Factors Affecting Mechanical Dough Development. IV. Effect of Cysteine[1, 2]

R. H. KILBORN and K. H. TIPPLES, Canadian Grain Commission, Grain Research Laboratory, Winnipeg 2, Manitoba

ABSTRACT

Three flours of widely differing mixing requirements and two mixers at various mixing speeds were used to study the effects of adding different levels of L-cysteine hydrochloride in a Chorleywood-type process. Cysteine reduced the energy level required to achieve peak dough development, and reduced the critical mixing speed necessary to produce bread of satisfactory (high) volume. The magnitude of these effects increased with increasing addition of cysteine. Cysteine also increased slightly the rate of energy input at a given mixing speed and increased the tolerance to "undermixing", enabling satisfactory bread to be produced with energy levels less than those required to achieve peak dough development. There was an optimum level (range) of cysteine addition for the production of satisfactory bread. This optimum level increased with increasing flour mixing requirements and with decreasing mixing speed.

Mechanical dough development is achieved by the use of high-speed mixers that impart more than a critical minimum level of work (dependent on the flour used) to a dough, at a mixing speed higher than a minimum critical level dependent on the mixer and the flour used (1). By contrast, "chemical dough development" (or "activated dough development", as it is referred to by the British Flour Milling and Baking Research Association) is said to be achieved by the reducing action of L-cysteine hydrochloride or other reducing agents followed by oxidation by potassium bromate (2). Tsen (2) has recently carried out an extensive review of chemical dough development in which he outlined the experimental work with reducing agents, dwelt at length with the current thinking on the action mechanism in dough, and outlined the advantages of using reducing agents in the breadmaking process.

The effect of cysteine in reducing mixing requirements of flours has been well established. Henika and Rodgers (3) showed that 60 p.p.m. of cysteine reduced peak mixing time of unfermented doughs 30 to 65%, depending on flour strength. Using a 40-min. fermentation time they found that 100 p.p.m. cysteine gave optimum extensibility and relaxation. In the continuous-mix process, use of a cysteine-bromate-whey blend reduced development requirement 40%, leading to increased throughput or allowing a decrease in developer speed for the same throughput (4). Tsen (2) cites unpublished data to illustrate how use of cysteine is especially suitable for making bread from very strong (long-mixing) flour. With Red River 68 flours the first 40 p.p.m. cysteine reduced mixing time by one third and further (lesser) reductions in mixing requirements were obtained at higher treatment levels. Coppock (5) stated that only about 0.2 h.p./min./lb. of dough was required for chemical dough development, compared with a level of 0.4 h.p./min./lb. for mechanical dough development.

---

[1]Paper No. 322 of the Canadian Grain Commission, Grain Research Laboratory, Winnipeg 2, Manitoba, Canada.

[2]Presented at the 56th Annual Meeting, Dallas, Texas, October 1971.

Copyright © 1973 American Association of Cereal Chemists, Inc., 3340 Pilot Knob Road, St. Paul, Minnesota 55121. All rights reserved.

Ewart (6) reported that in chemical dough development, mixing was achieved with a work consumption of about one fifth of that required in mechanical dough development.

The object of this paper is to present results obtained in a study of the effect of cysteine in no-dough-time processes on energy requirements, critical mixing speed, mixing time, dough handling properties, and bread properties. A laboratory-scale programmed mixing unit and the GRL pin mixer were used as described previously (1) to investigate the effect of different work levels and mixing speeds with different levels of cysteine in combination with a basic oxidation mixture of ascorbic acid and potassium bromate.

MATERIALS AND METHODS

Three flours were used to study the effect of L-cysteine hydrochloride (from here on referred to simply as cysteine) in the GRL-Chorleywood baking method (1). In this method, two "pup-loaf" sized doughs (95°F.) were scaled and rounded immediately after mixing. One dough was given an intermediate proof of 20 min., the second one received 25 min., and the final bread results were averaged. Panning was as for the Remix baking test with the GRL moulder. Proofing was at 95°F. for 55 min. Loaves were baked for 25 min. at 430°F. Doughs were mixed with both the GRL pin mixer (7) at speeds of 130 and 68 r.p.m., and the GRL experimental mixer (8) at various speeds. All baking formulas contained the basic oxidant mixture of 75 p.p.m. ascorbic acid with 45 p.p.m. potassium bromate. Cysteine levels used during the course of experiments ranged from 0 to 320 p.p.m.

The baking formula included: flour, 200 g. (GRL mixer) or 220 g. (experimental mixer); sugar, 2.5%; salt, 1%; shortening, 1.5%; yeast, 3%; malt syrup (250°L.), 0.3%; and ammonium phosphate (monobasic), 0.1%.

Flour A was a straight-grade flour laboratory-milled from a commercially grown sample of HRS wheat, variety Chinook. This variety is generally a little stronger in mixing characteristics than other more commonly grown Canadian licensed varieties. Flour protein content (14% m.b.) was 12.9%; farinograph absorption was 61.5% and farinograph development time was 7.0 min.

Flour B was a straight-grade flour laboratory-milled from a sample of No. 2 Manitoba Northern wheat selected on the basis of its relatively short mixing requirement. Protein content of this flour was 13.0%; farinograph absorption was 63.9% and development time was 4.75 min.

Flour C was a sample of Red River 68 wheat flour obtained from Fargo, N.Dak. Protein content was 12.5% and farinograph absorption was 59.3%. The farinograph curve was extremely flat with a peak at around 25 min. This sample was included because of its extremely long mixing requirements in baking tests.

EXPERIMENTAL AND RESULTS

Effect of Cysteine on Dough Mixing Characteristics

Mixing Curves. Cysteine had a profound effect on the mixing characteristics of the three flours studied. The shape of the mixing curves changed so that the peak occurred sooner and consistency level at peak increased. Examples of mixing curves are shown in Figs. 1 to 3. Chorleywood-process doughs containing the basic

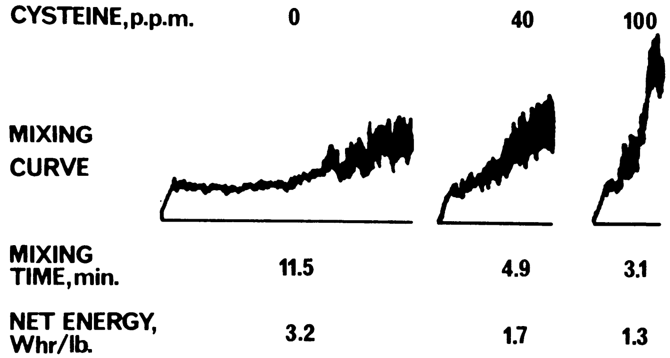


Fig. 1. Mixing curves (GRL pin mixer, 130 r.p.m.) for sample A showing effect of increasing levels of cysteine. Mixing times and net energy levels are for peak dough consistency. Absorption = 64%.

