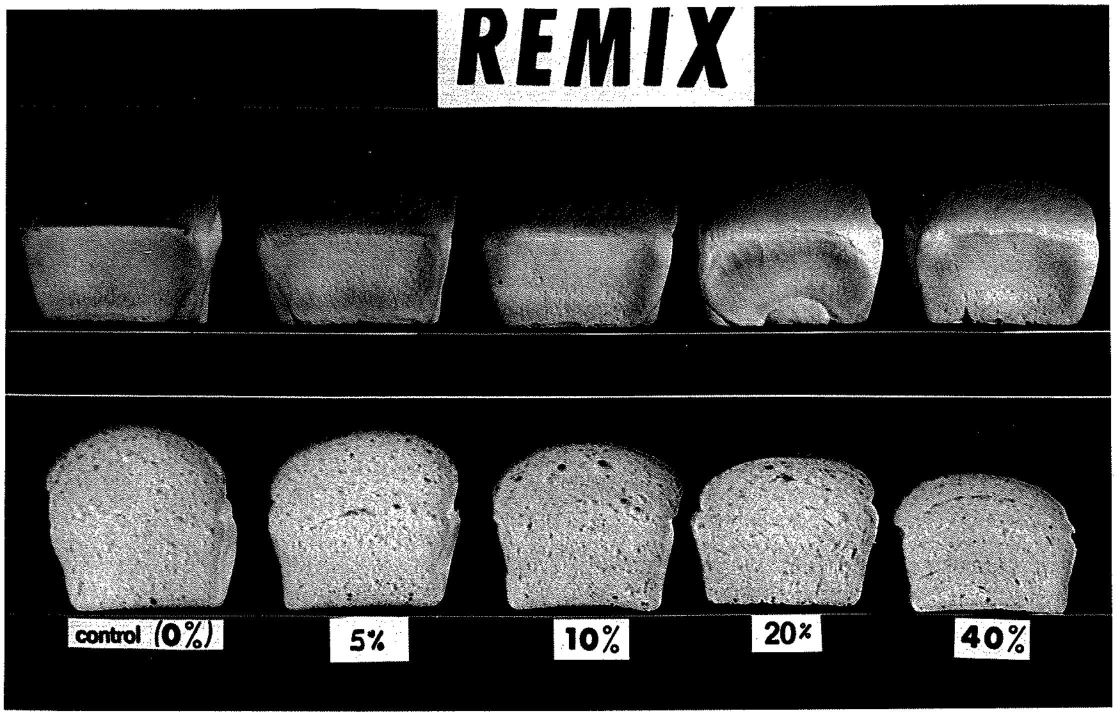
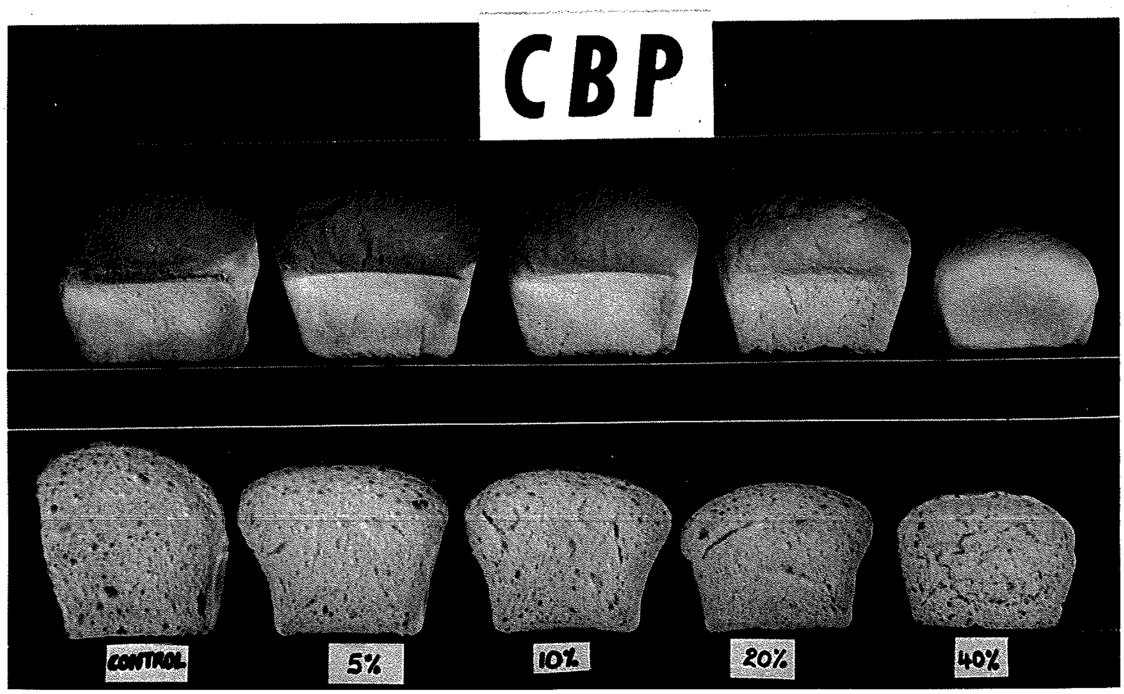

900
800
700
600
500
LOAF VOLUME, cc/100g FLOUR
CB PROCESS
γ=−0.998**
GRL REMIX
γ=−0.999**
0
10
20
30
40
MAIZE STARCH ISOLATE, % (MF equivalent)

Figure 19. Bread from composite flours containing increasing proportions of maize starch isolate. Percentages represent maize flour equivalents.


REMIX
control (0%)
5%
10%
20%
40%


CBP
CONTROL
5%
10%
20%
40%

crumb grain and crust color generally deteriorated (Table 10). Similar results were obtained by Pringle et al. (1969), and Seyam and Kidman (1975).

As was the case with the remix baking test, MSI composites gave higher loaf volumes than the MF composites. The CB process baking test produced bread of better overall quality (volume, grain, etc.) than the Remix test.

F. Proximate Analyses and Measurements Related to Breadmaking Properties of Wheat-Maize Protein Isolate Composite Flours

This section presents the results of proximate analyses and rheological measurements for composite flours prepared by replacing 0.3%, 0.6%, 1.2%, and 2.4% of the base wheat flour (WF) with maize protein isolate (MPI). The replacement levels of MPI are equivalent to 5%, 10%, 20%, and 40% of WF replaced with maize flour (MF). The presentation of the data follows the same order as was done in Sections B and D.

1. Moisture Content

The moisture contents of the MPI composites were closer to the moisture content of WF (13.0%) than to that of MPI (7.6%)(Table 11). It appears that the composites picked up some moisture during the blending under laboratory conditions.

Table 11. Proximate Analysis and Other Data for Wheat-Maize Protein Isolate Composite Flours

	MAIZE PROTEIN ISOLATE, %[1]					
PARAMETER	0(0)	5(0.3)	10(0.6)	20(1.2)	40(2.4)	100(6.2)
Moisture, %	13.0	12.5	12.6	12.6	12.5	7.6
Protein (N x 5.7), %[2]	13.0	13.1	13.2	13.3	13.6	38.3
Fat (Ether Extract), %[2]	1.82	1.81	1.81	1.80	1.79	0.69
Ash, %[2]	0.43	0.43	0.45	0.46	0.47	1.50
Starch Damage, Farrand Units	22	20	21	22	23	nd[3]
Gassing Power, mm. Hg.	360	350	330	300	285	6.35
Zeleny Sedimentation Value, ml.	70.0	69.0	65.0	64.5	54.5	59.0

1 Maize flour equivalent; proportion of MPI shown in parentheses

2 14% moisture basis

3 nd - not determined

2. Protein Content

As expected, the protein content increased slightly as the proportion of MPI increased (Table 11). There was a direct relationship between protein content and the proportion of MPI ($r = +0.880*$) indicating that protein content of composite can be calculated from the protein contents of the constituent flours (WF and MPI).

3. Fat Content

Fat content decreased slightly as the proportion of MPI increased; the relationship between fat content and composition of composite flours was nonlinear indicating that fat contents for composites cannot be determined by calculation from fat contents of WF and MPI precisely. The reason for this discrepancy was not investigated.

4. Ash Content

As expected, increasing the proportion of MPI in the composite increased ash content (Table 11). There was a direct relationship between ash content and flour composition (proportion of MPI in composite).

5. Damaged Starch

The damaged starch contents of the composite flours were essentially the same as the damaged starch content of WF (22 F.U.). The variability in damaged starch values obtained for the composites can be attributed to experimental error rather than to flour composition.

6. Gassing Power

Gassing power decreased slightly with increasing proportion of MPI in the composite flour. This can be attributed to the dilution of the starch and fermentable sugars of WF by the addition of MPI.

7. Zeleny Sedimentation Value

Sedimentation value decreased as the proportion of MPI increased. This indicates that maize proteins do not have the same functionality as wheat proteins in the Zeleny Sedimentation Test. It is known that for wheat, the sedimentation value is directly proportional to the protein content. The results of the Zeleny Test indicate that maize proteins are relatively (compared with wheat) low in breadmaking quality (as measured by the Zeleny Sedimentation Test).

The correlation between the sedimentation value and proportion of MPI in composite was not significant ($r = -0.473$) at the 5% level.

