A PROCEDURE FOR THE PRODUCTION OF MILLET ROTIS

by

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love to

Jan Olewnik

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INTRODUCTION

The food shortages, especially in the developing countries of the tropics and subtropics underscores our need for food. From the standpoint of our ability to produce and their effect on human nutrition, millets and sorghum constitute one of the most important food sources in tropical nations.

The term 'millet' refers to many small seeded cereals and forage grasses used for food, feed, or forage (Rachie 1975). Millets are generally short-term, warm season (summer) crops sometimes used in emergencies following failure of less adaptable crops. Some species of millet have the ability to resist drought conditions, high temperatures, low soil fertility, and disease.

The world's millet crop is grown largely in China, India, Russia, and those African countries along the southern fringe of the Sahara. The average world production of millet is in excess of 44 million tons with about 85% of this being utilized directly as human food. China and India produce over half of the world's crop; along with the Soviet Union and Africa they produce almost 90% of the total. Millet is used as food by over 400 million people. In many areas of India and North Africa, millet is the principal staple and may constitute 80 to 90% of that populations total caloric intake.

The millets are composed of ten genra. This study deals with Pennesetum Americanum (L.) Leeke, commonly known as pearl millet or, in India, bajra. Pearl millet appears to have the greatest potential of all the millets. It is extremely drought tolerant, can resist high temperatures, and grows well in light soil. Thus it will produce a crop under semi-arid growing conditions.

In India and Africa, pearl millet is eaten in many forms. There are a number of porridges that vary in whether they are fermented and on their ratio of meal to water. Millet is also prepared as a rice substitute. The whole or cracked grains are decorticated and steamed until soft (Badi et al 1980). A steam leavened flat bread called a chapatti or roti is traditionally made with wheat, but in arid and/or semi-arid regions sorghum and/or millet is used.

In the rural areas of the India states of Fajasthan, Mahasta, and Mysore the millet roti is consumed on a daily basis. Little has been reported in scientific literature on production of millet rotis. Mason and Hoseney (1980) proposed a preliminary method for the production of pearl millet rotis.

The purpose of this study was to optimize a procedure for the production of rotis in the laboratory. The procedure can then be used to identify quality parameters in grain. The study also included the development of a rheological testing procedure useful in determining optimum water absorption in millet roti doughs.

LITERATURE REVIEW

Milling Process

In many rural areas of developing countries the traditional mortar and pestle method of milling pearl millet is still used (Reichert and Youngs, 1977; Goussault and Adrian, 1977). In this method, millet and water (10 to 20% of the grain) are placed in a mortar and the grain is dehulled by pounding with the pestle. Although generally described as dehulling, the process acutally removes part of the pericarp, the hull is removed during threshing. The grain is then dried and the light material removed by winnowing with a woven basket. The dried milled grain may be ground to produce a fine flour, by reduction between two flat stones or additional pounding with a mortar and pestle.

Traditional milling is time-consuming and requires much human energy. Most villages in both India and African countries now have diesel powered hammer or burr (attrition) type mills (Vogel and Graham, 1979). The fineness of these mechanically produced flours is not necessarily dictated by consumer desire, but may vary depending on the ability of the mill to produce fine meals (Murty et al 1981). Table 1 illustrates the particle distribution of millet meals ground on mills in three different Indian villages.

In his studies of the production of millet and sorghum flours, Perten (1976) concluded that wheat milling technology was not appropriate. The bran coat and germ of millet and sorghum adhere tightly to the endosperm and are easily pulverized to a fine powder which is then difficult to separate from the flour. A logical approach to the problem appears to be to separate the pericarp by a decortication step before crushing the endosperm into flour.