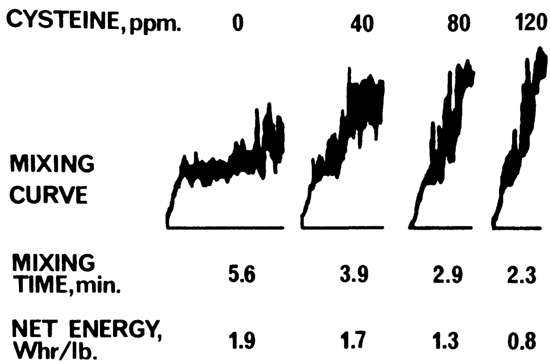


Fig. 2. Mixing curves (GRL pin mixer, 130 r.p.m.) for sample B showing effect of increasing levels of cysteine. Absorption = 63%.

oxidation mixture of 75 p.p.m. ascorbic acid + 45 p.p.m. potassium bromate were mixed in the GRL mixer at 130 r.p.m. with various levels of cysteine.

As seen in the figures, increasing cysteine markedly reduced both the mixing time and the energy level required to produce a peak in the mixing curve.

It should be noted that all energy requirement values reported in this paper are "net" energy values, obtained by correcting the "gross" energy (consumed by the mixer motor) for the mechanical efficiency of the particular mixer drive mechanism as outlined in another paper (9). Thus, for example, the "gross" energy requirement to achieve peak development for sample A in the absence of cysteine was 7.5 w-hr. per lb. Correction for the 42% mechanical efficiency of the GRL mixer drive gave a "net" energy requirement of 3.2 w-hr. per lb.

The higher consistency at peak development suggested an increase in the overall average rate of energy input to the dough during mixing.

Mixing requirements for the Red River 68 sample were so high that it was not possible to develop the dough at 130 r.p.m. on the GRL mixer, indicating a critical

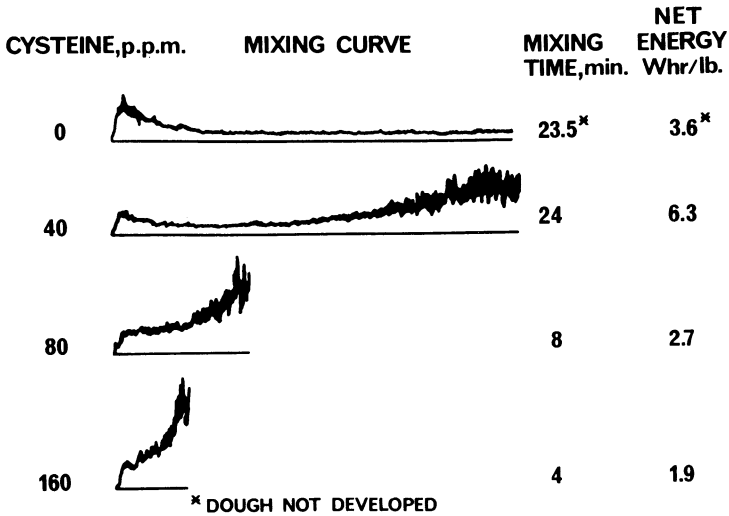


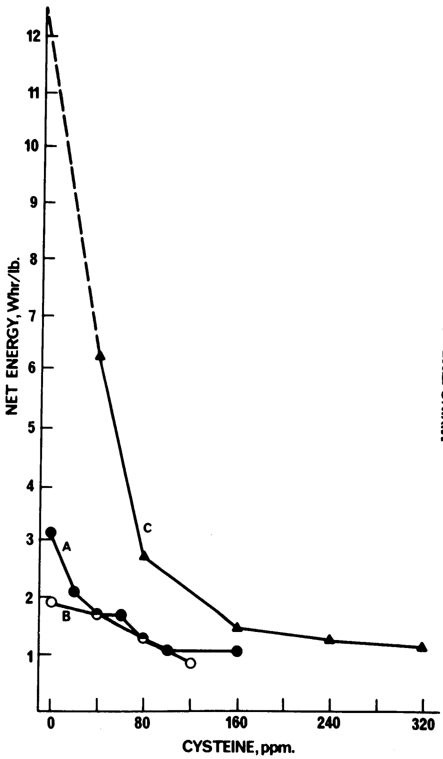
Fig. 3. Mixing curves (GRL pin mixer, 130 r.p.m.) for sample C showing effect of increasing levels of cysteine. Mixing times and energy levels shown for 40, 80, and 160 p.p.m. cysteine are for peak dough consistency. Absorption = 62%, except for 0 cysteine, 59%.

speed on this mixer well in excess of 130 r.p.m., although this speed is normally sufficiently high to develop doughs from most flours. Only in the presence of cysteine was a fully developed dough obtained.

Energy Requirement. The effect of cysteine on net energy-input requirement for peak development for the three flours is summarized in Fig. 4. The magnitude of the effect appeared to be greater as energy requirement in the absence of cysteine increased. For example, in order to reduce energy requirement to one half of the requirement with no cysteine, approximately 110 p.p.m. cysteine was needed for sample B, 50 p.p.m. for sample A, and 40 p.p.m. for sample C (although the last was based on an extrapolated value for no cysteine). It was possible, by the use of cysteine, to mix samples A and C to peak development using the same net energy level (1.9 w-hr. per lb.) as that required for the shorter mixing sample B in the absence of cysteine, with levels of approximately 30 p.p.m. for sample A and 135 p.p.m. for sample C.

Mixing Time. The effect of cysteine on mixing time was even more marked for the longer mixing flours than was the effect on energy requirement, and this is illustrated in Fig. 5 which shows mixing times plotted against cysteine level for the GRL mixer at 130 r.p.m. For example, increasing cysteine from 40 to 80 p.p.m. reduced the mixing time of sample C from 24 to 8 min.

