THE RELATIONSHIP OF DOUGH CHARACTERISTICS AT CONVENTIONAL AND ELEVATED TEMPERATURES TO THE QUALITY OF BREAD MADE BY CONVENTIONAL AND CONTINUOUS PROCESSES

by

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INTRODUCTION

The farinograph is used extensively to estimate the baking absorption and mixing requirements of flour. The instrument was developed during the 1930's well before the advent of continuous mixed bread doughs (12). Consequently the instrument in general use and the procedure for its use (3) corresponds to conventional bread mixing conditions. Temperature was standardized at 30°C. When the amount of water or absorption is adjusted to give a maximum consistency peak of 500 Brabender Units (B.U.), the resulting time to peak, or mixing time, values are of the same order of magnitude as bakery mixing times. However, the commercial development of the continuous breadmaking process in 1954 brought about many changes in the technology of breadmaking (6). To arbitrarily approximate continuous-mix conditions the farinograph would have to be operated at about 40°C.(60).

The present investigation was conducted to study the effect of temperature on physical dough characteristics and to develop a new farinograph procedure and its interpretations to be used in continuous bread production.

REVIEW OF LITERATURE

Physical Dough Testing

Studies on the relationship between temperature and dough properties have not been many. Skovholt and Bailey (65) noted that temperature differences caused plasticity variations in dough of 12 to 40 farinograph units per $1^{o}C$. depending upon the range of consistency. Further light was shed on the subject by Moore and Herman (50) who studied the effect of temperature and absorption on a variety of practical farinogram indices and reported that as the temperature increased, the arrival time decreased, and the stability increased. The consistency of the dough likewise exhibited a very substantial influence on the characteristics of the curve. The effect of variations in absorption and temperature on flour-water farinograms was studied by Bayfield and Stone (9). They observed that at constant absorption, consistency softened with increase in temperature. With consistency held constant, the absorption decreased as the temperature increased. Irvine et al. (37) indicated that at a constant absorption as the temperature of the mixing bowl increased, dough development time decreased, miximum consistency decreased and tolerance index increased. Hlynka (33) extensively studied the effect of temperature, mixer speed and absorption on the characteristics of the farinograph curve of an unbleached hard spring wheat flour. Increasing temperature, increasing mixer speed and reducing the absorption each shortened development time. Increased mixer speed, reduction in temperature and reduction in absorption each increased consistency. In a later paper, Conn and Kichline (15) conducted studies on temperature, mixer speed and salt effects on farinograph characteristics. These workers increased the temperature from $30^{o}C$. to $40^{o}C$. to correspond with the temperature of a continuous-mix dough. They reported that increase in temperature reduced dough consistency and two peaks appeared in the curves made with both hard spring wheat and hard winter wheat flours.

It is generally believed that testing of doughs under continuous mixing fails to give a complete insight into the effects of such factors as fermentation and mechanical or chemical treatment on extensibility and related physical dough properties. A description of the extensigraph, an instrument designed to test extensibility and resistance to extension after various periods of rest was given by Munz and Brabender (52). They indicated that a study of the rate, direction, and magnitude of change in extensibility and resistance to extension after a time of rest would be a valuable aid in classifying flours for specific uses. The same authors (54) concluded that a combination of farinogram and extensigram data serves to classify soft wheat flours as to their adaptability for specific uses. These workers also demonstrated positive relationships between extensigram dimensions, protein content, and various farinogram measurements. Aitken et al.(1) confirmed Munz and Brabender's findings. The former found significant positive relationships between extensigram length, height, and protein content. Work by Merritt and Bailey (49) demonstrated that the extensibility and the curve area decreased with rest time and reworking. Resistance to extension was increased with the stronger flours; with the weak flours, resistance to extension was at a maximum after the second rest period. Extensive studies on the subject were also conducted by Johnson et al.(39). They indicated that extensibility, resistance to extension, and extensigram area were individually positively correlated with protein content, farinogram mixing time, valorimeter value, mixogram area, and height. Extensigram properties were more highly correlated with protein content than with farinogram or mixogram properties. In studying the effect of mixing, salt, and consistency on extensigrams, Fisher, Aitken and Anderson (21) reported that increasing the consistency of dough made the extensigram higher and shorter (decreased extensibility and increased resistance to extension). By contrast, increasing the salt concentration increased both extensibility and resistance to extension. In a recent paper, Brabender (12) stated that extensigraph measures structural parameters of a dough which the farinograph does not detect, namely, the ratio between dough extensibility and dough resistance. This ratio can be influenced by heat conditioning as well as maturing agent.

Dry Milk Solids in Bread

Dry milk solids are a desirable ingredient of bread since they supply valuable proteins, vitamins and minerals and frequently improve the appearance as well as the palatability and keeping quality of the bread. However, dry milk solids influence both the physical properties and baking performance of bread doughs. In studying the effect of temperature and of the inclusion of dry skim milk upon the properties of doughs, Skovholt and Bailey (65) found that inclusion of dry milk solids in wheat flour doughs increased the time required to reach the maximum plasticity as indicated by the farinograph. Moore and Herman (50) also found that dry milk solids when added to the flour and water mixture had a pronounced effect upon the arrival time and stability. In 1940, Ofelt and Larmour (56) studied the effect of milk on the bromate requirements of flour. These workers observed that the addition of dry milk solids created a tolerance to bromate which tended to prevent damage to loaf volume and to grain and texture when relatively large dosages were used. These findings were confirmed by West and Bayfield (84). The presence of 6% dry milk solids in doughs was found to reduce the possibility of damage from an excessive amount of bromate used in baking unbleached or bleached samples of flour. The same authors also indicated that the inclusion of dry milk solids increased the loaf volume and improved the crust and crumb color, grain, and texture. Swanson and Bayfield (73) used three mixing machines and mixing speeds from 50 to 200 r.p.m. to study the effect of mixing speed and dry milk solids on bread volume. These workers reported that at all speeds of the mixers, the relation between mixing time and dry milk solids was linear. At the slower speeds, optimum mixing time increased with increasing amount of dry milk solids. The effect of baking on the nutritive value of proteins in rye bread with and without supplements of nonfat dry milk was studied by Stromnaes and Kennedy (72) in 1957. They found that supplements of milk solids increased the protein efficiency ratio 9% for the bread and 11% for the unbaked ingredients.

Continuous Breadmaking Process

Ever since the first introduction of continuous dough mixing in 1954, its technology has been undergoing a progressive development. The advantages of the continuous-mix process are of considerable significance. First, it results in a greatly improved uniformity of the doughs and breads. Secondly, the continuous production of dough, coupled with continuous dividing, proofing and baking, greatly reduces labor and power requirements. The greater yield of dough and bread and the saving in space are additional advantages (58). A method for the successful production of white bread was reported by Baker (6) in 1954. He suggested the use of a liquid broth or ferment system to replace the conventional sponge of the sponge dough process.

The introduction of continuous-mix laboratory units in 1959 was an important factor in improving methods of continuous-mix production (57). With these scaled-down pilot models, complicated factorially designed experiments could be performed because of reduction of cost of ingredients and less time involved in operation. Reproducability of different laboratory scale continuous doughmaking units was studied by Titcomb et al.(79). They reported that reproducability within a given laboratory could be predicted; however, precision depended on the technique and particular type of unit involved. Johnson and Miller (40) performed various analyses on preferments. Tests to determine utilization of sugar, production of gas, production of acid, and amounts of protease retained in different preferments were performed. These workers found that a flour that produced good bread by the sponge method also produced good bread by the preferment process. A flour of fair baking quality by the sponge process made very poor bread by the preferment process.

Dry milk solids, when properly processed and used at appropriate levels, exerted a perceptible improving effect on such physical properties of the baked product as its volume, grain and texture, flavor, eating qualities and shelf life. However, the use of nonfat dry milk in the production of commercial white bread was being subjected to a reappraisal as a result of the introduction of continuous-mix processes. Initial practical experience with the operation of the continuous-mix process had indicated that the use of the usual levels of nonfat dry milk may yield bread of variable quality(76). Swanson and Sanderson (74) indicated that nonfat dry milk could not be used at the 4 to 6% level. A level of 1 to 2% had been found desirable in pH-buffering. The effects of individual milk proteins on continuous-mix bread were characterized by Baldwin et al.(7) in 1964. Casein had no effect other than dilution. The albumin and globulin fractions weakened and slackened the dough. This effect was somewhat overcome by high heat treatment. The heat treatment was thought to result in insolublization and protein-protein interaction, rendering the groups responsible for dough weakening ineffective. Work by Swortfiguer (76) has indicated that an oxidant ratio of 3 parts KB_rO_3 to 1 part KIO_3 produced the best results in high milk formulas. Calcium acid phosphate was used for lowering the pH of high milk brews.