8. Alveograph

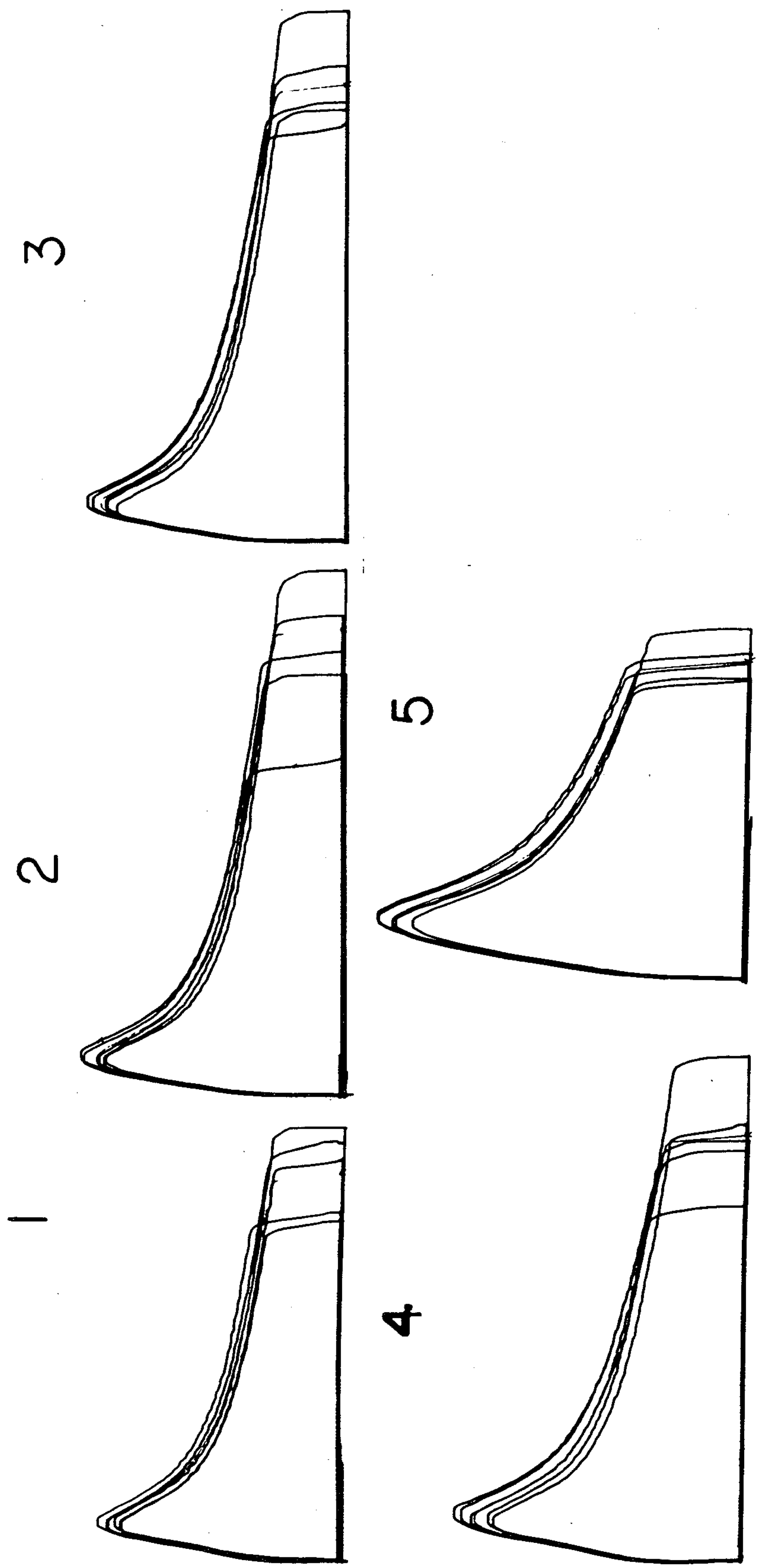
Stability (P values) and strength (S and W values) of dough increased as the proportion of MPI added to WF increased (Table 12, Fig.20). The doughs made from composite flours containing up to 1.2% MPI were only slightly different (somewhat more extensible) from the control dough. Extensibility of dough from composite flour containing 2.4% MPI was significantly less than that of dough from wheat flour. These results indicate that small additions of

Table 12. Dough Mixing and Rheological Data of Wheat-Maize Protein Isolate Composite Flours

	MAIZE PROTEIN ISOLATE, %[1]				
PARAMETER	0(0)	5(0.3)	10(0.6)	20(1.2)	40(2.4)
ALVEOGRAM					
Height (P), mm.	87	94	95	102	134
Length (L), mm.	135	163	159	150	111
Area (S), cm^2	56.5	66.0	67.2	73.0	77.3
Work Value (W), $x10^3$ ergs	294.6	338.8	341.0	373.1	401.4
AMYLOGRAM					
Peak Viscosity, B.U.	550	590	620	760	921
Time to Peak, min.	40	40	41	42	43
EXTENSIGRAM					
Resistance to extension, cm.	8.6	8.5	8.5	10.3	11.5
Extensibility, cm.	25.4	25.8	26.9	25.6	25.9
Ratio Figure	0.34	0.33	0.32	0.40	0.44
FARINOGRAM					
Absorption, % (14% m.b.)	60.2	60.5	60.6	61.0	61.3
Dough Development Time, min.	4.3	5.2	6.0	7.4	8.0
MIXOGRAM					
Maximum height, cm.	3.5	3.5	4.0	4.4	4.4

[1] Maize flour equivalent; proportion of MPI shown in parentheses.

Figure 20. Alveograms for composite flours containing increasing proportions of maize protein isolate:
1 - 0%; 2 - 0.3%; 3 - 0.6%; 4 - 1.2%; 5 - 2.4%.


1
2
3
4
5

MPI weaken the dough slightly. At very high levels of addition, the doughs become short or tight.

Statistical analysis of the data obtained from alveograph measurements gave the following correlations:

Proportions of MPI vs:

P - r = 0.955**

S - r = 0.830*

W - r = 0.884*

L - r = -0.478

In accordance with normal statistical designation, a double asterisk indicates significance at the 1% level and a single asterisk indicates significance at the 5% level.

9. Amylograph

Addition of MPI to wheat flour increased the amylograph peak viscosity (Table 12; Fig.21). The correlation between the proportion of MPI and peak viscosity was positive and significant at the 1% level ($r = 0.989$).

At equivalent substitutions, MPI had a greater effect than either MF or MSI on peak viscosity. The increase in peak viscosity resulting from the addition of MPI can be attributed to the binding of water by maize proteins. This effect indirectly increases the starch to water ratio in the test slurry.

10. Extensigraph

Resistance to extension did not show any substantial change for composites containing up to 0.6% MPI; then it increased slightly

Figure 21. Amylograms for composite flours containing increasing proportions of maize protein isolate:

1 - 0%; 2 - 0.3%; 3 - 0.6%; 4 - 1.2%; 5 - 2.4%.

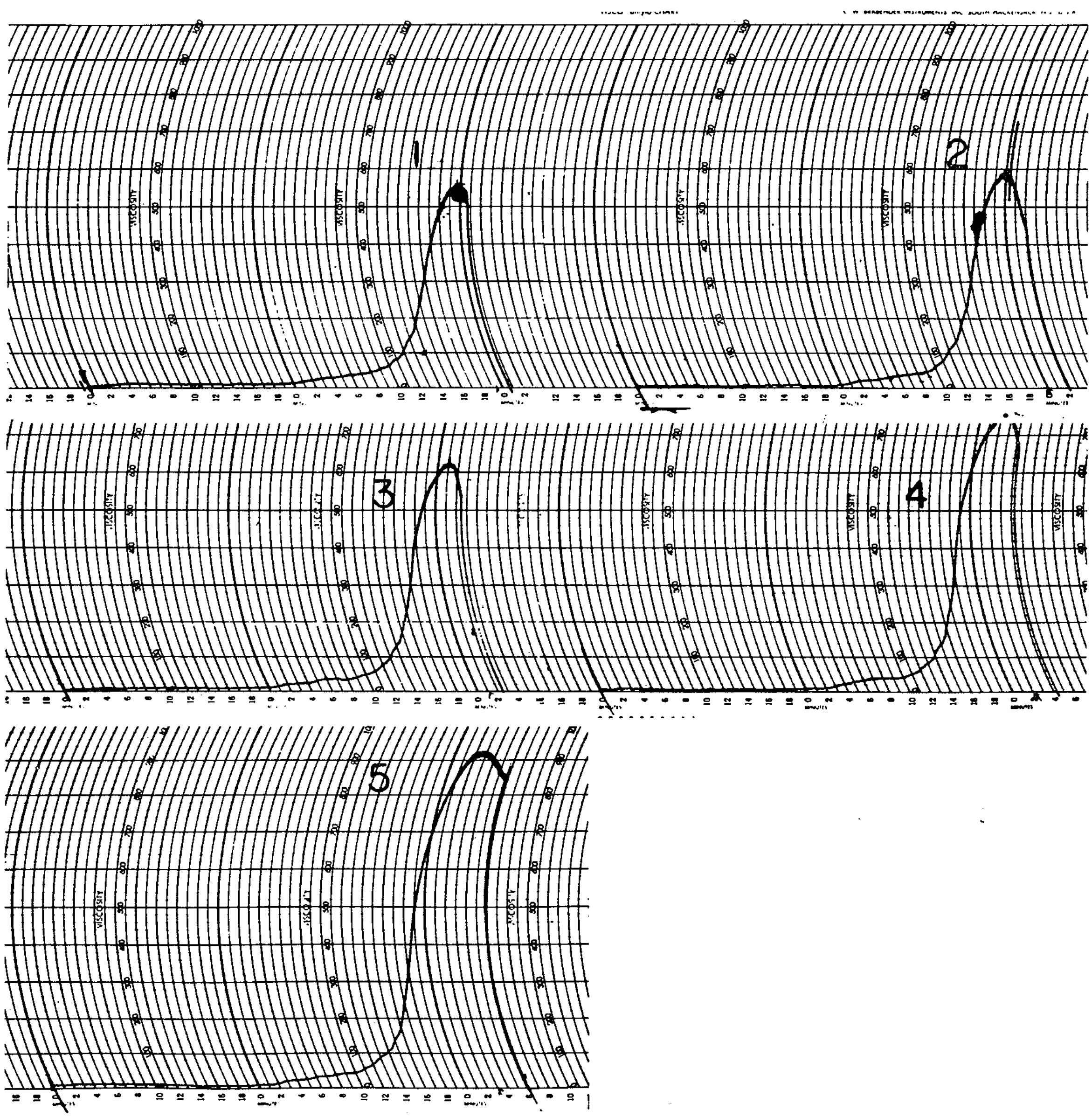
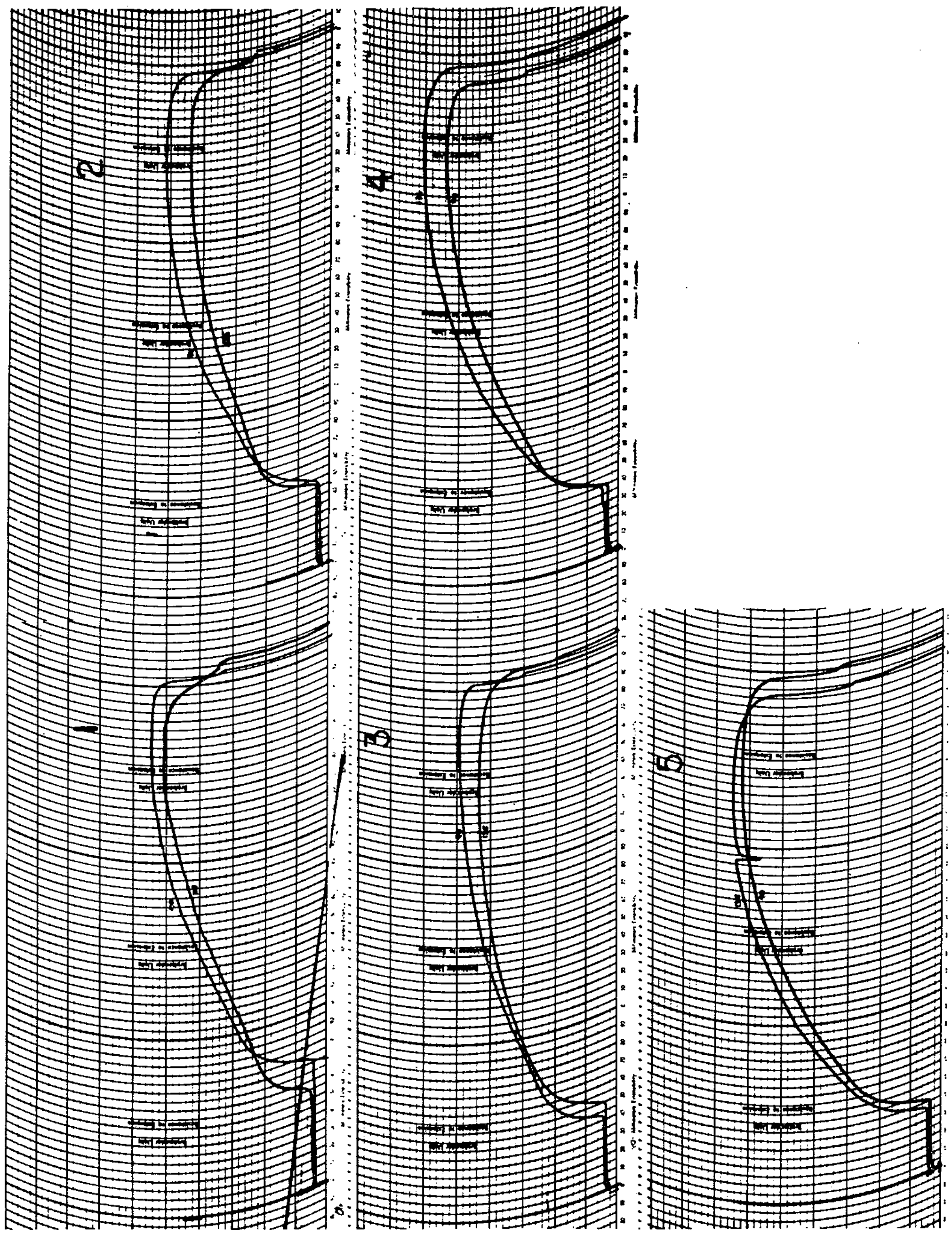