When doughs were mixed on the GRL mixer at 68 r.p.m., mixing times needed to impart the required energy levels were extremely long in the absence of cysteine. Addition of cysteine brought about a dramatic decrease in mixing time. Flour A required 51 min. to impart the necessary energy, whereas mixing time was reduced to 14 min. with 60 p.p.m. cysteine. Similarly, mixing time was reduced from 30 min. to 10 min. by the addition of 80 p.p.m. cysteine to sample B. Mixing times for the GRL mixer at 68 r.p.m. are summarized in Fig. 6. It was not practical to mix



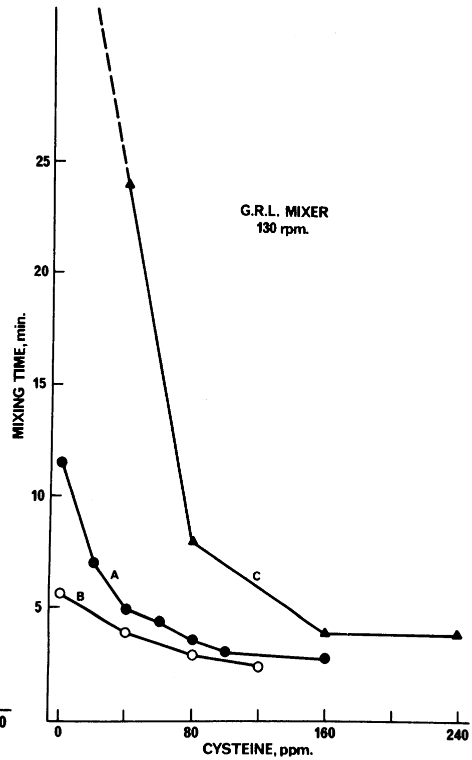


Fig. 4 (left). Effect of various levels of cysteine on net energy requirements for three flours (GRL pin mixer at 130 r.p.m.).

Fig. 5 (right). Effect of various levels of cysteine on mixing time (for peak dough development) for three flours using the GRL pin mixer at 130 r.p.m.

sample C at 68 r.p.m. without fairly high levels of cysteine. However, at these high levels (e.g., around 200 p.p.m.) it was possible to develop a dough in about 10 min. on the slow-speed mixer.

Rate of Energy Input. As noted above, dough consistency at peak was increased with increasing cysteine suggesting that there might be an increase in the overall average rate of energy input to the dough. Figure 7 shows average rate of energy input plotted against cysteine level for the three flours using two mixing speeds with the GRL mixer. At the higher speed of 130 r.p.m. the rate of energy input increased sharply for cysteine additions up to 60 to 80 p.p.m., but leveled off or decreased at higher cysteine levels. At 68 r.p.m. no such decrease was observed for flours A and B at the cysteine levels studied, and average rate of energy input increased steadily with increasing cysteine.

Effect of Cysteine on Dough Handling Properties and Baking Absorption

Sample A. A baking absorption of 64% (as judged by dough handling properties at panning) was considered satisfactory for cysteine levels from 0 to 160 p.p.m. At 0 and 40 p.p.m. cysteine, at 130 r.p.m. in the GRL mixer, doughs were very lively, extensible, and springy at the time of panning. At 80 p.p.m. doughs were less springy, and at 160 r.p.m. were lively, fairly springy, and showed increased extensibility.

At 68 r.p.m., doughs were soft and showed characteristics of gross undermixing with no cysteine. With 40 p.p.m. cysteine, dough properties had improved to fairly lively, extensible, and fairly soft. Increasing levels of cysteine further improved dough handling properties so that a well-balanced dough was obtained (lively, extensible, and springy) with 160 p.p.m. cysteine at a baking absorption of 64%.

Sample B. An absorption of 63% was considered satisfactory for cysteine levels from 0 to 120 p.p.m. At 130 r.p.m. on the GRL mixer, in the absence of cysteine, a well-balanced dough was obtained. Increasing cysteine produced a gradual deterioration in dough properties such that at 120 p.p.m. doughs were fairly lively, extensible, and fairly soft.

At 68 r.p.m., doughs containing no cysteine were soft and lacked cohesion. Properties improved to lively, extensible, and fairly springy at 80 and 120 p.p.m. cysteine.

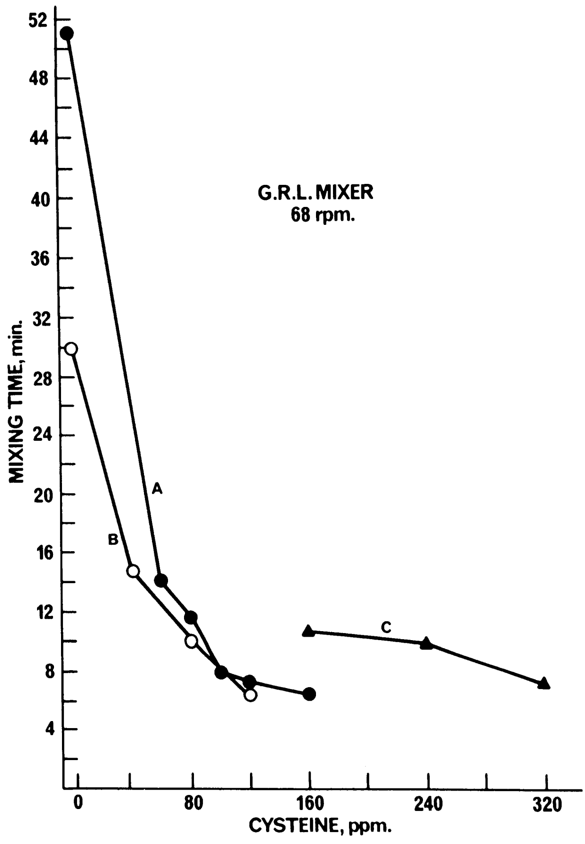


Fig. 6. Effect of various levels of cysteine on mixing time for three flours using the GRL pin mixer at 68 r.p.m.

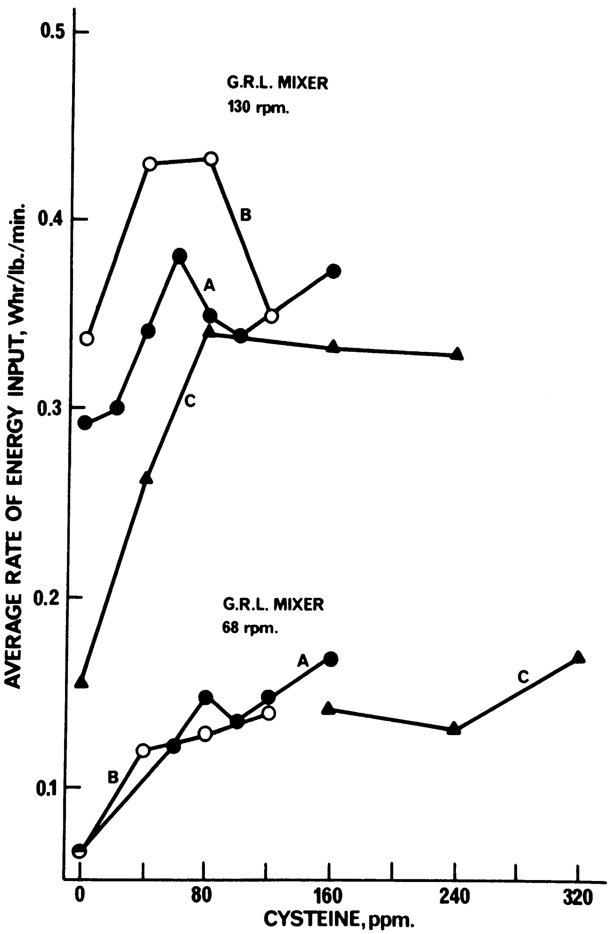


Fig. 7. Effect of various levels of cysteine on average rate of energy input for three flours mixed at 130 and 68 r.p.m. in the GRL pin mixer.