The type of flour used in continuous-mix bread has been shown to be an important factor. Trum and Rose (80) reported that in calculating absorption an increase of 3% should be added to the farinogram value. They also reported on other farinogram measurements, including arrival time, departure time, and mixing tolerance. These workers found that flours with rapid arrival time produced the best results. Flours with long departure times were found to be undesirable in that throughputs had to be decreased due to the increased mixing and power requirements. When dough properties were measured at 38°C. with a farinograph, certain dough characteristics such as medium mixing tolerance with a relatively short departure time were shown to be superior for use in the continuous breadmaking process. Schiller (62) extensively studied the subject of flour requirements for continuous breadmaking. He compared the time involved in various steps of the continuous breadmaking process with the time for similar steps for the sponge dough process and concluded that the fermentation and mixing times are shorter in the continuous doughmaking process than in the conventional process, therefore greater stresses are placed on the flour. A study of optimum developer speed as related to absorption, oxidation level, and starch damage was performed by Schiller and Gillis (61). It was found that as absorption increased, developer speed had to be increased; oxidation level was also directly related to optimum developer speed. As starch damage was increased, optimum developer speed increased. Increasing starch damage also decreased tolerance and drastically affected quality of the bread.

The fats used for the production of continuous-mix bread are also important. In addition to the fats naturally present in flour, continuous-mix bread formulations generally contain 2 to 5% additional fat. Baldwin, et al. (8) found that a hard fat fraction was necessary; however, it was found that its addition in an emulsified or hydrated state produced much better results than when it was melted for addition.

MATERIALS AND METHODS

Flour Data

Several commerical flours obtained from four milling companies were used. Each had been bleached and supplemented with enzymes for breadmaking. The types, sources of flour and the analyses, corrected to a 14% moisture basis, were as follows:

Sample	Flour Type	Source	Protein (%)	Ash (%)
1	Hard winter wheat	Bay State Milling Co.	11.7	.41
2	50% Northern spring and 50% Hard winter wheats	The Pillsbury Co.	11.9	.41
3	75% Northern spring and 25% Hard winter wheats	The Pillsbury Co.	12.4	.43
4	Hard red winter wheat (Kansas)	The Pillsbury Co.	11.4	.41
5	Hard winter wheat	Peavey Co.	11.3	.45
6	Hard winter wheat Hard spring wheat	Peavey Co.	12.1	.45
7	Hard red spring wheat	Peavey Co.	14.8	.55
8	Spring and winter wheats	The Colorado Milling & Elevator Co.	12.0	.44
9	Hard winter wheat	The Colorado Milling & Elevator Co.	11.8	.44
10	Spring wheat	The Colorado Milling & Elevator Co.	12.3	.39
11	Hard red winter wheat Hard red spring wheat	The Colorado Milling & Elevator Co.	12.3	.40
12	Hard red winter and 25% Hard red spring wheats	The Colorado Milling & Elevator Co.	12.2	.40
Control	Hard red winter wheat	Kansas State Univ.	11.4	.40

Sample	Flour Type	Source	Protein (%)	Ash (%)
Balancer	High gluten hard red spring wheat	The Pillsbury Co.	16.9	.49
7+C	50% sample 7 + 50% control		14.0	.47
7+B	50% sample 7 + 50% balancer		16.7	.52
12+C	50% sample 12 + 50% control		12.6	.40
12+B	50% sample 12 + 50% balancer		14.9	.46

Physical Dough Testing

I. Farinograph:

A farinograph, with a 300 gram stainless steel bowl was operated at 63 r.p.m. and at a temperature of 30°C. Approved method no. 54-21 of the American Association of Cereal Chemists (3) was used. For the temperature study, the temperature was adjusted to 40°C. by controlling the temperature of a circulating water bath. Three hundred grams of flour at 14% moisture basis were used when testing samples. For nonfat dry milk (NFDM) study, 3% NFDM based on flour as 100% was added. The values for the following interpretations of farinograph curves were recorded (45):

1. Absorption: Obtained as the amount of water necessary or required to center the farinograph curve on the 500 B.U. line for a flour-water dough.
2. Arrival Time: The time required for the top of the curve to reach the 500 B.U. line after the mixer has been started and water introduced.
3. Peak Time: The time required for the curve to reach its full development or maximum consistency.
4. Stability: The time that the curve remained on the 500 B.U. line and was measured from the arrival time to the departure time.
5. Departure Time: The time that the top of the curve left the 500 B.U. line.
6. Mixing Tolerance Index (M.T.I.): Measured in B.U. from the height of the curve at its peak time to the height of the curve five minutes after the peak.
7. Time-to-breakdown: The time from the start of the mixing to a decrease of 30 units from the peak point.
8. Valorimeter Value: A numerical value based on a logarithmic function of

the peak time in relation to the breakdown of the dough 12 minutes after peak time. The valorimeter value was determined by placing a logarithmic template over the farinograph curve and noting where the lines intersected.

II. Extensigraph:

All doughs were mixed in the large farinograph bowl to a 500 unit consistency at 30°C. or 40°C. with or without 3% NFDM. Then the offical method no. 54-10 of the American Association of Cereal Chemists (2) was used. The values for the following extensigraph measurements were recorded:

1. Resistance to Extension: Height of curve in Extensigraph Units at 50 mm. after the curve was started on Kymograph chart.
2. Extensibility: Total length of curve in mm.
3. Energy: The area surrounded by the curve was measured by means of a planimeter and recorded in cm^2.
4. The Ratio Figure: Resulting from the relation that exists between the resistance to extension and the extensibility.

i.e. $$\frac{\text{Resistance to Extension}}{\text{Extensibility}}$$

Baking Methods

Flours used in baking were samples 7, 12, control, balancer, 7+C, 7+B, 12+C and 12+B. Flours 7 and 12 were chosen for baking test because they present two different types of farinograph curves. Flour 7 had a short curve with short stability and a short peak whereas flour 12 gave a long curve.

A weak flour milled from a hard red winter wheat blend on the Kansas State University pilot mill was used as a control. Another flour milled from a high gluten hard red spring wheat blend, obtained from the Pillsbury Company, was used as a balancer. Flours 7 and 12 were blended individually with the control and with the balancer, each at one to one ratio on the blending system of the Kansas State University pilot mill. The resultant, 7+C, 7+B, 12+C, and 12+B were also used in the baking studies. Farinograph absorptions were 66.4, 63.9, 59.4, 67.0, 63.0, 63.2, 62.0 and 66.8 for flours 7, 12, control, balancer, 7+C, 7+B, 12+C and 12+B, respectively.

I. Sponge dough method:

A typical sponge-dough formulation was used (Table 1). The sponge was mixed with 70% of the total water for two minutes. The mixture was then placed into a fermentation pan and put into the fermentation cabinet at 86^{o}F. and 86% humidity for four hours. After the fermentation period the sponge and dough with the remaining water were remixed in a Hobart A-200 mixer. Three mixing times, optimum, 1.5 min. under- and 2.5 min. over-optimum, were used. After twenty minutes in the fermentation cabinet each dough was divided and scaled at 510 grams. The two scaled dough pieces were rounded by hand and given a twenty minute rest period before being moulded on a moulder. The moulded doughs were panned and placed into the proof box for 55 minutes at

98% humidity and 105°F. The bread was baked at 425°F. for 25 minutes in a gas reel oven. The finished baked product was allowed to cool for several hours before the volume (seed displacement) and weight were recorded.

Three pieces of dough were made from each flour at optimum, 1.5 min. under- and 2.5 min. over-optimum mixing times. Each dough was divided into two loaves, so a total of 36 loaves were baked. One day following baking, eighteen loaves of bread were evaluated for total score, symmetry, break and shred, grain, crumb texture and penetrometer value. The duplicates of these loaves was placed in the freezer (-10°F.) for storage.

II. Continuous-mix process:

An AMF laboratory continuous pilot dough making unit was used in this study. It was a completely integrated unit that consisted of component parts that made up a complete doughmaking system. The system consisted of two 30-gallon jacketed brew tanks with high- and low- speed agitators for mixing the ingredients. After the brew had fermented for 2 hours, it was pumped by a positive displacement pump into a holding tank. This holding tank and five other ingredient tanks were connected to separated variable speed pumps that allowed metering of the ingredients into the premixer. Flours were fed by two volumetric feeders on a track system above the incorporator which allowed changing flours without recalibration. The five ingredient tanks were used for other ingredients not included in the brew. These ingredients were oxidant solution, sugar, shortening, salt and malt. From the incorporator, the ingredients entered a positive displacement pump and were pumped to a variable speed developer head. The dough was given final development at this stage. The dough was then extruded and cut off by a semi-automatic cut-off device. Eight flours, four mixing speeds and an oxidation level of 65 p.p.m.

were used (Table 2). A typical formula for continuous-mix white bread was used (Table 3).

Table 1. Sponge Bread Formula

Sponge		
Ingredient	%*	Grams
Flour	70.0	490.0
Yeast food**	0.5	3.5
Malt	0.5	3.5
Yeast	2.5	17.5
Water***	70.0 of total	variable
Dough		
Flour	30.0	210.0
Sugar	6.0	42.0
Salt	2.0	14.0
Shortening	3.0	21.0
Water***	30.0 of total	Variable

* All ingredients based on flour 100% (700 grams).