VISCOSITY
1
2
3
4
5

Figure 22. Extensigrams for composite flours containing increasing proportions of maize protein isolate:

1 - 0%; 2 - 0.3%; 3 - 0.6%; 4 - 1.2%; 5 - 2.4%.



for the 1.2% and 2.4% MPI composites (Table 12; Fig.22). Dough extensibility was not affected by the addition of MPI. The increase in ratio figure of doughs from the 1.2% and 2.4% MPI composites is due to the marked increase in resistance to extension. The results of extensigraph measurements and the shape of the extensigrams showed that the levels of MPI used (up to 40% equivalent of MF) had little or no effect on dough properties measured in the extensigraph test.

11. Farinograph

Farinograph water absorption and dough development time increased as the proportion of MPI increased (Table 12). The width of the farinograph curve (Fig.23) increased with addition of MPI. The correlation between dough development time and proportion of MPI was positive (r = +0.878) and significant at the 5% level.

The increase in water absorption can be attributed to the higher water binding capacity of MPI compared with that of WF. There is a suggestion that maize proteins interfere with gluten (dough) development during mixing. This is an interesting observation that warrants further study.

12. Mixograph

The increase in maximum height of mixograms (Table 12; Fig.24) as the proportion of MPI added to WF increased indicates that maize proteins increase dough strength and absorption as measured by the mixograph. Results of mixograph measurements give

Figure 23. Farinograms for composite flours containing increasing proportions of maize protein isolate:

1 - 0%; 2 - 0.3%; 3 - 0.6%; 4 - 1.2%; 5 - 2.4%.

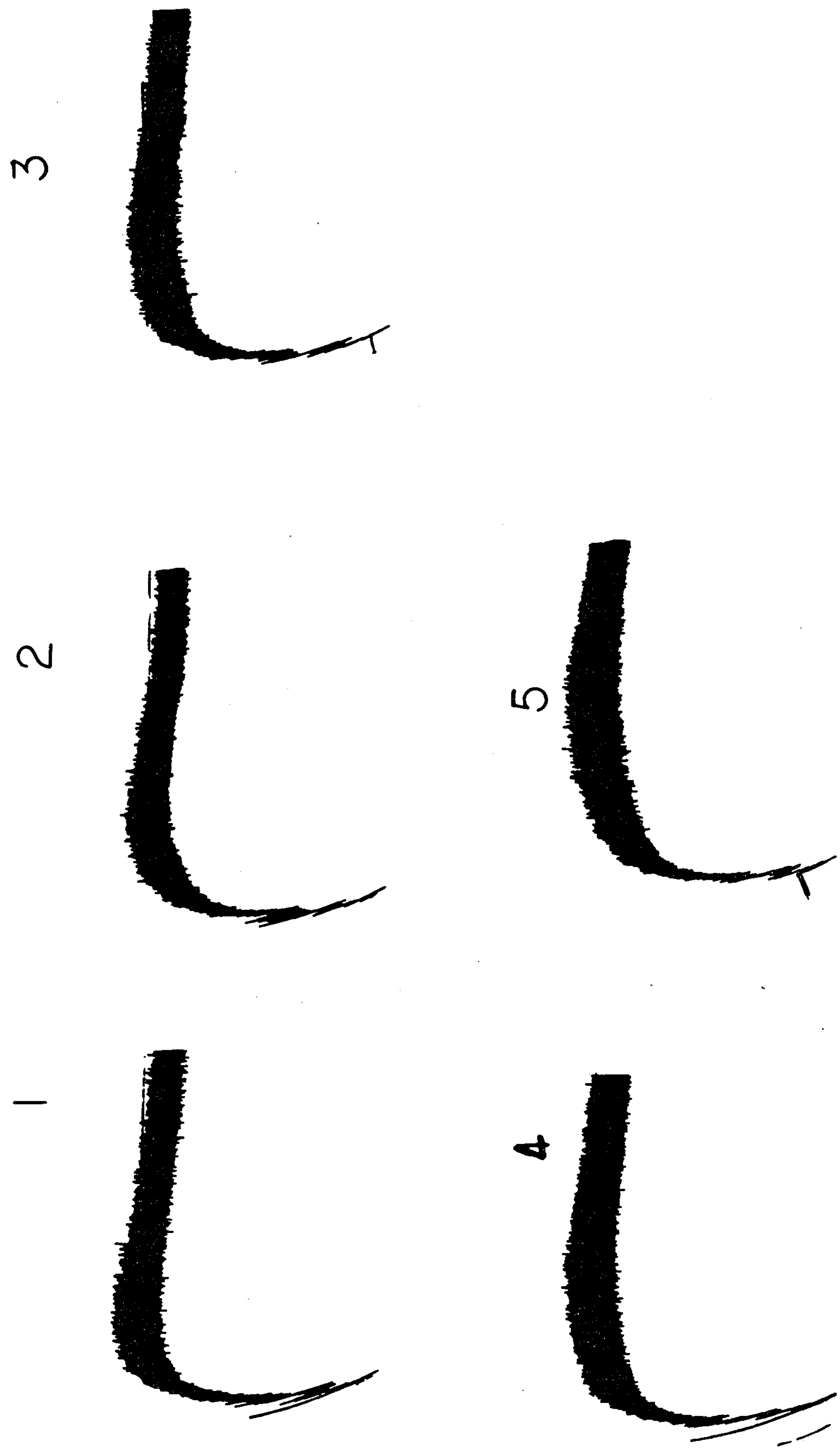
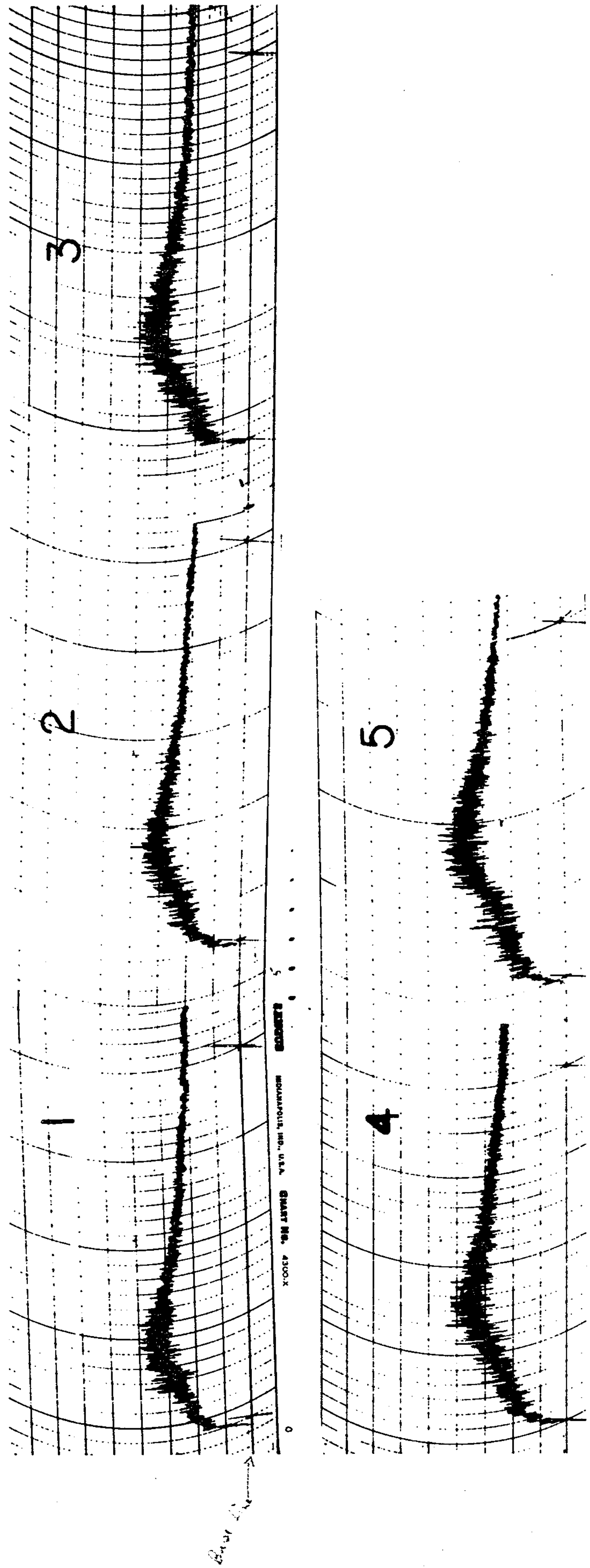

1
2
3
4
5

Figure 24. Mixograms for composite flours containing increasing proportions of maize protein isolate:

1 - 0%; 2 - 0.3%; 3 - 0.6%; 4 - 12.%; 5 - 2.4%.