Sample C. With no cysteine, it was impossible to produce a developed dough, even at 130 r.p.m. and an absorption level of 59%. With 40 p.p.m. cysteine, at 130 r.p.m., an absorption level of 62% was considered satisfactory. However, although development was achieved, doughs were bucky. Buckiness was decreased and doughs were classed very springy with 80 p.p.m. cysteine, while 160 p.p.m. produced a well-balanced dough that was lively, extensible, and springy. A level of 240 p.p.m. cysteine at 62% absorption produced a dough having similar properties to those at 160 p.p.m., but which was "tacky" and therefore more difficult to sheet.

At 68 r.p.m., it was impossible to produce a developed dough unless fairly high levels of cysteine were used. With cysteine levels of about 200 p.p.m., dough handling properties were satisfactory at 62% absorption.

General. For this baking method, a good balance between extensibility and resistance to extension (at the time of panning) is normally coincident with optimum bread characteristics. Addition of cysteine causes an increase in dough extensibility and a corresponding decrease in resistance to extension. Where this direction of change is necessary to achieve a well-balanced dough, addition of cysteine is desirable and causes no reduction in absorption. Where dough characteristics already show good balance in the absence of cysteine, however, a deterioration in handling properties occurs proportional to the amount of cysteine added. A point is reached where marked extensibility is accompanied by "tackiness" which may have to be corrected for by reducing absorption. This also applies when too much cysteine is added to doughs which require some cysteine for good balance.

Effect of Cysteine on Bread Characteristics

Critical Speed–Experimental Mixer. In a previous study (1) the "critical speed" for a given flour with a given mixer was defined as the minimum speed at which bread of satisfactory (high) volume may be produced in a Chorleywood-type process.

The effect of increasing mixer speed was studied using the experimental mixer

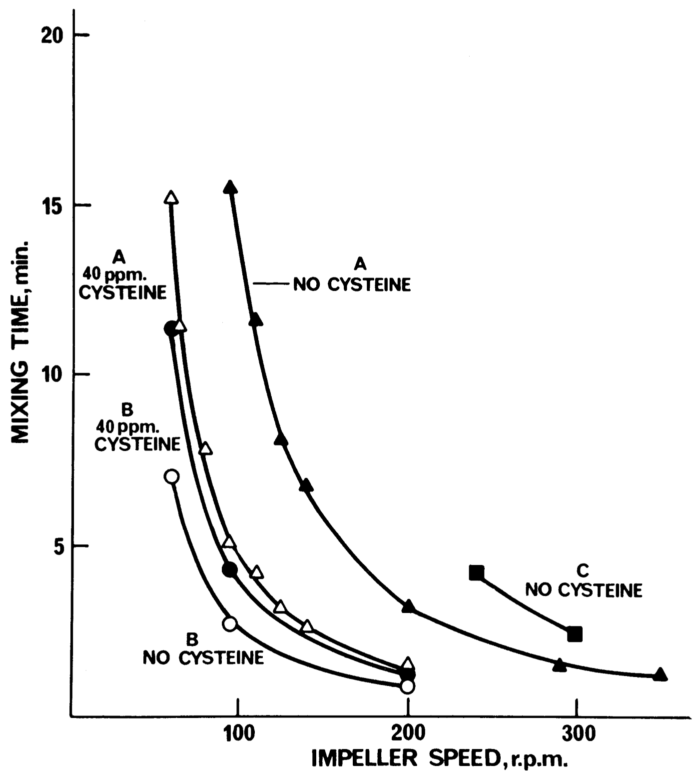


Fig. 8. Effect of mixing speed on mixing time for three flours mixed in the experimental mixer with 0 and 40 p.p.m. cysteine.

with flours A and B with 0 and 40 p.p.m. cysteine. Mixing time (to achieve peak dough development) decreased curvilinearly as mixing speed was increased (Fig. 8), and at all speeds mixing time was significantly less for the doughs containing cysteine.

Addition of 40 p.p.m. cysteine reduced the critical speed necessary to achieve bread of high volume for both samples, as shown in Fig. 9, in which loaf volumes are plotted against mixer speed.

Flour A had rather a high critical speed in the absence of cysteine, and bread of high volume was only obtained at speeds of about 175 r.p.m. and higher. Addition of 40 p.p.m. cysteine lowered the critical speed for this sample to about 95 r.p.m. Figure 10 shows the external appearance of loaves baked from sample A mixed just past peak consistency for 0 and 40 p.p.m. cysteine at various mixing speeds.

Critical speed for sample B was reduced from about 120 r.p.m. with no cysteine to 90 r.p.m. with 40 p.p.m. cysteine. The effect of cysteine on loaf volume was particularly apparent at speeds below critical speed. At 60 r.p.m., for example, loaf volume was increased by 140 cc. when 40 p.p.m. cysteine was used.

Only limited amounts of the Red River 68 sample C were available, but it is apparent that critical speed for this flour was extremely high with the experimental mixer in the absence of cysteine (at least 300 r.p.m.), as indicated by the 95-cc. loaf volume increase going from 240 to 300 r.p.m.