** Arkady.

*** The total amount of water used was according to farinograph absorptions.

Table 2. Mixing Speeds and Dough Temperatures of Continuous Doughmaking Process.

Sample	Mixing Speed (r.p.m.)				Dough Temp. (F^o)			
	1	2	3	4	1	2	3	4
7	195	218	240	265	95	98	100	102
12	170	195	218	240	97	100	102	103
Control	120	143	166	190	87	94	91	95
Balancer	195	218	240	265	96	98	99	101
7+C	170	210	223	250	94	95	101	104
7+B	170	195	218	240	97	99	101	102
12+C	175	200	222	245	92	95	96	98
12+B	170	195	218	240	95	96	100	101

Table 3. Continuous-Mix White Bread Formula.

Ingredients	% **	Phase I***	Phase II****	Mixing Phase
Flour	100.0			100.0
Water	Table 4			
Sugar	7.0	1.0		6.0
Yeast	3.5	3.5		
Shortening				3.5
Salt	2.0		2.0	
Yeast food*	0.5	0.5		
Malt flour	0.15	0.15		
Inhibitor	0.15		0.15	
Oxidation	65p.p.m.		65 p.p.m.	

* Arkady.

** All ingredients based on flour 100%.

*** Initial ingredients of the liquid sponge.

**** Included ingredients added to the liquid sponge after 1 hour and 45 minutes fermentation.

Table 4. The Absorption Used in The Continuous-Mix Bread Formulae.

Samples	Absorption(%)	Phase I (%)	Phase II(%)	Mixing Phase(%)
7	69.4	47.0	4.0	18.4
12	66.9	47.0	4.0	15.9
Control	62.4	47.0	4.0	11.4
Balancer	70.0	47.0	4.0	19.0
7+C	66.0	47.0	4.0	15.0
7+B	66.2	47.0	4.0	15.2
12+C	65.0	47.0	4.0	14.0
12+B	69.8	47.0	4.0	18.8

Objective Scoring Methods

I. Bread scoring procedure:

A standard scoring system was designed that included six characteristics. The maximum score possible with this system was 100. A specific volume of 7.2 or greater was considered optimum and given the maximum score of 20 points. The scores for specific volume are shown in Table 5. The other characteristics scored included a maximum of 10 points each for symmetry, break and shed; and a maximum of 20 points each for grain, crumb texture and penetrometer values.

A. Specific volume: The specific volume was obtained by dividing loaf volume in cc's by the loaf weight in grams.

B. Internal loaf score: The internal loaf score was a combination of the individual score of grain, crumb texture and penetrometer value.

C. Total loaf score: The total loaf score was a combination of the six other individual scores. The maximum total score was 100 points.

II. Penetrometer determinations:

The penetrometer value was carried out using a Precision Penetrometer to measure the compressability of bread after it had been bagged and stored 1,3, or 5 days at room temperature. The penetrometer was calibrated into one-tenth millimeter divisions. A thick slice of bread was placed beneath the steel, cone shaped disc. The disc and a connecting rod were lowered until the point of the disc came into contact with the product. The rod was then released allowing the disc to drop onto the product. The compressability was recorded in tenths of a millimeter from both sides of the slice in triplicate for each loaf of bread. The scores for penetrometer values are shown in Table 6 and Table 7.

Table 5. The Scores for Specific Volume of Bread

Specific Volume (cc/gm.)	Loaf Score (pts.)
7.2 or greater	20
7.0	18
6.8	16
6.6	14
6.4	12
6.2	10
6.0	8
5.8	6
5.6	4
5.4	2
5.2 or less	0

Table 6. The Scores for Penetrometer Values of Continuous Bread

Penetrometer Value, 1 day (o.1 millimeter)	Loaf Score (pts.)
230 or greater	20
220	18
210	16
200	14
190	12
180	10
170	8
160	6
150	4
140	2
130 or less	0

Table 7. The Scores for Penetrometer Values of Sponge Bread

Penetrometer Value, 1 day (o.1 millimeter)	Loaf Score (pts.)
130 or greater	20
125	18
120	16
115	14
110	12
105	10
100	8
90	6
80	4
70	2
60 or less	0

Statistical Analyses

All characteristics of farinogram, extensigram and baking results were subjected to analysis of variance method. Simple linear correlations between stability, valorimeter value at both 30°C. and 40°C. and total loaf scores obtained from continuous-mix process were calculated. Multiple linear correlations between total loaf score of continuous-mix bread and stability and valorimeter value of farinogram at both 30°C. and 40°C. were established.

RESULTS AND DISCUSSION

For convenience in presentation, the experimental results have been divided into three major sections. The first section deals with the effect of temperature on dough properties, the second with the effect of nonfat dry milk (NFDM) in doughs, and the last with the effect of baking methods.

I. Effect of Temperature:

A. Effect of temperature on farinograph characteristics:

1. Absorption:

Statistical analysis for absorption of farinograms (Table 8) showed that, at constant maximum dough consistency, a higher temperature of mixing gave a lower farinograph absorption, i.e., with consistency held constant, the absorption decreased as the temperature increased (Table 9). These results appear to corroborate the conclusions of Bayfield and Stone (9). It may be inferred that as the temperature of the dough increases the amount of "bound" water decreases and, therefore, the amount of absorption for a fixed consistency decreases (31,33). This interpretation helps to provide a reasonable explanation as to why the absorption of the dough decreases with increasing temperature.

2. Arrival time:

Arrival times measured from farinograms produced at 40°C. were shorter than those produced at 30°C. (Table 9). No differences were found due to flour types (Table 10).

3. Peak time:

There were significant differences due to flour types and mixing temperatures (Table 11). The same type of flour processed at 30°C. or 40°C.

gave different peak times. The former temperature caused significantly longer peak times than the latter (Table 9).

4. Mixing tolerance index (MTI):

Significant differences resulted from the use of different mixing temperatures and flour types (Table 12). Farinograms produced at 40°C. showed very fast break-down after the dough had reached its full development time (high MTI values) (Table 9). Control, flours 4, 5 and 12+C had less tolerance to mixing than other flours (Table 13).

5. Stability:

It was found that high mixing temperature caused a great decrease in stability (Table 9). Differences were also found due to flour types (Table 14). Balancer, flours 10, 11, 12 and 12+B had longer stabilities while the control had the shortest (Table 13).

6. Valorimeter value:

Statistical analysis indicated that 40°C. mixing temperature caused a decrease in valorimeter values (Table 9). The analysis of variance of valorimeter value data is reported in Table 15.

7. Time-to-breakdown:

All farinograms produced at 30°C. gave higher time-to-breakdown values than those produced at 40°C. Results are shown in Table 16 and Table 9.

Table 8. The Analysis of Variance of Absorption

Source of Variance	Degree of Freedom	Mean Squares	F
Flours	17	14.5845	27.2047**
Temperatures	1	175.5000	327.3616**
NFDM	1	21.5625	40.2207**
F x T	17	0.1618	0.3017ns
F x NFDM	17	0.3566	0.6652ns
T x NFDM	1	0.6875	0.0000ns
Error	17	0.5361	
Total	71		

** Significant at 1% level.

ns Not significant at 5% level.

Table 9. Effect of Mixing Temperature on Farinogram

Characteristic	30°C.	40°C.	LSD 0.05
Absorption	63.9583	60.8527	0.3641
Arrival Time	2.1528	1.2708	0.2749
Peak Time	7.5556	2.3611	0.4503
Stability	13.7222	3.9236	0.8573
Mixing Tolerance Index	30.9722	99.0277	3.8117
Valorimeter Value	58.2500	24.3333	1.9152
Time-to-breakdown	15.3056	4.4375	0.8345

Table 10. The Analysis of Variance of Arrival Time

Source of Variance	Degree of Freedom	Mean Squares	F
Flours	17	0.9617	3.1467ns
Temperatures	1	14.0009	45.8131**
NFDM	1	3.6675	12.0008**
F x T	17	0.5266	1.7231ns
F x NFDM	17	0.2595	0.8490ns
T x NFDM	1	2.2578	7.3878*
Error	17	0.3056	
Total	71		

ns Not significant at 5% level.

** Significant at 1% level.

* Significant at 5% level.

Table 11. The Analysis of Variance of Peak Time

Source of Variance	Degree of Freedom	Mean Squares	F
Flours	17	4.5221	5.5154**
Temperatures	1	485.6804	592.3928**
NFDM	1	40.5000	49.3990**
F x T	17	3.6475	4.4489**
F x NFDM	17	0.5515	0.6726ns
T x NFDM	1	40.5000	49.3984**
Error	17	0.8197	
Total	71		

ns Not significant at 5% level.