Table 1. Particle Size Distribution of Millet Meal Ground on Indian Village Mills

Sample (Village)	% >65 Mesh	% 65-100 Mesh	% <100 Mesh
Mahroli[a]	46.8	16.8	36.4
Churi Miyan[b]	11.6	29.6	58.8
Nechiva[b]	18.0	23.6	58.4

[a]Ground by hand between two stones

[b]Ground on a village burr mill

Several processes have been proposed recently for producing millet flour (Goussault and Adrian, 1977). The Sotramil, used in Zinder Niger, first cleans the grain by washing, removing large impurities, and small, low quality grains. The grain is then decorticated by passing it through two horizontal millstones. Milling is done on an "ultrafine" attrition mill.

The Sepial process utilized a two step procedure in decorticating the millet. The first step removes the "wetted" pericarp by passing the grain through rotating paddles which produces friction between the grain. The grain is further decorticated to remove the protein rich layers (Hyaline and alurone). The decorticated grain is then ground, producing about 80% extraction of the total grain.

Abdelrahman (1982) proposed a milling system using roller mills to produce low fat grits. Tempering millet to a high moisture content (22%) for a short time (1-6 hrs.) increased the amount of germ separated, therefore increasing the amount of fat separated with the germ. Using rolls with fine corrugations increased the yield of low-fat grits. Low fat millet is apparently advantageous because of its increased keeping quality after grinding.

Food Uses

There are a variety of foods traditionally made from millet. Products may be known under different names depending on the area, but generally there is little variation in those products (Hoseney et al, 1982; Vogel and Graham, 1979; Subramanian and Jambunathan, 1980; Deyoe and Robinson, 1979; and Cluskey et al, 1979).

Millet is often decorticated and steamed until it is soft. This product is eaten as a rice substitute (Badi et al, 1980). In Senegal, millet flour is agglomerated and steamed soft forming a product called "cous-cous".

An unleaved bread called a chapatti, or roti, is traditionally made from wheat. The gluten-forming properties of wheat allow the production of a semi-light bread that is flexible, firm but not tough, and that puffs evenly. In many areas of India, the roti is made of sorghum or millet. Sorghum and millet do not have the gluten-forming properties of wheat flour. Accordingly, the wheat dough behaves differently from sorghum or millet roti doughs. In short, sorghum and millet doughs trap gas less readily and tear more easily than do wheat roti doughs (Mason and Hoseney, 1980).

The millet roti is traditionally prepared with stone ground millet flour with an extraction rate of 80 to 100% (Rashi, 1974). The meal is mixed with water and sometimes salt, to produce a dough of proper consistancy. The dough is then rested under a moist cloth, rolled into a ball, rolled or patted into a disc, and baked on a greaseless iron plate. The roti may be puffed by placing it in the fire or against a heated coal for a few seconds. Puffing is encouraged by tamping the baking dough's upper surface with a moistened cloth before placing it in the fire (In general, millet dough does not puff.). The cooking time required depends on the temperature of the plate and size of the roti. Rotis are generally eaten soon after preparation.

Documented information on millet rotis is limited at best. Because a millet roti is an ersatz wheat roti, a consideration of desirable wheat roti quality was used in defining what a millet roti should be (Mason and Hoseney, 1980). Aziz (1960) noted that a roti should be flexible with a soft silky surface. The mouthfeel should be smooth with the roti easily chewable. Ahmed (1960) observed that the thickness and texture of the roti should be uniform across the diameter. Sinha (1964) stated that a roti should not be leathery, tough, brittle, or gritty, and that the roti should be well-puffed and well-baked inside. Because of the lack of dough strength, millet rotis will tend to be thicker, show less of a tendency to puff, and not be as well baked inside as are rotis made of wheat.

A steam leavened bread, kisra, made of sorghum or millet is popular in Sudan. A thin batter of flour and water is allowed to ferment overnight to produce a sour flavor from the lactic acid bacteria. This batter is spread thin on a hot griddle for a few seconds then stripped from the plate to give a thin moist sheet (Hoseney et al, 1982).