GRL Mixer. Experiments carried out with the GRL pin mixer were designed to explore both the implication of mixer speed (fast-speed and slow-speed mixing) and

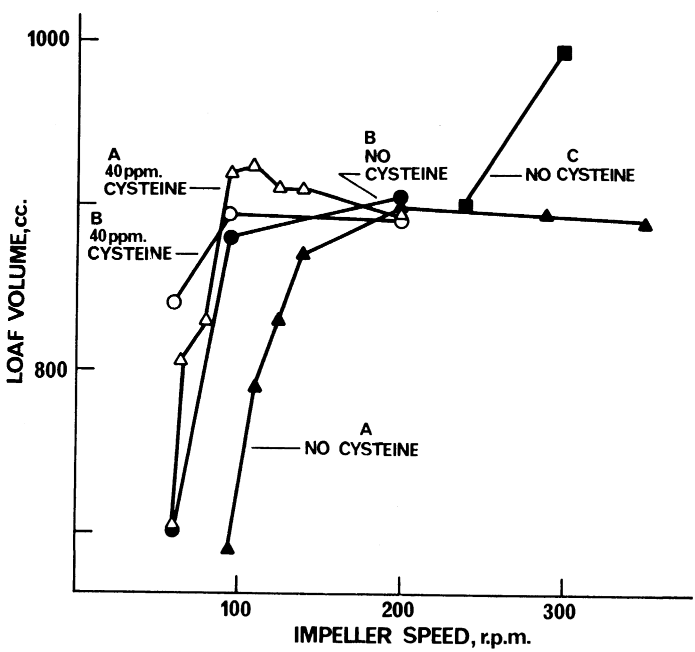


Fig. 9. Effect of mixing speed on loaf volume for three flours mixed in the experimental mixer with 0 and 40 p.p.m. cysteine.

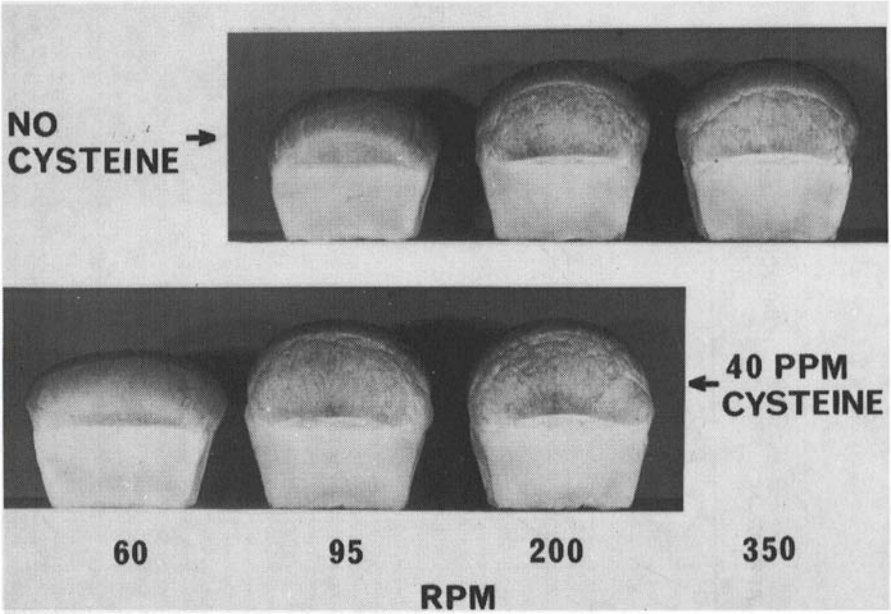


Fig. 10. External appearance of loaves baked from sample A using four different mixing speeds with the experimental mixer. Upper row: no cysteine. Bottom row: 40 p.p.m. cysteine.

the possibility of using energy-input levels below those required to achieve peak dough consistency. With flours A, B, and C, a wide range of cysteine levels was used with the GRL mixer at 130 r.p.m. (fast speed) and 68 r.p.m. (slow speed), and with energy-input levels corresponding in each case to peak dough consistency and one half of this level (reduced work).

The energy levels required to achieve peak dough development were determined, for the various levels of cysteine, using the higher speed (130 r.p.m.) where mixing curve peaks were clearly defined (except for sample C with no cysteine as described previously). These values were then applied when using slow-speed mixing. At 68 r.p.m., mixing curves for low levels of cysteine were quite flat, and in many cases the peak was not readily discernible. An earlier publication (1) showed that energy requirements for peak dough consistency remain essentially constant over a wide range of mixing speeds.

Data for this series of experiments are summarized in Figs. 11 to 13. The following three subsections discuss results from three different aspects.

(a) GRL Mixer at 130 r.p.m. (fast speed). As shown above, cysteine reduces the critical mixing speed required to achieve mechanical dough development. As illustrated in Fig. 11, the loaf volume for sample A increased with increasing cysteine: from 870 cc. with no cysteine to a maximum of 960 cc. with 80 p.p.m. cysteine, indicating that the speed of 130 r.p.m. was slightly lower than that necessary to achieve maximum loaf volume for this sample. At cysteine levels of 100 p.p.m. and higher, loaf volume decreased; and at 160 p.p.m. had fallen to 810 cc. Loaf appearance scores were similar at all cysteine levels, except that at the

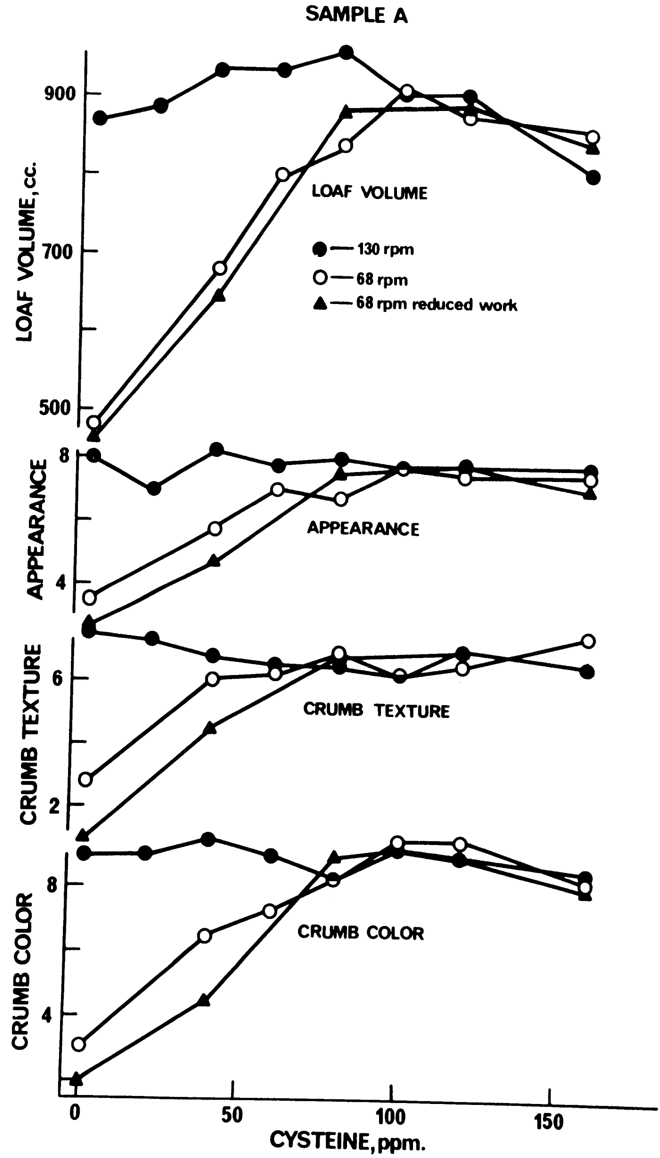


Fig. 11. Effect of various levels of cysteine on loaf properties for sample A. Closed circles = GRL mixer at 130 r.p.m. to peak dough consistency; open circles = 68 r.p.m. to peak dough consistency; triangles = 68 r.p.m. with reduced energy.