** Significant at 1% level.

Table 12. The Analysis of Variance of Mixing Tolerance Index

Source of Variance	Degree of Freedom	Mean Squares	F
Flours	17	481.6174	8.1989**
Temperatures	1	83,368.0000	1,419.2244**
NFDM	1	2,112.5000	35.9624**
F x T	17	151.1571	2.5731*
F x N	17	54.4118	0.9263ns
T x N	1	88.8867	1.5132ns
Error	17	58.7419	
Total	71		

* Significant at 5% level.

** Significant at 1% level.

ns Not significant at 5% level.

Table 13. Effect of Flour Types on Farinogram

Sample	Absorption (%)	Peak (Min.)	Stability (Min.)	Valorimeter Value (B.U.)	Time-to-breakdown (min.)
1	61.4000fgh	4.8125bcde	8.7500bcd	39.5000cde	10.0625bcd
2	62.9250de	4.2500de	7.7500bcde	38.5000cde	8.6875de
3	63.5500cd	4.6875cde	8.3750bcd	41.5000bcde	9.2500bcde
4	60.3500h	4.8750bcde	7.3125cde	40.0000cde	8.3125de
5	61.6750fg	4.8750bcde	7.2500de	41.0000cde	8.0000e
6	61.7500efg	3.9375e	8.0000bcd	36.2500e	9.1250bcde
7	64.5000bc	4.8750bcde	8.4375bcd	43.5000bcd	9.5625bcde
8	61.1250gh	5.1250bcde	8.6875bcd	42.7500bcd	9.9375bcde
9	61.2750fgh	5.1250bcde	7.5625bcde	42.7500bcd	8.8750cde
10	62.0250efg	5.5000bc	10.1250b	45.2500ab	11.2500bc
11	61.4250fgh	5.6250bc	10.1250b	45.0000abc	10.8750bcd
12	62.2750ef	5.7500bc	9.8750bc	44.7500abc	11.2500bc
Control	58.8250i	2.2500f	5.2500e	23.7500f	5.7500f
Balancer	66.1470a	7.5625a	18.0000a	49.7500a	18.5000a
7+C	62.2000efg	4.5625cde	8.8750bcd	40.5000cde	9.0000bcde
7+B	64.7750ab	5.1875bcd	8.1875bcd	43,7500bcd	9.9375bcde
12+C	61.2750fgh	4.1875de	6.8750de	37.5000e	7.8125e
12+B	65.8000a	6.0625b	9.3750bcd	47.2500b	11.5000b
$LSD_{0.05}$	1.0924	1.3509	2.5719	5.7458	2.5028

Values designated by the same lower case letter are not significantly different at the 5% level as determined by Fisher's LSD.

Table 14. The Analysis of Variance of Stability

Source of Variance	Degree of Freedom	Mean Squares	F
Flours	17	26.9490	9.0691**
Temperatures	1	1,728.2295	581.6001**
NFDM	1	64.6953	21.7719**
F x T	17	20.0830	6.7585**
F x NFDM	17	4.0299	1.3562ns
T x NFDM	1	54.6885	18.4043**
Error	17	2.9715	
Total	71		

ns Not significant at 5% level.

** Significant at 1% level.

Table 15. The Analysis of Variance of Valorimeter Value

Source of Variance	Degree of Freedom	Mean Squares	F
Flours	17	123.4191	8.3218**
Temperatures	1	20,706.1250	1,396.1492**
NFDM	1	946.1250	63.7942**
F x T	17	79.8309	5.3828**
F x NFDM	17	13.0074	0.8771ns
T x NFDM	1	946.1250	63.7942**
Error	17	14.8309	
Total	71		

** Significant at 1% level.

ns Not significant at 5% level.

Table 16. The Analysis of Variance of Time-to-breakdown

Source of Variance	Degree of Freedom	Mean Squares	F
Flours	17	26.6608	9.4717**
Temperatures	1	2,126.6625	755.3162**
NFDM	1	102.1250	36.2815**
F x T	17	20.6755	7.3453**
F x NFDM	17	3.4586	1.2287ns
T x NFDM	1	76.5703	27.2028**
Error	17	2.8148	
Total	71		

** Significant at 1% level.

ns Not significant at 5% level.

EXPLANATION OF PLATE I

Farinograms produced at 30^{o}C.


FARINOGRAM
30°C
FLOUR 1
FLOUR 2
FLOUR 3
FLOUR 4
FLOUR 5
FLOUR 6
FLOUR 7
FLOUR 8
FLOUR 9
FLOUR 10
FLOUR 11
FLOUR 12
CONTROL
BALANCER
7+C
7+B
12+B
12+C

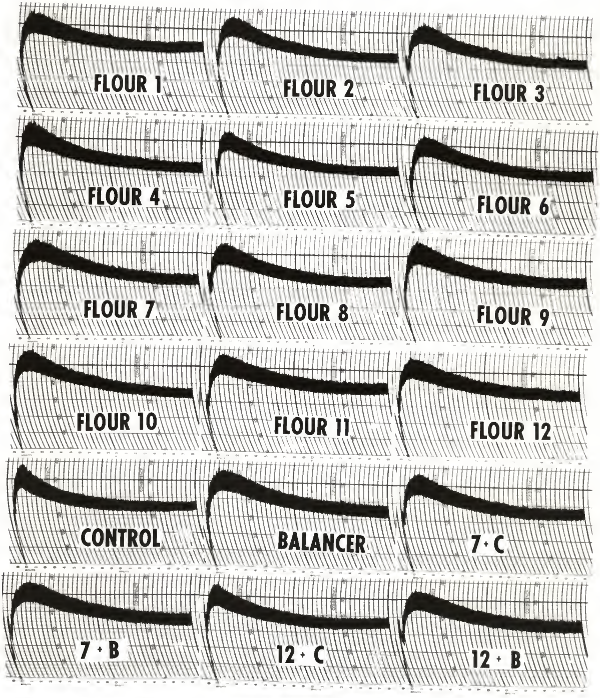
EXPLANATION OF PLATE II

Farinograms produced at 40°C.

PLATE II

FARINOGRAM

40°C



B. Effect of temperature on extensigraph characteristics:

1. Resistance to Extension:

Statistical analysis indicated that doughs produced at 40°C. had higher resistance to extension than doughs produced at 30°C. (Table 17). Extensigrams of the same piece of dough taken after a 135-minute rest period gave the highest value (Table 18). The analysis of variance of resistance to extension is shown in Table 19.

2. Extensibility:

There were significant differences due to mixing temperatures, rest periods and flour types (Table 20). High mixing temperature caused increase in extensibility (Table 17). Extensigrams taken after a 45-minute rest period gave the highest values (Table 18). Balancer, flours 7 and 7+B had high extensibilities while the control, 12+C and 12 had low ones (Table 21).

3. Energy:

It was found that high mixing temperature increased energy significantly (Table 17). Extensigrams taken after a 90-minute rest period had the highest over-all energy values (Table 18), however no significant difference in energy was found between doughs after 90- and 135-minute rest periods when doughs were mixed at 40°C. The analysis of variance of energy is shown in Table 22.

4. Ratio figure:

Statistical analysis showed that differences were due to flour types, rest periods and mixing temperatures (Table 23). High mixing temperature caused a decrease in ratio figure (Table 17). A rest period of 135 minutes gave the highest figure (Table 18). Extensigrams taken from flour 7 indicated only slight increase in ratio figure after each rest period. On the other hand, the control gave a large increase after each rest period, especially at 40°C.

Table 17. Effect of Mixing Temperature on Extensigrams

Temperature	Resistance to Extension (B.U.)	Extensibility (mm.)	Energy (cm^2)	Ratio
30°C.	450.1852	169.8380	135.4119	2.8076
40°C.	483.6111	189.7269	181.2739	2.6609
LSD 0.05	18.6646	2.4781	2.0433	0.0763

Table 18. Effect of Rest Period on Extensigrams

Rest Period (min.)	Resistance to Extension (B.U.)	Extensibility (mm.)	Energy (cm^2)	Ratio
45	363.4028	198.3611	146.3761	1.8614
90	501.2500	174.7917	165.9399	2.9275
135	536.0417	166.1944	162.7128	3.4139
LSD 0.05	22.8594	3.0350	2.5025	0.0934

Table 19. The Analysis of Variance of Resistance to Extension

Source of Variance	Degree of Freedom	Mean Squares	F
Flours	17	62,970.1525	13.7942**
Rest Periods	2	600,198.0324	131.4786**
F x R	34	5,971.5618	1.3081ns
Temperatures	1	60,333.7963	13.2167**
F x T	17	4,503.6492	0.9866ns
R x T	2	57,872.3380	12.6774**
F x R x T	34	3,914.9850	0.8576ns
NFDM	1	39,744.9074	8.7065**
F x N	17	6,116.7211	1.3399ns
R x N	2	8,886.9213	1.9468ns
F x R x N	34	3,714.6174	0.8137ns
T x N	1	10,556.0185	2.3124ns
F x T x N	17	9,846.9499	2.1571*
R x T x N	2	9,993.1713	2.1891ns
Error	34	4,564.9850	
Total	215		

ns Not significant at 5% level.