1
2
3
4
5

essentially the same information as the results of alveograph and farinograph measurements.

G. Baking Results for Wheat-Maize Protein Isolate Composite Flours

Baking results for the MPI composite flours are given in Table 13; Fig.26 shows internal and external characteristics of selected loaves baked from these flours.

1. GRL Remix Baking Method

Bread baked from composite flour containing 0.3% MPI had a slightly higher loaf volume than bread baked from the control flour; the other composite flours produced bread of lower loaf volume than the control flour. The decrease in loaf volume corresponds approximately to the increase in proportion of MPI (Fig.25). Specific weight followed the same pattern as loaf volume. Loaf appearance (Fig.26) deteriorated substantially at high (1.2% and 2.4%) proportions of maize proteins; similar detrimental effects were observed for crumb and crust color. Crumb grain improved slightly with addition of MPI.

Handling properties of dough during the make-up stages (mixing, sheeting, moulding, and panning) were satisfactory for all the composites. The color of dough became gradually darker (compared to the white color of the control wheat-flour dough) as the proportion of MPI increased. This change in color was also noticeable in color of the bread crumb and crust (Table 13).

Table 13. Baking Results for Wheat-Maize Protein Isolate Composite Flours

PARAMETER	MAIZE PROTEIN ISOLATE, %[1]				
	0(0)	5(0.3)	10(0.6)	20(1.2)	40(2.4)
BREAD - GRL REMIX METHOD					
Baking absorption, % (14% m.b.)	60.2	60.5	60.6	61.0	61.3
Loaf volume, cc/ g. flour	853	886	820	765	683
Loaf weight, g.	126.8	128.3	126.1	126.1	128.1
Specific weight, g/cc	0.15	0.14	0.16	0.16	0.19
Loaf appearance	8.7	8.7	8.5	8.3	8.0
Crumb color[2]	lt	lt	lt	d	d
Crumb grain[3]	8.2-o	8.3-o	8.4-e	8.3-e	8.4-o
Crust color[4]	y	y	y	dy	dy
BREAD - CB PROCESS					
Baking absorption, % (14% m.b.)	62.2	62.5	62.6	63.0	63.3
Loaf volume, cc/ 100 g. flour	858	905	857	768	698
Loaf weight, g.	128.5	129.1	129.8	131.1	132.9
Specific weight, g/cc	0.15	0.14	0.15	0.17	0.19
Loaf appearance	8.8	8.7	8.7	8.6	8.3
Crumb color[2]	lt	lt	lt	ld	ld
Crumb grain[3]	8.1-o	8.2-o	8.3-o	8.4-e	8.3-o
Crust color[4]	y	y	y	dy	dy

[1] Maize flour equivalent; proportion of MPI shown in parentheses

[2] lt - light
ld - light dark
d - dark

[3] o - open
e - even

[4] y - yellow
dy - dull yellow

Figure 25. Relationship between loaf volume and proportion (Maize flour equivalent) of maize protein isolate

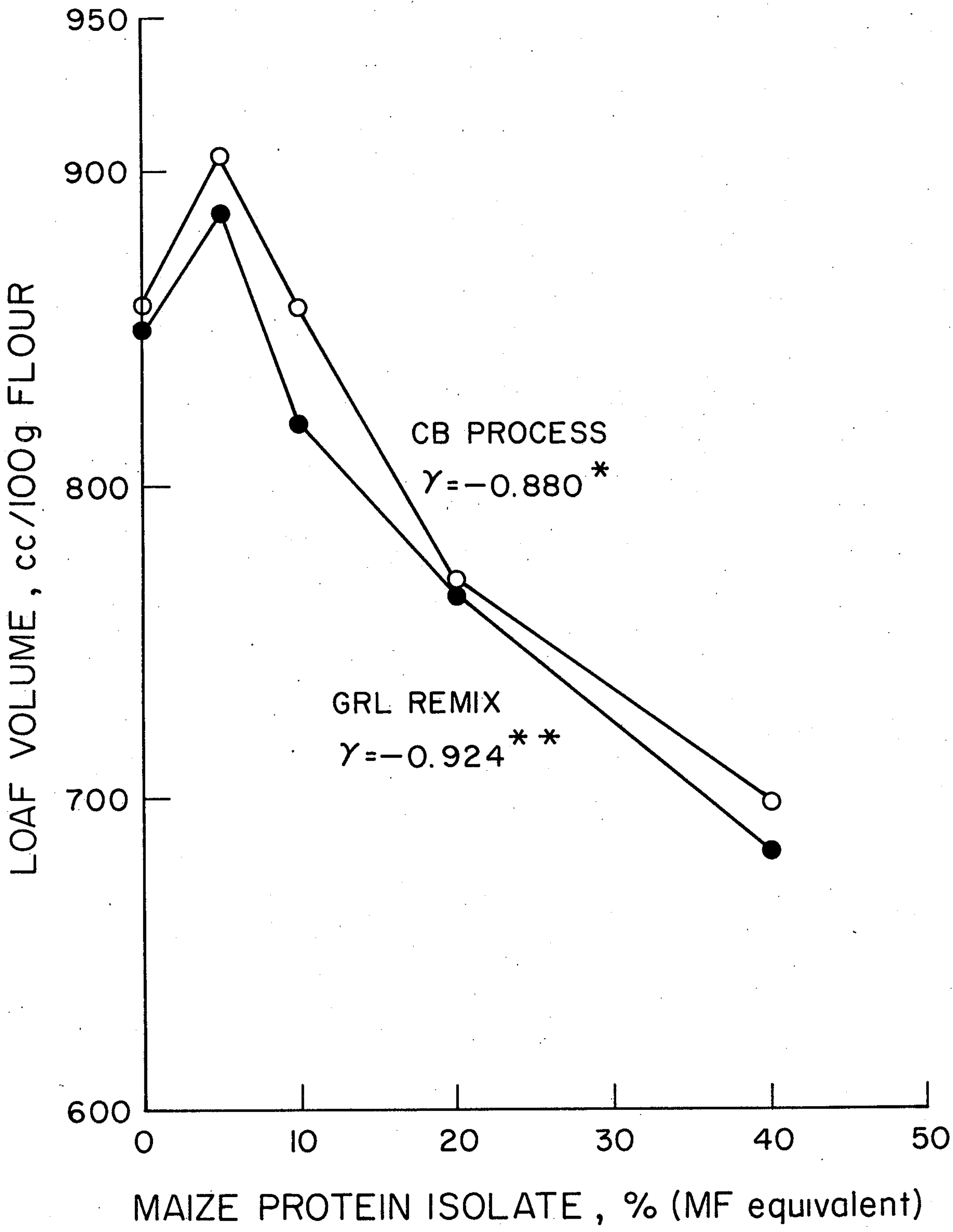

950
900
800
700
600
LOAF VOLUME , cc/100g FLOUR
CB PROCESS
γ=−0.880*
GRL REMIX
γ=−0.924**
0
10
20
30
40
50
MAIZE PROTEIN ISOLATE , % (MF equivalent)

Figure 26. Bread from composite flours containing increasing proportions of maize protein isolate. Percentages represent maize flour equivalents.

REMIX

CBP

2. Chorleywood Bread (CB) Process

Baking results by the CB process baking test are similar to the results by the Remix method. Loaf volume increased when 0.3% MPI was added and then decreased for higher proportions of MPI. Other quality parameters for bread by the CB process showed essentially the same effects of increasing MPI as did the bread by the Remix method. As found for other composites, the CB process again gave slightly higher loaf volumes.

Baking results by both methods were better for MPI composites that those for the MF or the MSI composites.

H. Results Related to Breadmaking Properties of Wheat-Maize Oil Composite Flour

Composite flours prepared from wheat flour and maize oil (MO) were not analyzed for proximate composition. With the exception of fat content, the components would be diluted according to the proportion of pure MO added. The results presented in this section are for rheological measurements of composites prepared by replacing 0.18%, 0.35%, 0.70%, and 1.40% of the control wheat flour (WF) with maize oil. The proportions of MO added are equivalent to 5%, 10%, 20%, and 40% maize flour. The alveograph test was not applied to the doughs from these composite flours.

1. Amylograph

Addition of MO to WF produced a decrease in amylogram peak, however, the decrease is not proportional to the amount of MO in the

Table 14. Dough Mixing and Rheological Data of Wheat-Maize Oil Composite Flours

	MAIZE OIL, %[1]				
PARAMETER	0(0)	5(0.18)	10(0.35)	20(0.70)	40(1.40)
AMYLOGRAM					
Peak viscosity, B.U.	550	440	440	450	420
Time to peak, min.	42.0	42.0	41.3	42.2	41.0
EXTENSIGRAM					
Resistance to Extension, cm.	7.6	7.2	7.4	7.5	7.2
Extensibility, cm.	25.5	25.9	26.8	25.6	26.5
Ratio figure	0.31	0.27	0.28	0.30	0.26
FARINOGRAM					
Absorption, % (14% m.b.)	61.4	59.1	59.0	58.7	57.9
Dough Development Time, min.	4.0	4.1	4.0	4.0	4.0
MIXOGRAM					
Maximum height, cm.	5.2	5.3	5.2	5.1	5.0

1 Maize flour equivalent; proportion of MO shown in parentheses.

composites (Table 14; Fig.27). These results indicate that the MO interferes with the normal gelatinization of the wheat starch. The mechanism of this effect was not investigated.