highest level of 160 p.p.m. some shrinkage occurred in the loaves after baking and "green" crust characteristics were noted. Crumb texture score was excellent (7.5) with no cysteine, but decreased with increasing cysteine to 6.5-open with 60 p.p.m. cysteine and higher. However, a score of 6.5-open is considered satisfactory for bread of high volume. Crumb color scores showed no marked trends with cysteine.

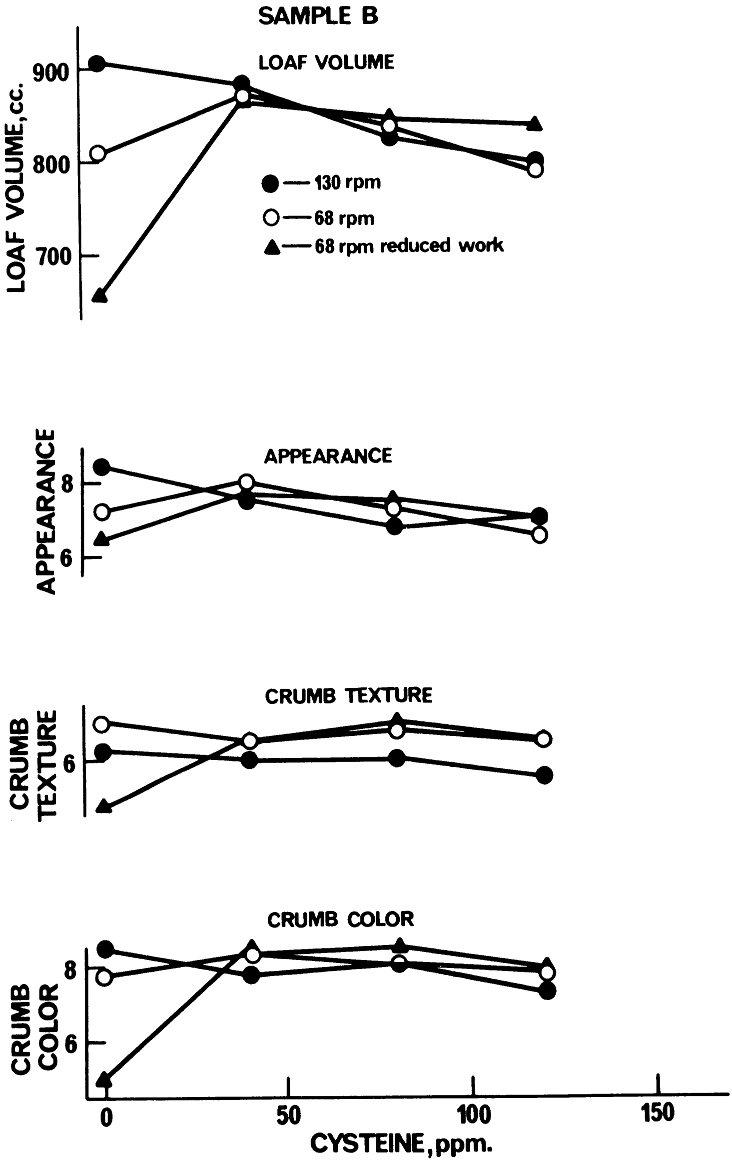


Fig. 12. Effect of various levels of cysteine on loaf properties for sample B.

Sample B, which had the shortest mixing requirements of the three flours studied, gave optimum results with no cysteine (Fig. 12). Loaf volume deteriorated steadily with increasing amounts of cysteine, while other loaf properties deteriorated to a lesser extent.

Sample C (Fig. 13) was shown to have an extremely high mixing requirement,

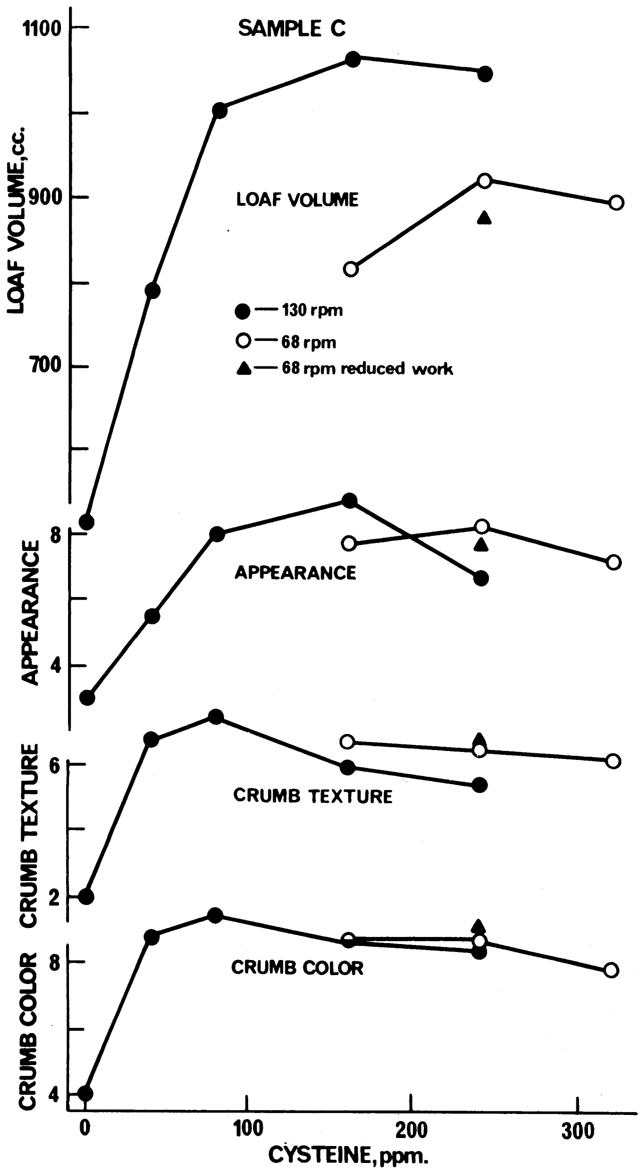


Fig. 13. Effect of various levels of cysteine on loaf properties for sample C.

both in terms of energy-input level and mixing speed. At the fast speed of 130 r.p.m. on the GRL mixer it was impossible to produce a developed dough in the absence of cysteine. Loaf volume was extremely low (510 cc.), and other bread characteristics were completely unacceptable. Addition of cysteine produced a striking improvement in all bread characteristics. Loaf volume increased to a maximum of 1,065 cc. with 160 p.p.m. cysteine. Best texture and crumb color scores, however, were obtained with 80 p.p.m. cysteine.