** Significant at 1% level.

* Significant at 5% level.

Table 20. The Analysis of Variance of Extensibility

Source of Variance	Degree of Freedom	Mean Squares	F
Flours	17	2,217.0896	27.5523**
Rest Periods	2	19,969.5046	248.1662**
F x R	34	91.0328	1.1313ns
Temperatures	1	21,360.6667	265.4545**
F x T	17	704.2353	8.7517**
R x T	2	5,458.4306	67.8333**
F x R x T	34	44.2308	0.5497ns
NFDM	1	872.0185	10.8368**
F x N	17	128.5970	1.5981ns
R x N	2	18.0046	0.2238ns
F x R x N	34	78.1014	0.9706ns
T x N	1	0.1157	0.0014ns
F x T x N	17	210.9589	2.6216**
R x T x N	2	75.8935	0.9423ns
Error	34	80.4683	
Total	215		

ns Not significant at 5% level.

** Significant at 1% level.

Table 21. Effect of Flour Types on Extensigrams

Sample	Resistance to Extension (B.U.)	Extensibility (mm.)	Energy (cm^2)	Ratio
1	398.7500ghi	178.8750cd	135.0892h	2.2867hi
2	376.6667i	187.4167bc	134.3433h	2.0675i
3	392.5000hi	185.0833c	142.1150g	2.1667hi
4	431.2500fgh	186.2083bc	149.9058f	2.1875hi
5	445.4167efgh	177.4167de	145.4258fg	2.5725fg
6	400.8333ghi	183.9583cd	139.8808gh	2.2442hi
7	353.7500i	209.0833a	156.2250de	1.7217j
8	426.2500fghi	176.9167de	139.5275gh	2.4917fg
9	450.0000ef	173.4167e	144.1133fg	2.7250ef
10	461.6667def	176.5833de	150.3775ef	2.7333ef
11	446.2500efg	184.7500c	162.9617d	2.3708gh
12	494.5833cde	172.1667e	154.1933e	3.0325cd
Control	517.9167bcd	150.2083f	142.6417g	4.1600a
Balancer	566.2500ab	194.2917b	222.4567a	3.0283cd
7+C	558.3333ab	175.2500e	183.2433c	3.2767bc
7+B	549.1667ab	194.2083b	212.3200b	2.9250de
12+C	590.4167a	154.0417f	153.3408e	4.0167a
12+B	544.1667abc	176.2083de	182.0117c	3.2100b
$LSD_{0.05}$	55.9938	7.4342	6.1299	0.2289

Values designated by the same lower case letter are not significantly different at the 5% level as determined by Fisher's LSD.

Table 22. The Analysis of Variance of Energy

Source of Variance	Degree of Freedom	Mean Squares	F
Flours	17	7,833.7563	143.1853**
Rest Periods	2	7,920.4927	144.7708**
F x R	34	100.6473	1.8396**
Temperatures	1	113,579.1692	2,076.0005**
F x T	17	662.6857	12.1126**
R x T	2	2,677.1048	48.9321**
F x R x T	34	87.7968	1.6048ns
NFDM	1	1,643.5805	30.0414**
F x N	17	385.2743	7.0420**
R x N	2	1,067.1059	19.6691**
F x R x N	34	121.9500	2.2290**
T x N	1	4,649.0017	84.9745**
F x T x N	17	553.2900	10.1130**
R x T x N	2	274.8310	5.0236**
Error	34	54.7106	
Total	215		

ns Not significant at 5% level.

** Significant at 1% level.

Table 23. The Analysis of Variance of Ratio

Source of Variance	Degree of Freedom	Mean Squares	F
Flours	17	5.0530	66.2557**
Rest Periods	2	45.4011	595.3092**
F x R	34	0.4787	6.2766**
Temperatures	1	1.1616	15.2312**
F x T	17	0.8531	11.1864**
R x T	2	5.7588	75.5103**
F x R x T	34	0.1386	1.8177*
NFDM	1	3.8774	50.8417**
F x N	17	0.2932	3.8447**
R x N	2	0.5514	7.2297**
F x R x N	34	0.1195	1.5668ns
T x N	1	0.5460	7.1595**
F x T x N	17	0.5079	6.6603**
R x T x N	2	0.0988	1.2948ns
Error	34	0.9763	
Total	215		

ns Not significant at 5% level.

** Significant at 1% level.

II. Effect of nonfat dry milk:

A. Effect of nonfat dry milk on farinograms:

The analysis of variance are shown in Tables 8, 11, 12 and 14 through 16. It was found that 3% nonfat dry milk in doughs caused increases in absorption, arrival time, peak, stability, time-to-breakdown and valorimeter value (Table 24). The dough containing 3% nonfat dry milk also had significantly more mixing tolerance (low mixing tolerance index) than did the product which did not contain nonfat dry milk. However, these increases were not significant when doughs were produced at 40°C.

B. Effect of nonfat dry milk on extensigrams:

The addition of 3% nonfat dry milk to doughs resulted in increases in resistance to extension and ratio figure, but led to significant decreases in energy and extensibility (Table 25). The analyses of variance are shown in Tables 19, 20, 22 and 23.

Table 24. Effect of NFDM on Farinograms

Characteristics	Without NFDM	With 3% NFDM	$LSD_{0.05}$
Absorption	61.8833	62.9277	0.3641
Arrival time	1.4861	1.9375	0.2749
Peak	4.2083	5.7083	0.4503
Stability	7.8750	9.7708	0.8573
Mixing tolerance index	70.4167	59.5833	3.8117
Valorimeter value	37.6667	44.9167	1.9153
Time-to-breakdown	8.6808	11.0625	0.8345

Table 25. Effect of NFDM on Extensigrams

Treatment	Resistance to Extension(B.U.)	Extensibility (mm.)	Energy (cm^2)	Ratio
Without NFDM	453.3333	181.7917	161.1014	2.6003
With 3% NFDM	480.4630	177.7732	155.5844	2.8682
$LSD_{0.05}$	18.6646	2.4781	2.0433	0.0763

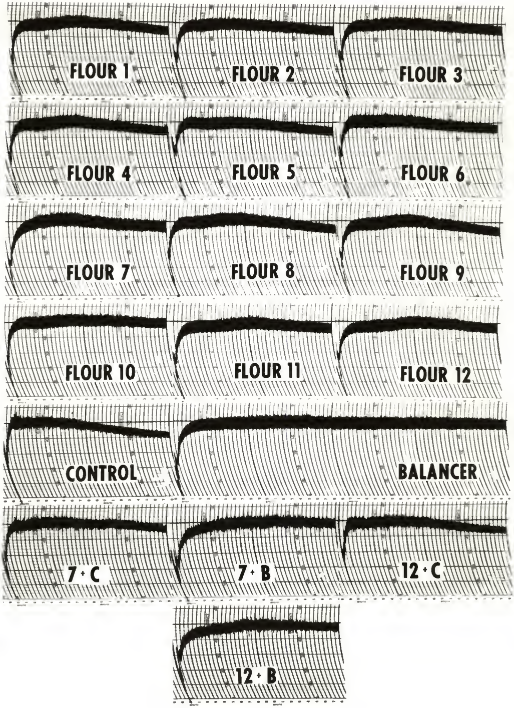
EXPLANATION OF PLATE III

Farinograms produced from doughs containing 3% nonfat dry milk at 30°C.

PLATE III

FARINOGRAM

30°C WITH 3% NFDM



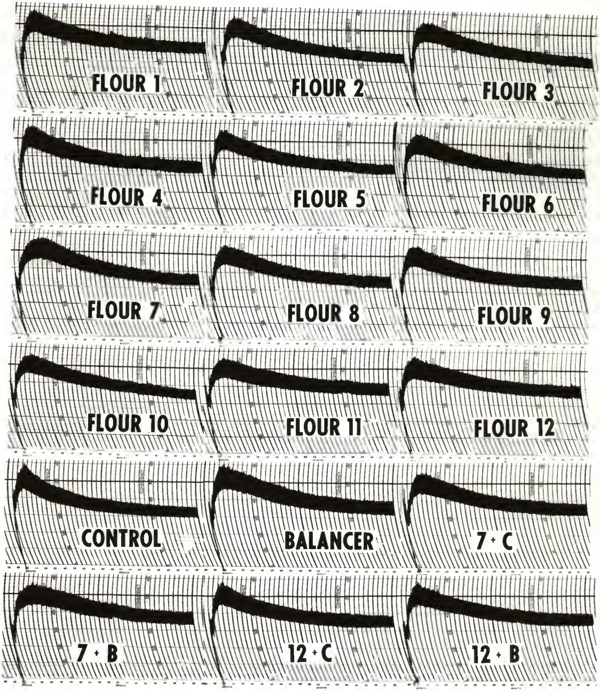
EXPLANATION OF PLATE IV

Farinograms produced from doughs containing 3% nonfat dry milk at 40°C.