2. Extensigraph

Maize oil, at the levels investigated, had little or no effect on the properties of dough made from the MO composites as measured by the extensigraph (Table 14; Fig.28).

3. Farinograph

Water absorption decreased slightly (Table 14), but mixing behavior of the dough (Fig.29) did not change on the addition of MO. The general shape of the farinogram was not affected.

4. Mixograph

Mixograph measurements on doughs from the MO composite flours showed no effects of MO on the dough properties assessed in this test (Table 14; Fig.30).

The negligible effect of small quantities of maize oil on mixing and rheological properties of wheat flour observed in the present study are in general agreement with the published results of Tao and Pomeranz (1968).

I. Baking Results of Wheat-Maize Oil Composite Flours

Baking results for the MO composite flours are given in Table 15. Figure 31 shows internal and external characteristics of bread baked from these flours.

Figure 27. Amylograms for composite flours containing increasing proportions of maize oil:

1 - 0%; 2 - 0.18%; 3 - 0.35%; 4 - 0.70%; 5 - 1.40%.

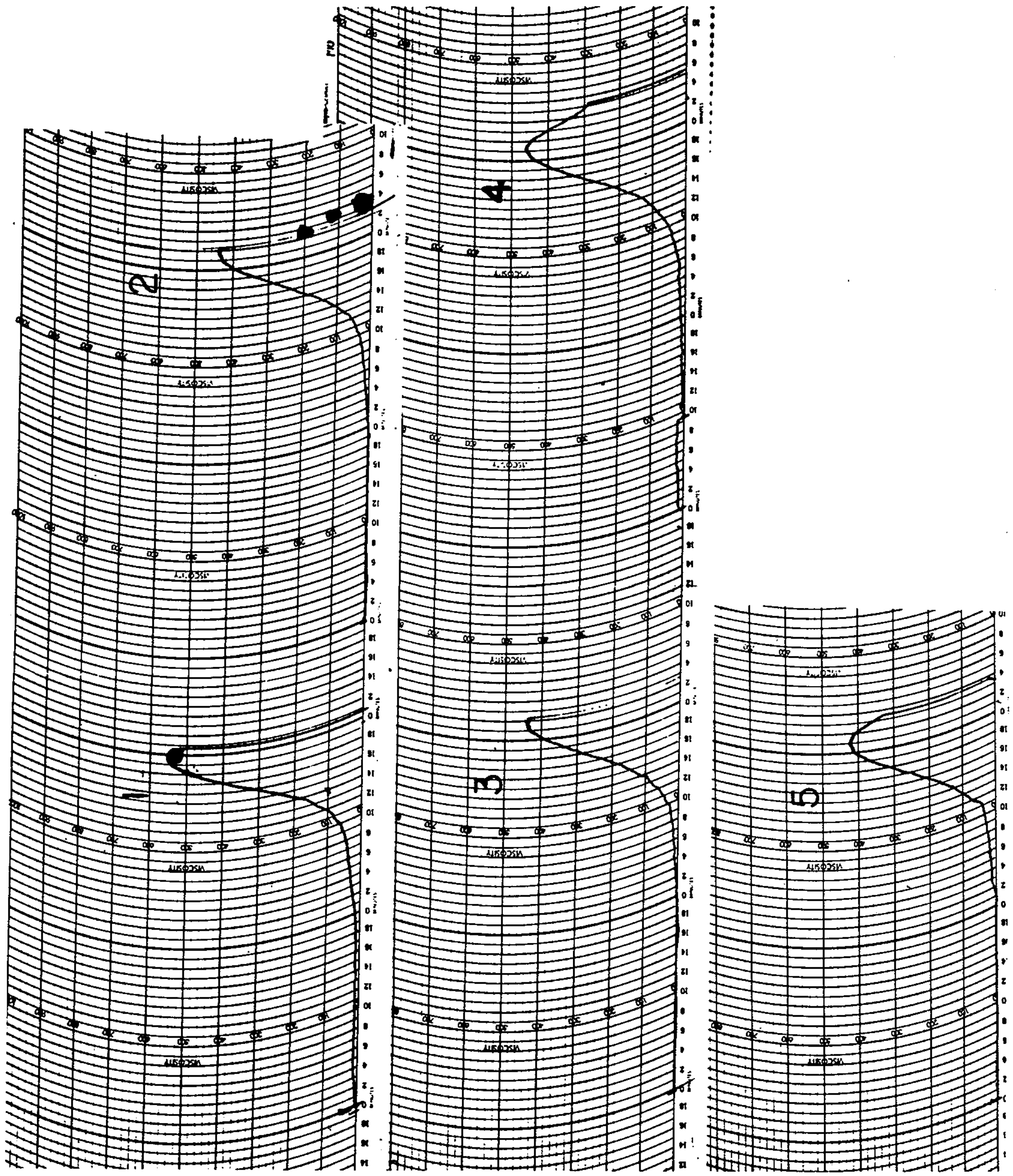

2
4
1
3
5

Figure 28. Extensigrams for composite flours containing increasing proportions of maize oil:

1 - 0%; 2 - 0.18%; 3 - 0.35%; 4 - 0.70%; 5 - 1.40%.

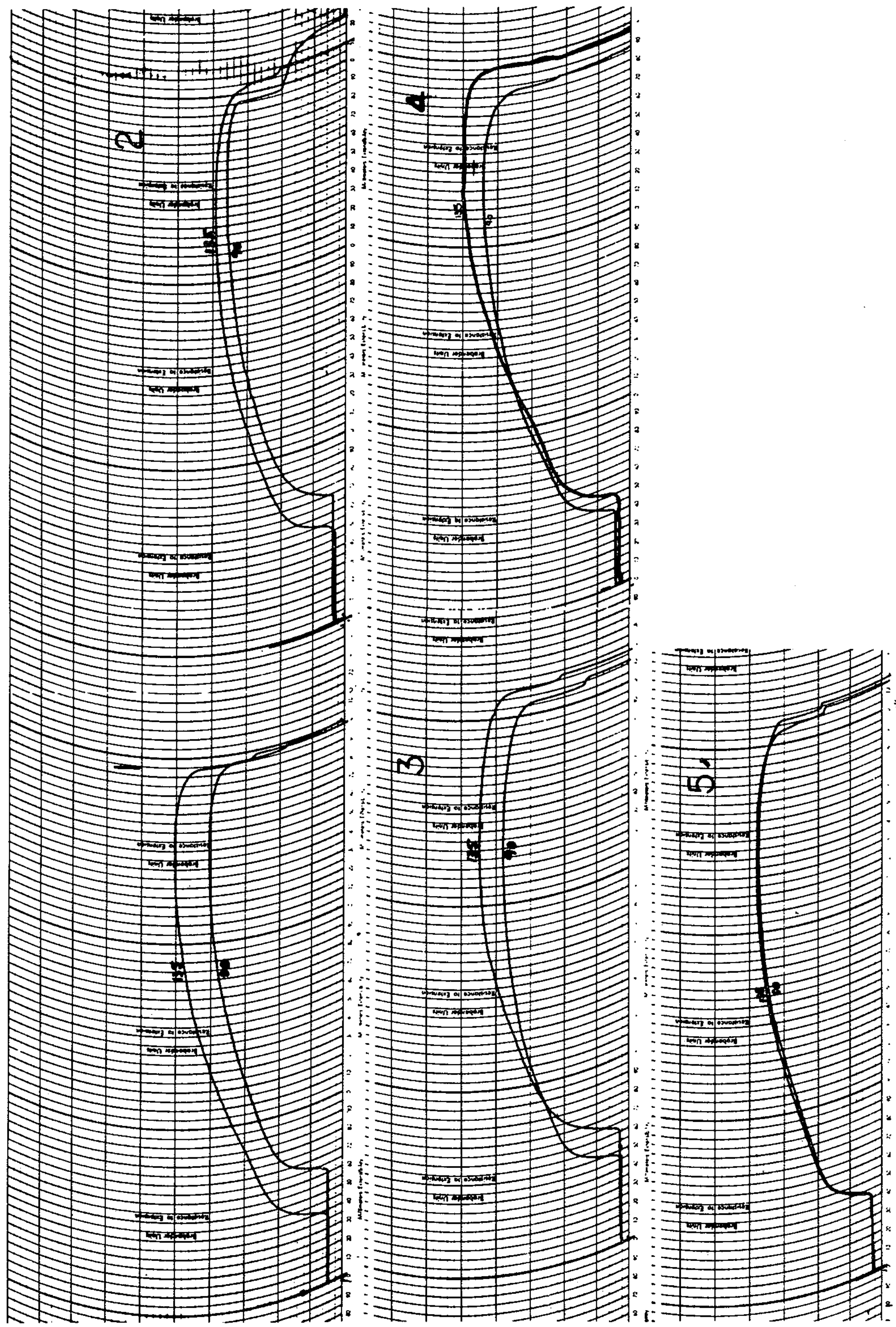


Figure 29. Farinograms for composite flours containing increasing proportions of maize oil:

1 - 0%; 2 - 0.18%; 3 - 0.35%; 4 - 0.70%; 5 - 1.40%.