It is obvious, therefore, that there is an optimum level (range) of cysteine that varies with the flour used. Cysteine requirement increased for the longer mixing flours, to the extent that although best results were obtained with no cysteine for sample B (the shortest mixer), a minimum of 80 p.p.m. cysteine was required to obtain satisfactory bread with sample C. Because best texture scores occur at cysteine levels somewhat lower than those necessary to achieve maximum loaf volume, in selecting a level of cysteine for a given situation some compromise would have to be reached depending on the relative importance attached to these characteristics.

(b) Slow-Speed Mixing–GRL Mixer at 68 r.p.m. The speed of 68 r.p.m. was markedly below the critical speed for all three samples in the absence of cysteine. To achieve bread of satisfactory volume, considerably higher levels of cysteine were required at this speed than at the higher speed of 130 r.p.m.

Sample A (Fig. 11) required 100 p.p.m. cysteine in order to obtain maximum loaf volume and satisfactory scores for other bread characteristics. Sample B (Fig. 12) produced best bread at 40 p.p.m., whereas an extremely high level of 240 p.p.m. was required for sample C (Fig. 13).

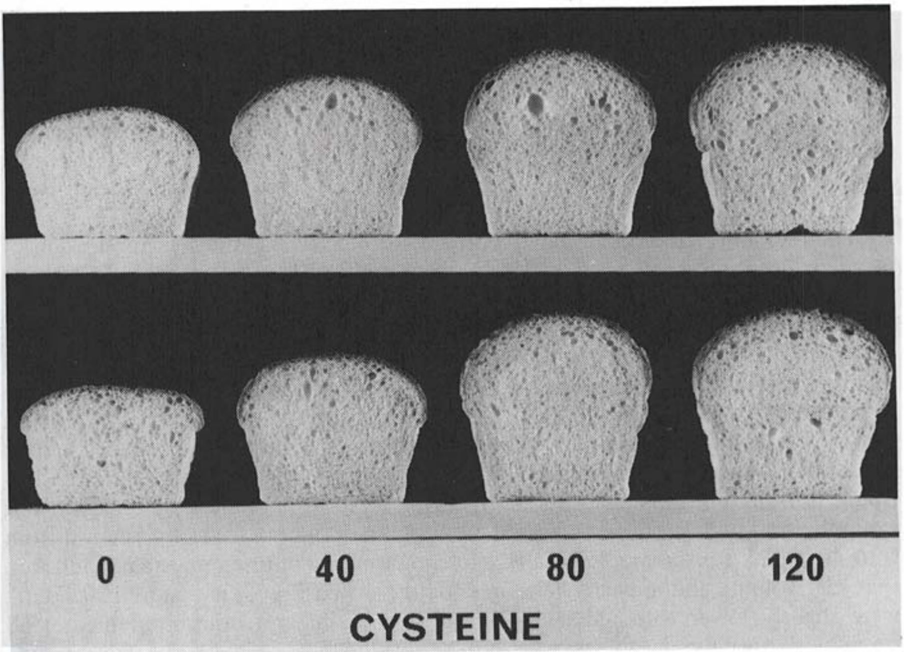


Fig. 14. Longitudinal sections of "pup" loaves baked from sample A at four levels of cysteine using the GRL mixer at slow speed (68 r.p.m.). Upper row: doughs mixed to peak consistency. Bottom row: doughs mixed with energy levels reduced to one half of those required for peak consistency.

TABLE I. LOAF VOLUME AND MIXING DATA FOR SAMPLE A MIXED AT 68 r.p.m. IN THE GRL PIN MIXER WITH 0, 80, and 120 p.p.m. CYSTEINE: (A) DOUGHS MIXED TO PEAK CONSISTENCY, AND (B) DOUGHS MIXED WITH ENERGY LEVELS REDUCED TO ONE HALF OF THOSE REQUIRED FOR PEAK CONSISTENCY

	Cysteine, p.p.m.		
	0	80	120
(a) Mixed to peak			
Loaf volume, cc.	480	840	875
Net energy, w-hr./lb.	3.2	1.7	1.0
Mixing time, min.	51.0	11.5	7.2
(b) Reduced energy			
Loaf volume, cc.	465	885	890
Net energy, w-hr./lb.	1.7	0.85	0.5
Mixing time, min.	25.0	7.1	4.4

Compared with the bread produced at 130 r.p.m., the bread (at optimum cysteine) obtained with slow-speed mixing was somewhat lower in volume. The difference in loaf volume between the two mixing speeds was greatest for sample C which had the longest mixing requirement. Other bread characteristics did not show any marked differences between the two mixing speeds.

(c) Effect of Reducing Energy Input. Although satisfactory bread may be produced with slow-speed mixing by the judicious use of cysteine, mixing times (Fig. 5) at this speed may still be a limiting factor in throughput. The possibility of using energy levels less than those necessary to achieve peak dough consistency was examined. Reducing energy levels to one half of peak values had little effect on bread characteristics for any of the three samples examined (see Figs. 11 to 13) at optimum levels of cysteine. In the absence of cysteine, poor bread was produced at 68 r.p.m. using optimum work levels. Reduction of energy input in this case produced bread of even lower volume, appearance, crumb texture, and crumb color.

The dramatic effect of cysteine with slow-speed mixing and the implication of using reduced energy levels are clearly illustrated in Fig. 14 and Table I. With no cysteine and full work, poor bread was produced from sample A, even though the dough was mixed for 51 min. to impart a net energy level of 3.2 w-hr. per lb. At 120 p.p.m. cysteine, when imparting less than one-sixth of this energy level and mixing for less than one-tenth of the time, loaf volume was almost doubled.