PLATE IV

FARINOGRAM

40°C WITH 3% NFDM



III. Effect of baking methods

A. Continuous doughmaking process:

1. Specific volume:

The statistical analysis for specific volume of bread indicated no significant difference due to mixing speeds (Table 26). However, significant difference was found due to flour types. The control and flours 12, 7+C and 12+C produced breads with significantly better specific volumes than did the other flours. Results are shown in Table 27.

2. Internal loaf score:

Statistical analysis of the internal loaf score indicated no difference due to flour types or mixing speeds (Table 28).

3. Total loaf score:

The analysis for total loaf score showed no significant differences due to mixing speeds (Table 29). However, significant difference was found due to flour types. Loaves produced from 7, 7+B and the balancer gave lower scores while loaves produced from the control gave the highest one (Table 27).

4. Penetrometer value:

There were significant differences due to flour types, mixing speeds and days of storage (Table 30). Breads made with mixing at the lowest r.p.m. gave superior penetrometer values (Table 31). Loaves baked from 12+B, the control, 7+C, 7+B and 12+C gave significantly higher values than loaves baked from other flours (Table 27). Penetrometer readings taken after the third day of storage indicated that different rates of staling had occurred in breads made from different types of flours. After six days of storage, the product maintaining the greatest compressability was found to be the bread made from 12+B.

Table 26. The Analysis of Variance of Specific Volume of Continuous Bread

Source of Variance	Degree of Freedom	Mean Squares	F
Flours	7	0.9756	15.6530**
Mixing speeds	3	0.0037	0.0601ns
Error	21	0.0623	
Total	31		

** Significant at 1% level.

ns Not significant at 5% level.

Table 27. Effect of Flour Types on Continuous-mix Bread

Sample	Specific Vol. (cc/gm.)	Total Loaf Score (pts.)	Penetrometer Value(0.1 mm.)
7	5.6250a	31.0000a	111.7500a
12	6.9500b	62.5000b	133.5833b
Control	7.1000b	62.7500b	147.0000cd
Balancer	6.0750e	53.0000b	137.5000bc
7+C	6.7250c	57.5000b	144.7500cd
7+B	6.2000e	49.0000c	140.4167bcd
12+C	6.5750cd	56.2500b	139.2500bcd
12+B	6.2000e	56.0000b	150.1667d
LSD 0.05	0.3672	13.5419	11.4185

Values designated by the same lower case letter are not significantly different at the 5% level as determined by Fisher's LSD.

Table 28. The Analysis of Variance of Internal Loaf Score of Continuous Bread

Source of Variance	Degree of Freedom	Mean Squares	F
Flours	7	116.8571	2.3173ns
Mixing speeds	3	99.0000	1.9632ns
Error	21	50.4286	
Total	31		

ns Not significant at 5% level.

Table 29. The Analysis of Variance of Total Loaf Score of Continuous Bread

Source of Variance	Degree of Freedom	Mean Squares	F
Flours	7	413.2141	4.8743**
Mixing speeds	3	120.4167	1.4204ns
Error	21	84.7738	
Total	31		

** Significant at 1% level.

ns Not significant at 5% level.

Table 30. The Analysis of Variance of Penetrometer Value of Continuous Bread

Source of Variance	Degree of Freedom	Mean Squares	F
Flours	7	1,698.5266	8.8069**
Mixing speeds	3	1,650.6665	8.5688**
Day	2	53,665.0000	278.2542**
M x F	21	605.9045	3.1416**
M x D	6	347.1665	1.8001ns
F x D	14	616.0044	3.1940**
Error	42	192.8631	
Total	95		

** Significant at 1% level.

ns Not significant at 5% level.

Table 31. Effect of Mixing Speeds on Continuous Bread Characteristics

Speeds*	Total Loaf Score(pts.)	Internal Loaf Score(pts.)	Specific Vol. (cc/gm.)	Penetrometer Value (0.1mm.)
1	55.6250	35.7500	6.4375	150.1250
2	51.3750	31.7500	6.4375	134.6250
3	49.2500	29.0000	6.4000	131.3333
4	57.7500	36.5000	6.4500	136.1250
LSD 0.05	9.5756	7.3854	0.2596	8.0741

Actual number of r.p.m. are shown in Table 2.

EXPLANATION OF PLATE V

Loaves produced by continuous-mix process.

PLATE V


CONTINUOUS MIX PROCESS
RPM
20
OPTIMUM
20
40
CONTROL
BALANCER
12
7
12 · B
12 · C
7 · B
7 · C

B. Sponge dough method:

1. Specific volume:

There were significant differences due to flour types and mixing times (Table 32). All breads made under optimum and over-optimum mixing times gave higher scores for all flour types (Table 33). Products of 7, 7+B, 12+B, balancer and 12 gave higher specific volumes than did the other flours. The control gave the lowest score (Table 34).

2. Internal loaf score:

Significant differences were found due to flour types and mixing times (Table 35). Loaves produced at optimum and over-optimum mixing times gave superior scores (Table 33). Products of the control flour gave the lowest score while products of 7+B, 7, 12, 12+B and balancer gave higher ones (Table 34).

3. Total loaf score:

The analysis of variance of total loaf scores is shown in Table 36. Significant differences were found due to both flour types and mixing times. Doughs produced at optimum and over-optimum mixing times gave relatively high total loaf scores (Table 33). Under-mixed doughs resulted in poor loaves of bread (on total loaf scores and individual scores). The ranking of total loaf score was 7+B, 12+B, 7, balancer, 12, 12+C, 7+C and control.

4. Penetrometer value:

Statistical analysis indicated significant differences due to both mixing times and flour types (Table 37). Doughs processed at optimum and over-optimum mixing times produced breads with superior compressability (Table 33). Loaves baked from 7+B and 7 gave better penetrometer values than did the products of other flours. The control gave the lowest value (Table 34). After three days storage, loaves baked from 7+B showed less evidence of staling than loaves produced from other flours.

Table 32. The Analysis of Variance of Specific Volume of Sponge Bread

Source of Variance	Degree of Freedom	Mean Squares	F
Flours	7	0.6666	15.0972**
Mixing times	2	0.5712	12.9360**
Error	14	0.0442	
Total	23		

** Significant at 1% level.

Table 33. Effect of Mixing Times on Sponge Bread

Mixing Time	Specific Volume	Total Loaf Score	Internal Loaf Score	Penetrometer Value
$1\frac{1}{2}$ min. under	5.8125a	55.2500a	30.0000a	74.6875a
Optimum	6.20000b	66.50000b	36.7500b	86.7500b
$2\frac{1}{2}$ min. over	6.3250b	69.5000b	39.5000b	89.5000b
$LSD_{0.05}$	0.2248	8.1777	5.3168	5.2775

Values designated by the same lower case letter are not significantly different at the 5% level as determined by Fisher's LSD.

Table 34. Effect of Flour Types on Sponge Bread

Flours	Specific Vol. (cc/gm.)	Total Loaf Score(pts.)	Internal Loaf Score (pts.)	Penetrometer Value(0.1 mm.)
7	6.4667a	72.6667a	41.3333a	93.5000ab
12	6.1000a	68.0000ab	40.6667a	83.0000cd
Control	5.0333c	34.0000c	18.6667c	62.1667e
Balancer	6.3333a	71.0000a	38.0000a	87.6667bc
7+C	6.0333b	56.0000b	30.0000b	76.6667d
7+B	6.4667a	78.6667a	43.3333a	101.1667a
12+C	6.0667b	56.3333b	30.6667	77.6667d
12+B	6.4000a	73.3333a	40.6667a	87.3333bc
LSD 0.05	0.3672	13.3541	8.6823	8.6182

Values designated by the same lower case letter are not significantly different at the 5% level as determined by Fisher's LSD.

Table 35. The Analysis of Variance of Internal Loaf Score of Sponge Bread

Source of Variance	Degree of Freedom	Mean Squares	F
Flours	7	210.8326	8.5389**
Mixing times	2	191.1680	7.7425*
Error	14	24.6908	
Total	23		

* Significant at 5% level.

** Significant at 1% level.

Table 36. The Analysis of Variance of Total Loaf Score of Sponge Bread

Source of Variance	Degree of Freedom	Mean Squares	F
Flours	7	627.6785	10.7459**
Mixing times	2	451.5000	7.7297**
Error	14	58.4108	
Total	23		

** Significant at 1% level.

Table 37. The Analysis of Variance of Penetrometer Value of Sponge Bread

Source of Variance	Degree of Freedom	Mean Squares	F
Flours	7	840.0691	17.3468**
Mixing times	2	993.2813	20.5105**
Day	1	24,979.6250	515.8093**
F x M	14	172.4598	3.5612*
M x D	2	78.8438	1.6281ns
F x D	7	134.8873	2.7853*
Error	14	48.4280	
Total	47		

* Significant at 5% level.

** Significant at 1% level.

ns Not significant at 5% level.

EXPLANATION OF PLATE VI

Loaves produced by sponge dough method.