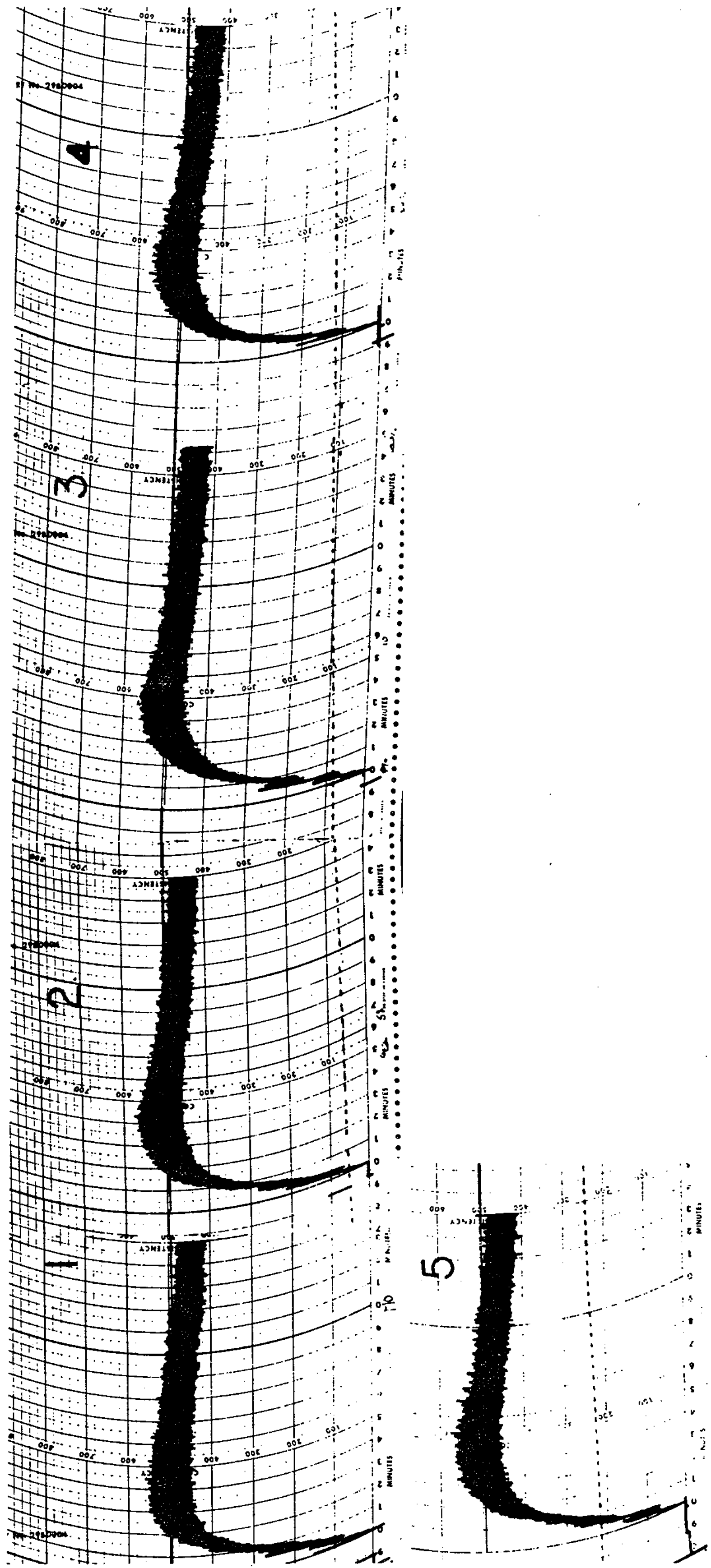


Figure 30. Mixograms for composite flours containing increasing proportions of maize oil:

1 - 0%; 2 - 0.18%; 3 - 0.35%; 4 - 0.70%; 5 - 1.40%.

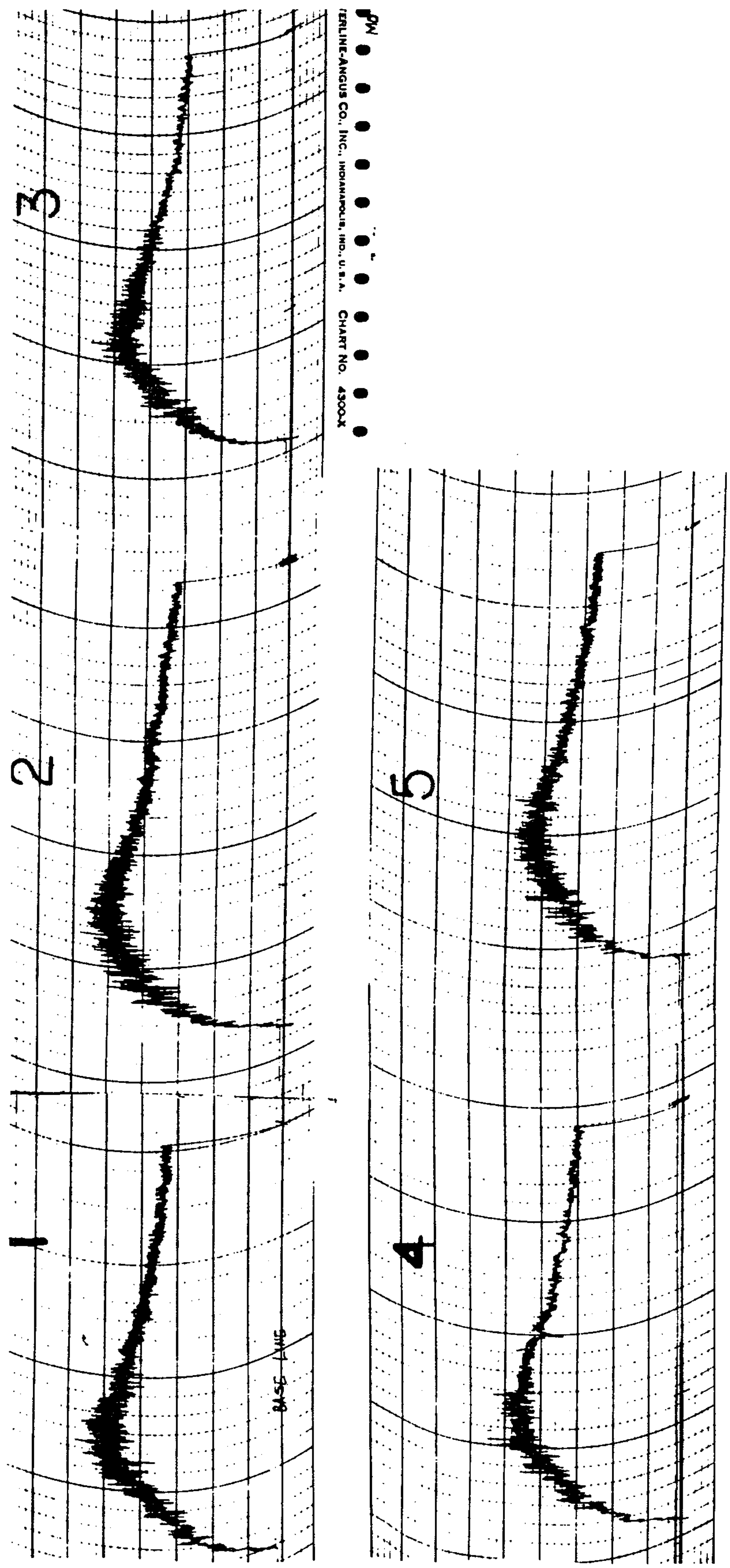

ERLINE-ANGUS CO., INC., INDIANAPOLIS, IND., U.S.A. CHART NO. 4300-X
3
2
1
5
4
BASE LINE

Table 15. Baking Results of Wheat-Maize Oil Composite Flours

	MAIZE OIL, %[1]				
PARAMETER	0(0)	5(0.18)	10(0.35)	20(0.70)	40(1.40)
BREAD- GRL REMIX METHOD					
Baking absorption, % (14% m.b.)	61.4	59.1	59.0	58.7	57.9
Loaf volume, cc/100 g. flour	820	810	820	815	800
Loaf weight, g.	126.4	129.4	130.5	124.9	130.3
Specific weight, g/cc	0.16	0.16	0.16	0.15	0.16
Loaf appearance	8.8	9.0	8.6	8.6	8.5
Crumb color[2]	lt	lt	lt	vl	vl
Crumb grain[3]	8.4-o	8.5-e	8.4-o	8.4-o	8.3-e
Crust color[4]	y	y	y	y	y
BREAD - CB PROCESS					
Baking absorption, % (14% m.b.)	63.4	61.1	61.0	60.7	59.9
Loaf volume, cc/100 g. flour	860	848	840	845	850
Loaf weight, g.	123.0	123.9	122.8	121.4	120.9
Specific weight, g/cc	0.14	0.15	0.15	0.14	0.14
Loaf appearance	8.6	8.4	8.5	8.5	8.5
Crumb color[2]	lt	lt	vl	vl	vl
Crumb grain[3]	8.3-o	8.3-o	8.2-o	8.4-e	8.5-e
Crust color[4]	y	y	y	y	y

[1] Maize flour equivalent; proportion of MO shown in parentheses

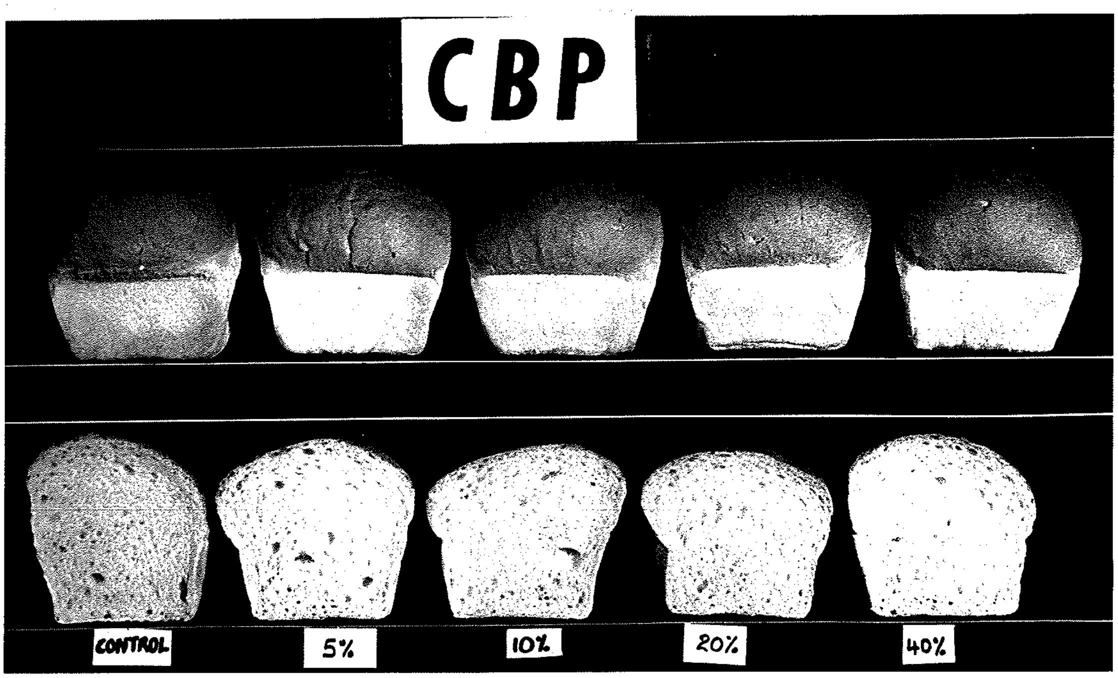
[2] lt - light
vl - very light

[3] o - open
e - even

[4] y - yellow

Figure 31. Bread from composite flours containing increasing proportions of maize oil. Percentages represent maize flour equivalent.