Casier et al (1977) reported on the production of a yeast-leavened bread made from millet and sorghum flours. He reported that addition of 4% rye pentosans to millet flour produced loaves with improved crumb structure and volume when compared to those without rye pentosans. The breads containing the rye pentosans also showed resistance to staling for at least one week. The breads produced were not directly compared to wheat breads or organoleptically evaluated.

Badi et al (1976) looked at the effect of substituting millet flour for a percentage of the wheat flour in white pan bread and cookies. They found that there was an improving effect on loaf volume and crumb when 10% millet flour was added to a white pan formula containing no sugar or salt. The effect was attributed to the highly active α-amylase in the millet flour.

Untreated millet flour alone did not produce acceptable cookies. The cookies had essentially no spread and no top cracks; they were tough, hard, gritty, and mealy in texture and taste. Badi (1976) found that millet treated by hydrating the flour for 3 hours and then air drying, gave improved cookies. Although the cookies were more fragile than those made with wheat flour, the eating quality was satisfactory.

Determining Absorption Properties through Stress Relaxation

It is well known that moisture absorption can significantly change the physical characteristics of powders, most notably their bulk density and compressibility. Peleg et al (1979) studied the effect of moisture on powders by obtaining stress relaxation data with an Instron Universal Testing Machine. In this test, the powder/water specimens were compressed at a rate of 0.05 cm/min until a stress of 5 kg/cm^2 was reached. At that point the compression was stopped and the stress relaxation curve was recorded. Figure 1 shows a schematic view of deformation and relaxation curves for 'wet' and 'dry' powders. As expressed by Peleg et al (1979), "The wet powders were more deformable than the dry powders. Therefore the time to reach the set force was considerably longer in the case of wet powders (allowing for more stress relaxation to occur during deformation stages)."

The stress relaxation curve is influenced by a number of parameters (i.e. in a meal these would include starch damage, particle size, variety, shape of particles, etc.). These parameters can vary independently making it difficult to compare data obtained for different materials. Peleg et al (1979) noted that if the relaxation curve were normalized to give a straight line using the equation $t/y(t)=\frac{1}{ab}+\frac{t}{a}$, (where y(t) is the decaying parameter and a and b are constants) it would be possible to compare data obtained from different materials. In this application, a is the asymptotic residual level of y(t) (e.g., if a=1.0 the stress relaxes to

Figure 1. Schematic view of the deformation of relaxation curves of dry and wet powders