PLATE VI


SPONGE DOUGH METHOD
2.5 MIN
OPTIMUM
2.5 MIN
CONTROL
BALANCER
12
7
12 · B
12 · C
7 · B
7 · C

EXPLANATION OF PLATE VII

Loaves produced by continuous-mix process and sponge dough method under optimum mixing conditions.

PLATE VII


OPTIMUM MIXING
CONTINUOUS MIX PROCESS
SPONGE DOUGH METHOD
CONTROL
BALANCER
12
7
12 · B
12 · C
7 · B
7 · C

Summary of farinograph data represented by stability and valorimeter values obtained at 30°C. and 40°C. and the total loaf score of continuous-mix bread are shown in table 38. Work by Johnson et al.(38) suggested that the valorimeter value gives an indication of strength of flour. Stability, in general, gives some indication of the tolerance to mixing a flour will have (45). Since the mixing tolerance index and departure time are directly and indirectly related to the stability of a farinogram, what is generally found for a stability is true for those values. Therefore, simple linear correlations between stability, valorimeter value at both 30°C. and 40°C. and total loaf scores obtained from continuous-mix process were calculated.

The simple correlation coefficients between total loaf score of continuous-mix bread and stabilities at 30°C. and 40°C. and that and valorimeter values obtained at 30°C. and 40°C. are shown in Table 39. All the correlation coefficients were found to be nonsignificant. However, the multiple correlation coefficient between total loaf score and stability and valorimeter value obtained at 40°C. was apparently higher than that obtained at 30°C. The portion of the total loaf score accounted for by stability and valorimeter value obtained at 30°C. and 40°C. were indicated by $R^2_{LS.13}$ and $R^2_{LS.24}$ respectively (Table 39). It was shown that approximately 3% of total loaf score was accounted for by stability and valorimeter value obtained at 30°C. and approximately half of total loaf score was accounted for by stability and valorimeter value obtained at 40°C.

Table 38. Stability and Valorimeter Value of Farinograph and Total Loaf Score of Continuous Bread

Sample	Stability 30°C.	Stability 40°C.	Valorimeter Value 30°C.	Valorimeter Value 40°C.	Total Loaf Score
7	7.75	4.50	49.00	28.00	31.00
12	14.25	5.00	61.00	22.00	62.50
Control	6.25	2.75	14.00	16.00	62.75
Balancer	25.00	4.50	64.00	27.00	53.00
7+C	10.75	4.25	48.00	26.00	57.50
7+B	8.00	4.50	46.00	30.00	49.00
12+C	9.25	3.25	52.00	20.00	56.25
12+B	16.25	3.75	65.00	26.00	56.00

Table 39. Linear Correlation Coefficients Between Variables, Total Loaf Score (LS), Farinograph Stabilities at 30°C. (1) and 40°C. (2), and Farinograph Valorimeter Values at 30°C. (3) and 40°C. (4), Derived from Eight Flour Samples

Variables Correlated	Correlation Coefficient	Coefficient of Determination
LS;1	$r_{LS;1} = 0.1641$ns	
LS;3	$r_{LS;3} = -0.1426$ns	
LS;13	$R_{LS;13} = 0.1686$ns	$R^2_{LS;13} = 0.0284$
LS;2	$r_{LS;2} = -0.3393$ns	
LS;4	$r_{LS;4} = -0.6289$ns	
LS;24	$R_{LS;24} = 0.6453$ns	$R^2_{LS;24} = 0.4172$

ns Not significant at 5% level.

SUMMARY AND CONCLUSIONS

The purpose of this investigation was to study the effect of temperature on physical dough characteristics and to develop a new farinograph procedure and its interpretations to be used in continuous-mix bread production.

The farinograph was operated at 30°C. and 40°C. to correspond with conventional and continuous-mix conditions respectively. It was found that, at constant consistency (500 B. U.), the absorption, arrival time, peak, stability, departure time and time-to-breakdown were lower at 40°C. than at 30°C. Flours which had satisfactory farinograms at 30°C. were proved to be unsatisfactory when they were run at 40°C.

Extensigrams taken from doughs produced at 30°C. and 40°C. were also obtained. It was found that extensibility, resistance to extension and energy increased, but ratio decreased when doughs were mixed at 40°C.

The addition of 3% nonfat dry milk to doughs caused increases in absorption, peak, stability, tolerance of mixing, resistance to extension and ratio. However, these increases were not significant when doughs were produced at 40°C. Nonfat dry milk also reduced the extensibility and energy of doughs.

On the baking studies, sponge dough method and continuous-mix process were used. Eight different types of flour, 3 mixing times (sponge methods), and 4 mixing speeds (continuous-mix process) were used. For the sponge dough method, 7+B, 12+B and 7 produced breads with higher total loaf scores than did the product of 7+C and control. Optimum and over-optimum mixing produced superior loaves while under-mixing process resulted in producing poor loaves. For continuous-mix process, statistical analyses of total loaf score, specific volume and internal loaf score indicated no difference due to mixing speeds. Breads produced from 7, 7+B and balancer gave significantly lower total loaf scores than the product of other flours did. Loaves produced from control gave the highest score.

Penetrometer values taken from bread made at the lowest mixing speed gave the highest values. After one or three days of storage, loaves baked from 12+B, control, 7+C and 7+B gave significantly higher penetrometer readings than bread made from flour 7. After six days of storage, the product maintaining the greatest compressability was found to be the bread made from 12+B.

Simple linear correlations between stability, valorimeter value obtained at both 30°C. and 40°C. and total loaf scores of continuous-mix bread were calculated. Correlation analyses showed that approximately 3% of total loaf score was accounted for by stability and valorimeter value obtained at 30°C. and approximately half of total loaf score of continuous-mix bread was accounted for by stability and valorimeter value obtained at 40°C. Further investigation on the farinograph characteristics at 40°C., such as the effect of mixer speeds on farinograms, might contribute to the development of the new procedure for evaluating flours to be used in continuous dough-making process.

APPENDIX

Farinogram Data

1. Absorption (%)

Sample	30°C.		40°C.	
	No NFDM	+3% NFDM	No NFDM	+3% NFDM
1	62.1	64.1	59.4	60.0
2	63.9	64.9	61.0	61.9
3	64.8	65.7	61.8	61.9
4	61.6	62.3	58.4	59.1
5	62.5	63.2	60.5	60.5
6	62.5	63.4	60.1	61.0
7	66.4	66.6	62.4	62.6
8	62.2	63.0	59.5	59.8
9	62.4	63.1	59.3	60.3
10	63.0	64.3	60.2	60.6
11	62.7	63.7	59.3	60.0
12	63.9	64.7	60.0	60.5
Control	59.4	60.8	57.1	58.0
Balancer	67.0	68.8	64.2	64.4
7+C	63.0	64.2	59.6	62.0
7+B	63.2	68.6	63.2	64.1
12+C	62.0	63.3	59.6	60.2
12+B	66.8	68.4	62.8	65.2

2. Arrival Time (min.)

Sample	30°C.		40°C.	
	No NFDM	+3% NFDM	No NFDM	+3% NFDM
1	1.25	2.25	1.00	1.25
2	1.75	2.25	1.25	1.25
3	2.00	2.50	1.50	1.25
4	1.75	2.25	1.00	1.00
5	1.25	1.75	1.00	1.00
6	1.75	1.75	1.25	1.25
7	3.25	3.00	1.75	1.50
8	2.00	1.75	1.25	1.75
9	2.25	2.25	1.00	1.25
10	1.75	1.75	1.25	1.50
11	2.00	3.50	1.25	1.50
12	2.25	3.50	1.25	1.25
Control	0.75	1.00	0.75	1.00
Balancer	2.00	3.50	1.25	1.25
7+C	0.75	1.50	1.25	1.50
7+B	2.00	5.00	1.25	1.50
12+C	0.75	1.00	1.00	0.25
12+B	2.00	5.50	1.75	1.50

3. Peak Time (min.)

Sample	30°C.		40°C.	
	No NFDM	+3% NFDM	No NFDM	+3% NFDM
1	6.00	9.25	2.00	2.00
2	5.25	7.50	2.50	2.00
3	6.00	7.75	2.50	2.50
4	6.25	9.00	2.25	2.00
5	6.25	9.00	2.00	2.25
6	5.25	6.50	2.00	2.00
7	5.25	8.00	2.75	3.50
8	5.75	9.75	2.50	2.50
9	7.00	9.00	2.00	2.50
10	6.25	10.00	3.00	2.75
11	7.25	10.25	2.50	2.50
12	7.75	10.75	2.25	2.25
Control	1.25	4.50	1.50	1.75
Balancer	8.50	17.00	2.75	2.00
7+C	5.50	7.50	2.50	2.75
7+B	5.25	9.50	3.00	3.00
12+C	5.75	7.00	2.00	2.00
12+B	8.50	11.00	2.50	2.25