REMIX
control (0%)
5%
10%
20%
40%


CBP
CONTROL
5%
10%
20%
40%

1. GRL Remix Method

Addition of MO had essentially no effect on loaf volume, specific weight, appearance, and crumb grain of the bread produced by the remix baking test. Crumb and crust color were improved somewhat as the proportion of maize oil increased.

Handling properties of all doughs were satisfactory at all stages though dough made from composite flour containing 1.40% MO was slightly softer than the doughs made from composites containing lower proportions of MO.

2. Chorleywood Bread (CB) Process

Loaf volume of bread made from each composite flour was slightly lower than the loaf volume of the bread made from the control flour. There was essentially no change in loaf volume and specific weight with increasing proportion of maize oil. Internal and external characteristics of bread were somewhat improved with respect to crumb and crust color by adding maize oil. The CB process again produced slightly higher loaf volumes than the remix process.

Loaf volume results, by both methods, obtained in this study do not agree with the results obtained by Pomeranz and Hayes (1968) who showed that MO increased loaf volume. In contrast to the results presented above, Pomeranz and Hayes (1968) showed that hydrogenated maize (corn) oil increased the loaf volume obtained by the A.A.C.C. malt-phosphate-bromate baking test (A.A.C.C., 1969). This minor discrepancy is attributed to differences in the oil and the baking tests.

VI. GENERAL DISCUSSION

The main objective of this thesis was to study the effects of various levels of maize flour and its major components (starch, protein and oil) on the breadmaking properties of wheat flour. This type of information is basic to the utilization of maize flour in composite flours for producing bread. A selected wheat flour, maize flour, isolated fractions of maize starch and maize protein, and a commercial refined maize oil were used for this investigation. Where possible, the results obtained were compared with results reported in the literature for other types of maize flour. The information presented in this thesis should be useful in relation to optimal utilization of maize flour in composite flours for bread production.

Base materials and all composites (except those containing maize oil) were analyzed for proximate composition. Other measurements related to breadmaking quality such as gassing power, damaged starch, etc. were also made.

The starting materials, wheat flour, maize breakfast meal, and maize flour gave values of moisture, fat, and ash contents and color grade that are typical for such flours (Table 2). The moisture content of maize starch isolate was comparable to that of maize flour but its ash and fat contents were higher. Maize protein isolate had a relatively low moisture content and high ash and fat content values.

Starch contents of wheat and maize flours were similar to literature values; the content of maize starch isolate was relatively high indicating a high recovery of this component from the parent maize flour.

Amino acid compositions of maize flour and maize protein isolate (Table 3) showed that the relative lysine content for maize protein isolate was lower than that for maize flour or wheat flour indicating that some of the higher lysine protein fractions were lost in the preparation of the maize protein isolate. This is relevant to nutritional quality especially since lysine is the first limiting amino acid of both maize and wheat. Fatty acid composition for maize oil (Table 4) showed that it contains a high proportion of unsaturated fatty acids comprising mainly linoleic and oleic acids.

The initial interest in the microscopic investigation of maize starch isolate resulted from a desire to understand more fully the physical characteristics of the maize starch granules. Results of scanning electron microscopy showed that the granules of the maize starch isolate used were typical of maize starch and showed no damage. Damaged starch values determined by biochemical methods agreed with microscopy results.

Generally, the proximate composition of all the composite flours studied can be determined from the analytical values of the constituent flours and the known flour composition. The only components that gave erratic values were moisture and fat. In most cases, there was a gain in moisture during blending and the apparent lack of additivity of fat content for the composite flours is attributed to the low precision of the method used to analyze for this component.

Though data for damaged starch, gassing power and the Zeleny Sedimentation Test were presented and discussed together with proximate analysis data, these determinations should not be regarded as part of proximate composition of the flours. The levels of damaged starch for the two starting flours were quite different; wheat flour had a much higher level of damaged starch than the breakfast meal (Table 2). Maize flour had a higher level of damaged starch than breakfast meal indicating that grinding of meal into flour caused considerable physical damage to maize starch granules. The apparent lack of damaged starch in maize starch isolate indicates that all of the damaged starch (which is known to be highly soluble compared with native starch) was removed in the wash-water during preparation of maize starch isolate. Gassing power values are generally consistent with values for damaged starch. As expected, the addition of increasing proportions of maize flour to wheat flour increased the level of damaged starch and gassing power in direct proportion with flour composition whereas increasing proportions of maize starch and protein isolates had essentially no effect on damaged starch but both decreased gassing power. The decrease in gassing power can result from a dilution of fermentable sugars present in wheat flour. This is an interesting point that merits further investigation.

It is widely known and accepted that the protein content and Zeleny sedimentation value of wheat flour are directly related.

Both are good indices of breadmaking quality. These parameters were, therefore, given more weight than the others in this study. Protein values obtained for the wheat flour, breakfast meal, and maize flour are typical of these materials. The protein content for maize starch isolate was low and that for maize protein isolate, although relatively high, indicated that this component contained a major proportion of non-protein material (presumed to be starch). The Zeleny Test showed that wheat flour had the highest value, as expected. Breakfast meal and maize flour had comparable values, consistent with protein content data. Maize starch isolate had the lowest Zeleny sedimentation value and maize protein isolate had a relatively high value, second to that of wheat flour. The addition of increasing proportions of either maize flour or maize starch isolate to wheat flour caused a decrease in protein content in direct proportion to the proportion of either maize flour or maize starch isolate in the composite. These results suggest first that maize flour or maize starch dilutes wheat flour protein (this is relevant to baking quality) and second that the protein content of the composite flour can be calculated from the protein contents of the constituent flour and the known flour composition. On the other hand, the addition of increasing proportions of maize protein isolate to wheat flour produced a direct increase in protein content.

The addition of increasing proportions of maize flour to wheat flour produced a decrease in the Zeleny Sedimentation value; however, the decrease was not proportional to the amount of maize flour. This suggests that there is an interaction between the constituent flours insofar as their functionality in the Zeleny Sedimentation test is concerned. Increasing proportions of maize starch isolate produced a linear decrease in the sedimentation value, indicating that the starch isolate behaves as an inert diluent. Addition of increasing proportions of maize protein isolate to wheat flour also produced a decrease in sedimentation value even though the protein content of the composite flours increased. This indicates that maize proteins do not have the same functionality in the Zeleny Sedimentation test as wheat proteins. These results suggest that maize proteins do not have the breadmaking quality of wheat gluten proteins. This was subsequently confirmed by actual baking tests. The decrease in Zeleny Sedimentation value is greater than would be expected from the decrease in protein content by simple dilution effect of maize protein isolate. This suggests an interaction between maize and wheat proteins which inhibits the formation of gluten that is required for the Zeleny Sedimentation test (or loaf volume).

Dough mixing and rheological measurements related to breadmaking quality were performed on all composite flours studied. Maize flour produced a gradual change (with increasing proportion of maize flour) in rheological properties of the dough as measured with the alveograph, extensigraph, farinograph and mixograph. Results indicate that doughs containing up to 20% maize flour would require minor adjustments in processing while those containing 40% would require major adjustments. Similar results were obtained for doughs containing maize starch isolate at proportions equivalent to maize flour. However, the effect of maize starch isolate was generally greater in magnitude than that exerted by maize flour. The increase in starch content of wheat flour due to the addition of increasing proportions of either maize flour or maize starch isolate produced an increase in amylogram peak viscosity. Alveograph, farinograph and mixograph data showed that the addition of increasing proportions of small quantities of maize protein isolate to wheat flour caused a gradual positive change in some dough properties. The increase in amylogram peak viscosity and farinograph (water) absorption can be attributed to the higher water binding capacity of maize proteins compared with that of wheat flour; this indirectly increases the starch-to-water ratio in the slurry of the amylograph test. The farinograph results suggest that maize proteins interfere with dough (gluten) development during mixing. This effect is analogous to the negative effect in the Zeleny Sedimentation test (see above).

Maize oil had negligible effects on mixing and rheological properties of the composite flour doughs as measured with the extensigraph, farinograph and mixograph. The decrease in amylogram peak viscosity suggests that small quantities of maize oil interfere with the normal gelatinization of the wheat starch.

Two baking methods were used to measure the baking quality of all the composite flours. Both methods showed that maize flour and maize starch isolate caused a direct decrease in loaf volume and a parallel deterioration in bread quality. Variations in dough handling properties during the baking test could be anticipated from the observed effects in the alveograph, extensigraph and farinograph tests. Maize starch isolate composite flours produced bread of higher loaf volume than maize flour composites as measured by the Remix test, but the results were reversed in the Chorleywood Bread (CB) test. According to laboratory evaluation, bread containing up to 10% maize flour or 14.9% (20% maize flour equivalent) maize starch isolate by the Remix test and 20% maize flour or 14.9% maize starch isolate by the CB test would be acceptable by consumers. Both baking methods showed that small proportions of maize protein isolate (0.3%, equivalent to 5% maize flour) caused an increase in loaf volume and thereafter a gradual decrease. There was a slight deterioration in the other bread quality parameters at proportions of maize protein isolate above 0.3%. Bread containing up to 2.4% (equivalent to 40% maize flour) maize protein isolate, by both methods, was acceptable though the CB test produced bread of slightly better quality than the Remix test. Handling properties of dough were as expected from results of rheological tests. Addition of maize oil did not have substantial effect on bread characteristics, and bread containing up to 1.40% (40% maize flour equivalent) maize oil was considered acceptable.