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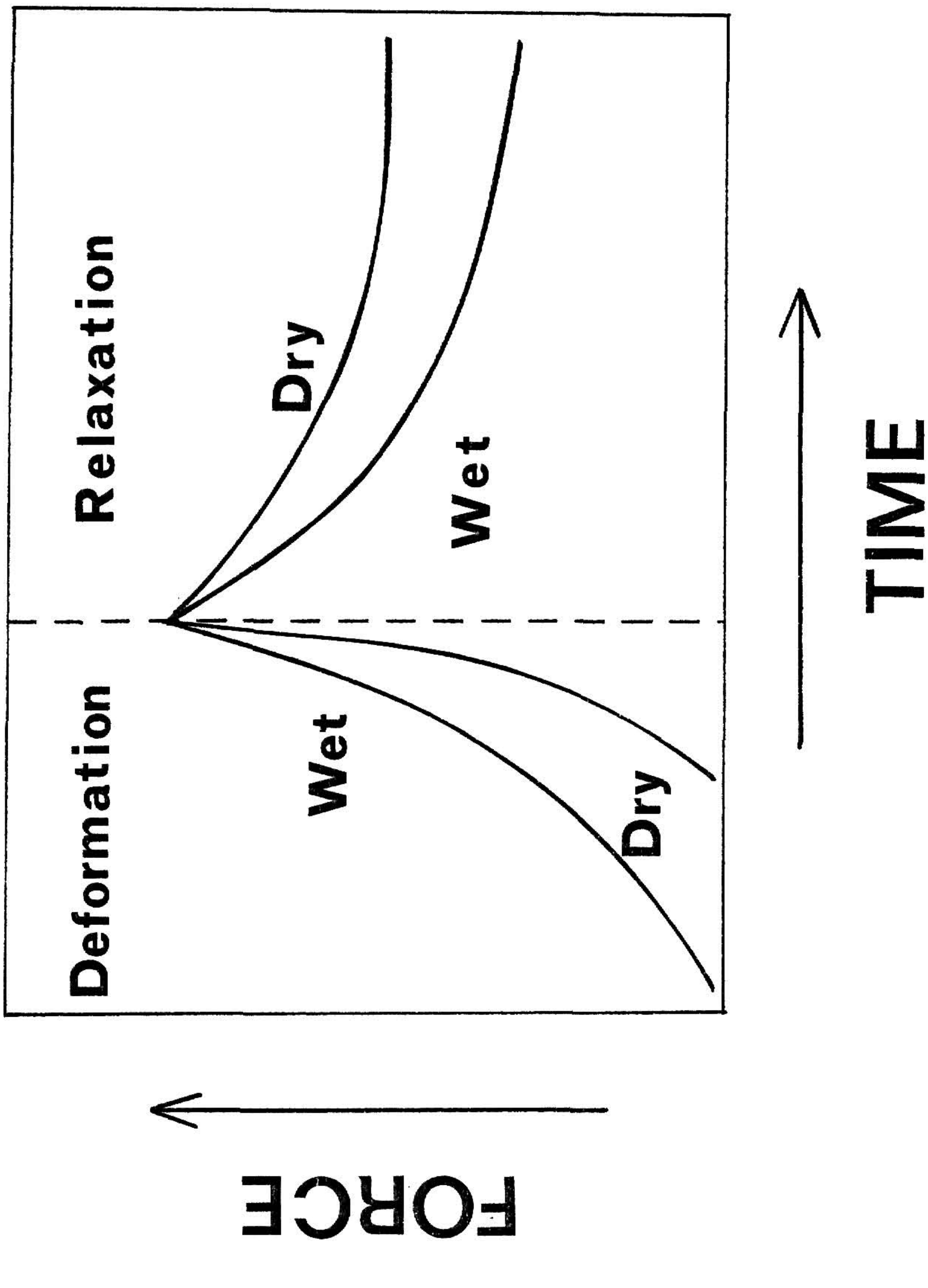
Deformation
Relaxation
Wet
Dry
Dry
Wet
FORCE
TIME

zero level as in the case of water). The constant b represents the steepness of decay. When the time allowed for stress relaxation is fairly short, the numerical value of constant a is a measure of what initial stress is relaxed, which is an indication of the general mechancial character of the material. In those cases where major rheological differences can be observed in a relatively short time therefore, the constant a can be employed as a practical index to quantify differences in relaxation patterns among materials by a uniform scale (Peleg, 1979).

MATERIALS AND METHODS

Grain Samples

Several pearl millet samples were used to study the physical characteristics of millet meal. To standardize the roti baking procedure, pearl millet cultivar 2090 x 7107 grown in Minneola, Kansas, was used. Three varieties grown in Sudan, i.e. Sudan Green, Sudan Yellow, and a Commerical Sudanese millet were used to test differences in cultivars. Other pearl millet cultivars grown in Hays and Minneola, Kansas, during the 1980 crop year were used and included: 79-2201 x 78-7024, 79-2017 x 79-4014, 79-2216 x 78-7024, 79-2161 x 79-4104, 79-2149 x 79-4104, and 79-2059 x 79-4104. Three millet samples grown in India, and ground on village mills were used to compare particle fineness of traditionally produced meals to those produced experimentally.

Preparation of the Samples

The grain was scoured on an experimental scourer to loosen and remove adhering husks. Husks and light weight debris were separated from the grain with the Kice Aspirator. Fines and broken kernels were separated from the whole kernels by sifting the grain over a 10W screen on a Smico Gyro-laboratory Sifter.