4. Stability (min.)

Sample	30°C.		40°C.	
	No NFDM	+3% NFDM	No NFDM	+3% NFDM
1	13.25	13.25	4.25	4.25
2	10.25	12.75	4.00	4.00
3	11.25	15.25	3.25	3.75
4	9.75	13.25	3.25	3.00
5	9.75	12.75	3.00	3.50
6	10.25	16.25	2.50	3.00
7	7.75	16.50	4.25	5.25
8	12.00	15.25	3.75	3.75
9	9.75	13.75	3.50	3.25
10	13.75	18.25	4.25	4.25
11	16.50	14.00	5.50	4.50
12	14.50	14.75	5.00	5.25
Control	6.25	9.50	2.75	2.50
Balancer	25.00	37.50	4.50	5.00
7+C	10.75	16.50	4.25	4.00
7+B	8.00	15.00	4.25	5.50
12+C	9.25	11.75	3.25	3.25
12+B	16.25	13.50	3.75	4.00

5 Mixing Tolerance Index (B.U.)

Sample	30°C.		40°C.	
	No NFDM	+3% NFDM	No NFDM	+3% NFDM
1	35	35	95	95
2	45	20	115	100
3	30	25	105	90
4	45	45	135	105
5	45	40	120	110
6	40	25	100	80
7	40	40	90	100
8	30	35	105	85
9	45	30	110	95
10	30	20	120	85
11	25	30	90	65
12	25	20	85	75
Control	40	30	150	130
Balancer	20	15	95	90
7+C	40	20	100	90
7+B	30	10	90	70
12+C	45	30	115	110
12+B	25	10	80	90

6. Departure Time (min.)

Sample	30°C.		40°C.	
	No NFDM	+3% NFDM	No NFDM	+3% NFDM
1	14.25	15.50	5.50	5.75
2	12.00	15.00	5.25	5.25
3	13.25	17.75	4.75	5.00
4	11.50	15.50	4.75	5.00
5	11.00	14.50	4.00	4.50
6	12.00	18.00	4.50	5.00
7	10.75	19.50	6.00	6.75
8	14.00	17.00	5.00	5.50
9	12.00	16.00	5.50	5.50
10	15.50	20.00	5.75	5.75
11	18.50	17.50	6.75	6.00
12	16.50	18.25	6.25	6.50
Control	7.00	10.50	3.50	3.50
Balancer	27.00	41.00	5.75	6.25
7+C	11.50	18.00	5.00	5.50
7+B	10.00	20.00	6.50	7.00
12+C	10.00	12.75	4.00	4.50
12+B	18.25	19.00	5.50	5.50

7. Valorimeter Value (B.U.)

Sample	30°C.		40°C.	
	No NFDM	+3% NFDM	No NFDM	+3% NFDM
1	50	68	20	20
2	46	60	26	22
3	52	60	28	26
4	52	66	22	20
5	53	66	22	23
6	48	54	22	21
7	49	62	28	35
8	50	69	26	26
9	57	66	22	26
10	53	70	30	28
11	58	71	25	26
12	61	72	22	24
Control	14	46	16	19
Balancer	64	88	27	20
7+C	48	60	26	28
7+B	46	69	30	30
12+C	52	58	20	20
12+B	65	74	26	24

8. Time-to-Breakdown (min.)

Sample	30°C.		40°C.	
	No NFDM	+3% NFDM	No NFDM	+3% NFDM
1	15.00	15.75	4.75	4.75
2	11.50	14.00	4.75	4.50
3	12.00	16.75	4.00	4.50
4	11.00	14.25	4.00	4.00
5	10.50	14.00	3.50	4.00
6	12.00	16.00	4.00	4.50
7	10.50	17.00	5.00	5.75
8	13.50	17.00	4.50	4.75
9	12.00	15.50	4.00	4.00
10	15.50	19.50	5.00	5.00
11	16.50	17.00	5.00	5.00
12	15.50	19.00	5.00	5.50
Control	7.00	10.50	2.50	3.00
Balancer	24.50	40.00	4.50	5.00
7+C	10.50	17.00	4.00	4.50
7+B	10.00	19.00	5.00	5.75
12+C	9.50	13.00	3.00	3.75
12+B	18.50	18.50	4.50	4.50

Baking Results of Continuous-Mix Process

1. Total Loaf Score (pts.)

Sample	Mixing Speed *			
	1	2	3	4
7	49.0	33.0	20.0	22.0
12	59.0	59.0	57.0	75.0
Control	63.0	53.0	64.0	71.0
Balancer	61.0	47.0	49.0	55.0
7+C	44.0	71.0	59.0	56.0
7+B	56.0	39.0	35.0	66.0
12+C	51.0	58.0	57.0	59.0
12+B	62.0	51.0	53.0	58.0

* Actual numbers of r.p.m. are shown in Table 2.

2. Specific Volume (cc/gm.)

Sample	Mixing Speed *			
	1	2	3	4
7	6.0	5.5	5.2	5.8
12	7.1	6.9	6.8	7.0
Control	7.0	7.0	7.3	7.1
Balancer	5.9	6.1	6.2	6.1
7+C	6.9	7.1	6.7	6.2
7+B	6.3	6.3	6.0	6.2
12+C	6.3	6.5	6.6	6.9
12+B	6.0	6.1	6.4	6.3

* Actual numbers of r.p.m. are shown in Table 2.

3. Grain (pts.)

Sample	Mixing Speed *			
	1	2	3	4
7	8.0	6.0	6.0	6.0
12	8.0	10.0	12.0	14.0
Control	10.0	8.0	10.0	14.0
Balancer	12.0	10.0	12.0	14.0
7+C	4.0	10.0	10.0	10.0
7+B	10.0	8.0	8.0	14.0
12+C	8.0	12.0	10.0	12.0
12+B	12.0	10.0	10.0	10.0

* Actual numbers of r.p.m. are shown in Table 2.

4. Crumb Texture (pts.)

Sample	Mixing Speed *			
	1	2	3	4
7	10.0	10.0	6.0	6.0
12	10.0	12.0	14.0	16.0
Control	12.0	8.0	10.0	16.0
Balancer	18.0	12.0	6.0	10.0
7+C	6.0	12.0	12.0	12.0
7+B	12.0	10.0	8.0	16.0
12+C	8.0	12.0	10.0	10.0
12+B	14.0	12.0	12.0	12.0

* Actual numbers of r.p.m. are shown in Table 2.

5. Penetrometer Value (0.1 millimeter)

Mixing Speed *	Day	7	12	Control	Balancer	7+C	7+B	12+C	12+B
1	1	191	188	203	205	179	194	214	226
	3	131	124	148	122	146	169	139	135
	5	105	104	102	98	113	107	120	140
2	1	166	180	216	182	216	135	175	198
	3	107	92	172	122	172	143	121	73
	5	62	84	112	108	112	91	85	107
3	1	129	155	193	151	178	147	193	192
	3	91	130	139	142	112	151	116	149
	5	67	92	102	103	96	98	110	116
4	1	121	201	180	168	181	195	166	234
	3	93	136	116	133	133	137	122	102
	5	78	117	81	116	99	118	110	130

* Actual numbers of r.p.m. are shown in Table 2.

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THE RELATIONSHIP OF DOUGH CHARACTERISTICS AT CONVENTIONAL AND ELEVATED TEMPERATURES TO THE QUALITY OF BREAD MADE BY CONVENTIONAL AND CONTINUOUS PROCESSES

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This investigation dealt with the effect of temperature on physical dough characteristics, and development of a new farinograph procedure and its interpretations to be used in continuous-mix bread production. The farinograph was operated at 30°C.(86°F.) and 40°C.(104°F.) to correspond with conventional and continuous-mix conditions respectively. Extensigraph and baking methods of sponge dough method and continuous-mix process were also used.

Characteristics including absorption, arrival time, peak, stability, mixing tolerance index, time-to-breakdown, valorimeter value, extensibility, resistance to extension, energy, ratio, specific volume, internal loaf score, total loaf score and penetrometer value were statistically analyzed.

At 40°C. values of farinograph characteristics decreased and the farinograph curve was shortened as if for a weak flour.

Extensigrams showed that extensibility, resistance to extension and energy increased, but ratio figure decreased as the temperature increased to 40°C.

The addition of 3% nonfat dry milk into doughs caused increases in absorption, peak, stability, tolerance of mixing, resistance to extension and ratio. However, these increases were not significant when doughs were mixed at 40°C. Nonfat dry milk also reduced the extensibility and energy of doughs.

On the baking studies, differences were found to be due to baking methods. The same type of flour produced loaves with varied qualities when loaves were processed by different baking methods. For the sponge dough method, optimum and over-optimum mixing produced superior loaves. Under-mixing process resulted in producing poor loaves. For the continuous-mix process, statistical

analyses of total loaf score, specific volume and internal loaf score indicated no difference due to mixing speeds.

Correlation analyses showed that approximately 3% of total loaf score was accounted for by stability and valorimeter value obtained at 30°C. and approximately half of total loaf score was accounted for by stability and valorimeter value obtained at 40°C.