Because of the limited data, heavy emphasis should not be placed on the correlations obtained by statistical analysis. However, it was felt that a statistical analysis would be interesting and useful, especially on parameters that are related to breadmaking quality such as protein content, Zeleny Sedimentation value, rheological measurements and loaf volume. Most of the parameters gave negative but significant (at the 1% and 5% levels) correlations with proportions of maize flour and maize starch isolate. Maize protein isolate gave positive (except with loaf volume) correlations while maize oil gave non-significant correlations.

This study shows that it is possible to make bread from composite flours containing relatively high proportions (up to 20%) of maize flour or its major components, subject to minor modifications in processing conditions. The study suggests that of the three major components of maize flour, maize protein exerts harmful (deleterious) effects on the breadmaking quality of wheat flour (as indicated by the Zeleny Sedimentation and farinograph tests) as opposed to simple dilution of the wheat flour by maize starch. The effects of maize oil suggest an interaction with wheat starch but this interaction does not affect the physical properties of bread produced from the composite flour. Total maize flour shows both the simple dilution and interaction effects. The nature of the interaction effects remains to be investigated.

It is hoped that the data presented in this thesis will be helpful in assessing and/or enhancing the utilization potential of maize flour in composite flours for bread production in countries that have a supply of maize but lack wheat. However, the extent to which maize flour will be used in composite flours for successful bread production will depend on consumer acceptance of the bread. Consumer acceptance will, in turn, be related to the quality of bread.

The ultimate success, therefore, of maize in bread production is totally dependent on positive results of pilot baking investigations which should include, among other constraints, panel tasting and consumer preferance studies in those developing countries that wish to incorporate maize flour in composite flours for bread production.

VII. SUMMARY

1. Except for some minor deviations, the basic composition of composite flours was directly related to the proportion of component flours in the composite. For example, the protein content of the composite flours can be calculated from the contents of the constituents in the component flours and the known composition (in terms of blended flours). Minor deviations in moisture and fat contents were observed.
2. Maize flour and maize starch isolate produced gradual changes (with increasing proportion) in breadmaking properties (damaged starch, gassing power, Zeleny Sedimentation value, and amylograph, alveograph, extensigraph, farinograph and mixograph measurements, and baking results) in a way that suggests a simple dilution of wheat protein (lowering of protein content).
3. The effect of maize protein isolate suggests an interaction between the maize and wheat proteins in a way that the negative effect on breadmaking properties is increased. This has been attributed to inhibition of gluten development by the maize proteins. An exception to this generalization is the increase in loaf volume obtained by the lowest increment of maize protein isolate investigated (0.3%).

4. The effects of maize oil on breadmaking properties were negligible. Amylograph measurements suggest an interaction of maize oil and wheat starch in a way that interferes with normal starch gelatinization.

5. This study showed that satisfactory bread (by laboratory evaluation) can be produced from composite flours comprising wheat and maize (or its components) containing up to 20% maize with minor modifications in the breadmaking procedures. High proportions of maize would probably require major modifications in baking methods and acceptance of lower bread quality. The minor modifications can be estimated from the results of this study. Delineation of major process modifications will require further investigation.

6. Practical application of the findings of this study will require consumer acceptance studies using baked products (e.g., bread) produced in commercial bakeries in consumer countries.

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APPENDIX A

Determination of Starch with Glucoamylase

Scope:

Applicable to starch determination in complex media, including all starcy products (food and feed, digestive contains) and glycogen.[1/]

Apparatus:

1. Autoclave
2. Spectrophotometer
3. Water bath with shaker for glucoamylase reaction
4. E-flask, 100 ml
5. Calibrated pipettes, 1 - 5 ml
6. Test Tubes 18 x 150 mm
7. Water bath capable of maintaining a temperature of $37^{o} \pm 1^{o}C$

Reagents:

1. Glucoamylase[2/] free of transglucosidase activity under assay conditions, dissolved in distilled water (50 mg/ml). Prepare a solution containing 30 International Units (I.U.) per mg.
2. 2 M Acetate Buffer, pH 4.8 (120 ml of glacial acetic acid and

164 g of anhydrous sodium acetate per liter).

3. Standard D-glucose solution - 400 mg pure anhydrous D-glucose per liter. Allow 4 hr for complete mutarotation before use.

4. "Tris-phosphate-glycerol" buffer. Dissolve 36.3 g of 'tris' (tri hydroxymethylaminomethane) and 50.0 g $NaH_2PO_4 \cdot H_2O$ or (45.5 g of anhydrous NaH_2PO_4) in 500 ml water. Add 400 ml redistilled glycerol and adjust pH to 7.0 with phosphoric acid before bringing to 1 liter with distilled water.

5. Enzyme-buffer-chromogen mixture.
   Available in convenient premixed form from: Worthington Biochemical Corp. (Glucostat special) Freehold, N.J. 07728; Fermco Laboratories Div., G.D. Searle and Corp., P.O. Box 5110, Chicago, Illinois. 60680, and calbiochem, 10933, N. Torrey Pines Road, La Jolla, California 92037.

Or prepare as follows:

Dissolve in 100 ml of "Tris-phosphate-glycerol" buffer; 30 mg of glucose oxidase (Type II from Aspergillus niger, Sigma Chemical Co., St. Louis, Missouri); 3 mg of peroxide (Type I from horseradish, Sigma); 10 mg of O-anisidine dihydrochloride (Sigma). This mixture can be stored at $+4^{\circ}C$ for 10 days.

6. Sulfuric Acid, 18 N.

Procedure:

1. Treat sample as given in Footnote[1/] if required.
2. Grind sample to particle size smaller than 0.5 m (.0195 inches) which is equivalent to a 40 mesh stainless steel sieve.
3. Determine the moisture content in the ground grain by an AACC approved method in order to correct starch data to dry weight basis.
4. Weigh a sample not more than 1.0 g (generally 0.5 g) and containing less than 0.5 g starch into dried and tared Erlenmeyer flask.
5. Add 25 ml water with stirring to disperse the product and adjust pH between 5-7 if necessary. The suspension is then boiled with gentle stirring for 3 min and pressure heated at 135° for 2 hours[3/]. Utilize, also 15# pressure, 121°C for 4 hours for this collaborative study.
6. Remove from autoclave, maintain temperature near 55°C and add 2.5 ml acetate buffer and 20 ml water to give total weight of 45 ± 1 g.
7. Immerse E-flask in water bath with shaker at optimal temperature of gluco-amylase used (Glucoamylase extract from Rhizopus delemar 55°C ± 1°C) and add 5 ml glucoamylase.
8. Hydrolyze 1 hr with continuous shaking, filter through folded filter paper into 250 ml volumetric flask, wash quantitatively and dilute to volume.

9. Transfer 1 ml aliquots containing 20-60 ug D-glucose to test tubes. To obtain this range of glucose concentration it may be necessary to dilute the hydrolysate of step 8.

10. Add 2 ml enzyme-buffer-chromogen mixture, shake tubes and place in dark at $37^{o}C \pm 1^{o}C$ exactly 30 min to develop color.

11. Stop reaction with 2 ml 18 N H_2SO_4 and measure absorbance at 540 nm.

12. Prepare standard D-glucose curve from 0 to 60 ug/ml and blank for each series of analyses.

Calculation:

$$\% \text{ Starch} = 0.9 \times \frac{M}{10^6} \times \frac{V_1}{1} \times \frac{250}{Vo} \times \frac{100}{E} \times \frac{100}{MS} = 2.25 \times \frac{M \times V_1}{Vo \times E \times MS}$$

in which . . . .

E = the weight in grams of the sample

M = the weight in micrograms of D-glucose obtained from the standard curve.

Vo = the volume in ml of the aliquot from the 250 ml flask.

MS = the percentage dry weight of the sample.

V_1 = the volume in ml after dilution.

Precision:

The standard error of the results of 2 determinations made at the same time on the same sample, and by the same analyst should not exceed 2%.

Footnotes:

1/ For products containing D-glucose and polysaccharides derived from starch with DP less than 14 extraction twice with boiling 80% ethanol and then twice with 80% ethanol at approximately 25°C should be conducted. Ethanol should be completely evaporated since even small amounts will inhibit glucoamylase.

2/ Particular attention should be paid to the source of the glucoamylase. Refer to "Methods in Carbohydrate Chemistry" R.L. Whistler, ed., Academic Press Inc., New York, N.Y., Vol. VI, 1972, pg.102.

3/ Autoclaving of the sample is recommended, and particular attention should be paid to the source of the starch since higher temperatures might be required primarily for high amylase starches.

References:

1. P. Thivend, Ch. Mercier and A. Guilbot in "Methods in Carbohydrate Chemistry". R.L. Whistler, ed., Academic Press, Inc., New York, N.Y., Vol. VI, 1972, pg.100.

APPENDIX B

The Grain Research Laboratory Standard "Remix" Baking Test

<u>Equipment</u>:

1. Mixer - The GRL Mixer (Hlynka and Anderson, 1955) with an open bowl run at 130 rpm.
2. Moulder - The GRL Laboratory Sheeter/Moulder (Kilborn and Irvine, 1963).

All other equipment as for the A.A.C.C. "Straight Dough" Method 10 - 10.

<u>Formula</u>:

Flour (14% moisture basis)		100 g
H_2O distilled		variable
Yeast compressed	3%	1 ml
Sugar	2.5%	25 ml
Salt	1.0%	
Malt syrup (250°L)	0.3%	1 ml
Ammonium phosphate, monobasic	0.1 ppm	1 ml
Potassium bromate	15 ppm	

<u>Procedure</u>:

1. Mix ingredients for 3.5 minutes in GRL mixer. Punch seven times to round dough.
2. Ferment for two hrs forty-five minutes at 30°C.
3. Remix for 2.5 minutes in GRL mixer. Punch seven times.

4. Ferment for twenty-five minutes (recovery time).
5. Sheet 3 times at 11/32 ins., 3/16 ins., and 1/8 ins. spacings, mould and pan.
6. Proof for forty-five minutes at 30°C.
7. Bake for 25 minutes at 221°C (430°F).

Loaf volume, by rapeseed displacement, is measured one-half hour after the bread comes from the oven and scores for loaf appearance, crumb texture, crumb color and assigned the same day.

Baking absorption is estimated by subtracting 2% units from the farinograph absorption (500 B.U. line) and an adjustment is made if the handling properties of the dough requires it.