Because mixing times with high-speed mixing are relatively short at optimum levels of cysteine, there would probably be little incentive to use reduced energy levels with high-speed mixing. Tests showed that more cysteine was required at 130 r.p.m. to obtain optimum results when energy levels were reduced by one half. For example, optimum cysteine increased from 40 to 60 p.p.m. for sample A and from 0 to 40 p.p.m. for sample B. Results (not shown) using optimum cysteine indicated that loaf volume and appearance scores for these two flours, mixed at 130 r.p.m., were slightly lower with reduced work and were similar to those obtained at 68 r.p.m. with optimum cysteine.

DISCUSSION

The results presented above indicate that it may be possible to "tailor-make" a dough formula with the correct level of cysteine for a given situation where it may be otherwise impossible to produce satisfactory short-process bread due to unsuitable mixer or flour characteristics, or both.

The effect of cysteine in reducing mixing requirements in terms of mixing time and energy levels has already been well established (e.g., 2 to 6). The most important effect of cysteine demonstrated in this paper appears to be that it lowers flour critical mixing speed, enabling dough development and bread of satisfactory (high) volume to be achieved at mixing speeds considerably below those required to develop doughs in the absence of cysteine. Cysteine also markedly increases the tolerance to undermixing (as judged by mixing curves) and enables satisfactory bread to be produced with energy levels considerably less than those necessary to achieve peak dough consistency.

There is an optimum level (range) of cysteine addition for the production of satisfactory bread. Use of too high a level of cysteine causes deterioration of loaf characteristics. Cysteine requirement for optimum crumb texture is somewhat lower than that for production of maximum loaf volume and cysteine level should be determined in the light of the relative importance attached to these two characteristics. Although it might be possible to minimize the deterioration in crumb texture by adjusting oxidation or absorption levels, or both, these factors were not investigated at this time.

The optimum level of cysteine varies with the flour used, and for a given flour increases with decreasing mixing speed below the critical mixing speed. For the three flours studied in different mixing situations, optimum cysteine levels ranged from 0 p.p.m. for sample B with high-speed mixing, to 240 p.p.m. for sample C with slow-speed mixing. These results are in general agreement with the conclusions of workers at the Bread Research Institute of Australia (10) who state that the level of L-cysteine hydrochloride required varies with flour strength and is between 30 and 75 p.p.m. in the "no-time" dough process using conventional mixing machines, 100 p.p.m. ascorbic acid, and 24 to 30 p.p.m. potassium bromate. They further state that if the "no-time" dough is mixed in a high-speed machine, the use of L-cysteine hydrochloride is not necessary.

It should be strongly emphasized that the optimum cysteine levels referred to in this paper relate specifically to the three flours studied; and while it can be generally said that Red River 68 (sample C), for example, has a long mixing and high critical-speed requirement, quite wide variations have been observed in mixing requirements between individual samples of this variety, suggesting that optimum cysteine requirement would also vary.

Another note of caution is related to the legality of using cysteine in breadmaking. At present it is not allowed in the United Kingdom although indications are that it will be permitted soon. In both the U.S. and Canada the maximum amount of L-cysteine hydrochloride permitted in flour is 90 p.p.m. This maximum would provide sufficient flexibility for using cysteine with flours milled from commercially available Canadian wheats. However, wheats with abnormally long mixing requirements, such as this example of Red River 68 (which is not a licensed variety in Canada), may not produce acceptable bread under many mixing situations at this level of cysteine.

It is possible that some adaptation in specific (optimum) levels of cysteine would be required when scaling up to commercial-sized doughs, as is the case with many other ingredients. However, it is felt that the underlying principles discussed in this paper are valid. The experimental work reported here indicates that cysteine cannot by itself bring about dough development, but rather, accelerates dough development by reducing critical mixing speed and energy requirements. Terms such as "chemical development" imply that the use of cysteine eliminates the need for physical (mechanical) dough development. It is suggested that a term such as "chemically accelerated dough development" more meaningfully describes the function of reducing agents in breadmaking.

In conclusion, the use of cysteine may be considered relative to three (mixing) situations.

1. Where mixing speed is fast enough to enable high-volume bread to be produced without cysteine, addition of cysteine may be advantageous in reducing energy-input requirement and mixing time to permit: (a) an increase in mixer throughput, (b) the use of lower (final) dough temperatures, and (c) a saving in the cost of electrical energy.

2. Where mixing speed is below the critical mixing speed for the flour used, cysteine reduces the critical mixing speed requirement of the flour, enabling peak dough development to be achieved and resulting in reduced work requirement, shorter mixing times, and the production of bread of satisfactory volume.

3. Where slow-speed mixers are used and mixing speed is very much below the critical mixing-speed requirement for any flour used, and where the use of the correct level of cysteine still requires relatively long mixing times with respect to peak dough development, it may be possible to achieve satisfactory bread with considerably less work and shorter mixing times.

Acknowledgments

The authors gratefully acknowledge the competent technical assistance of Mrs. Louise Mazur and E. J. Gander. The authors wish to thank W. Shuey of the USDA HRS and Durum Wheat Quality Laboratory, Fargo, N. Dak., for providing the sample of Red River 68 wheat flour.

Literature Cited

1. KILBORN, R. H., and TIPPLES, K. H. Factors affecting mechanical dough development. I. Effect of mixing intensity and work input. Cereal Chem. 49: 34 (1972).
2. TSEN, C. C. Chemical dough development. Baker's Dig. 44: 28 (1970).
3. HENIKA, R. G., and RODGERS, N. E. Reactions of cysteine, bromate, and whey in a rapid breadmaking process. Cereal Chem. 42: 397 (1965).
4. HENIKA, R. G. Cysteine, whey, and oxidant reactions in continuous mix. Cereal Sci. Today 10: 420 (1965).
5. COPPOCK, J. B. M. Accelerated mechanical dough development. Proc. Amer. Soc. Bakery Engrs., 45th meeting, 79 (1969).
6. EWART, J. A. D. A hypothesis for the structure and rheology of glutenin. J. Sci. Food Agr. 19: 617 (1968).
7. HLYNKA, I., and ANDERSON, J. A. Laboratory dough mixer with an air-tight bowl. Cereal Chem. 32: 83 (1955).
8. KILBORN, R. H., and TIPPLES, K. H. Improved small-scale laboratory mixing unit. Cereal Sci. Today 14: 302 (1969).
9. KILBORN, R. H., and TIPPLES, K. H. Factors affecting mechanical dough development. III. Mechanical efficiency of laboratory dough mixers. Cereal Chem. 50: 50-69 (1973).
10. GAY, H. W., and MOSES, K. S. There are many advantages in "no time" dough process. Australasian Baker 72: 27 (1969).

[Received October 1, 1971. Accepted August 23, 1972]