Five milling systems were used to produce samples that varied in particle size and starch damage. Those systems included the following:

A. Ross Experimental Roller Mill (Fig. 2) - The first break rolls had 22 corrugations/inch, a roll gap of 0.015 in. and a differential of 1.5:1. The function of these rolls was to tear open the kernel and break the stock into small particles. The second stand had rolls with 28 cor-

Figure 2. Ross Experimental Roller Mill, upper right

Figure 3. Hobart Coffee Grinder (attrition), middle

Figure 4. Quadrumat Junior Experimental Roller Mill, lower right

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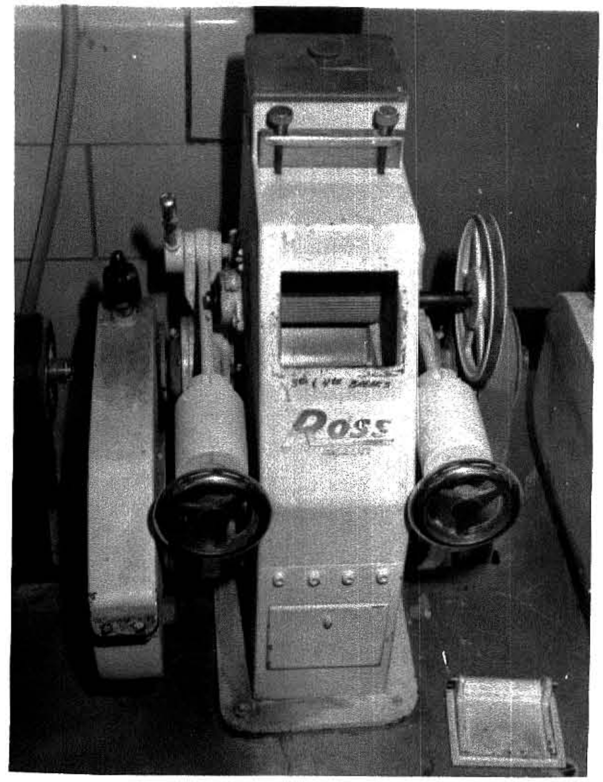
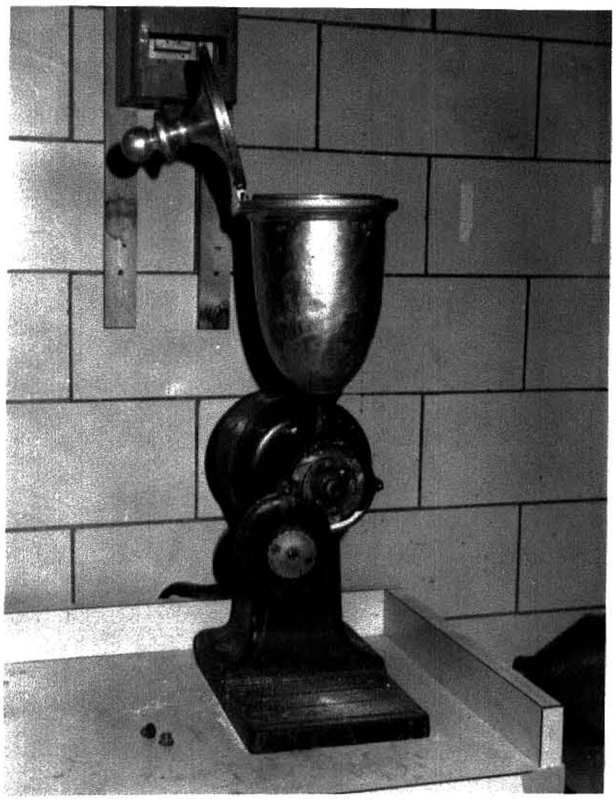
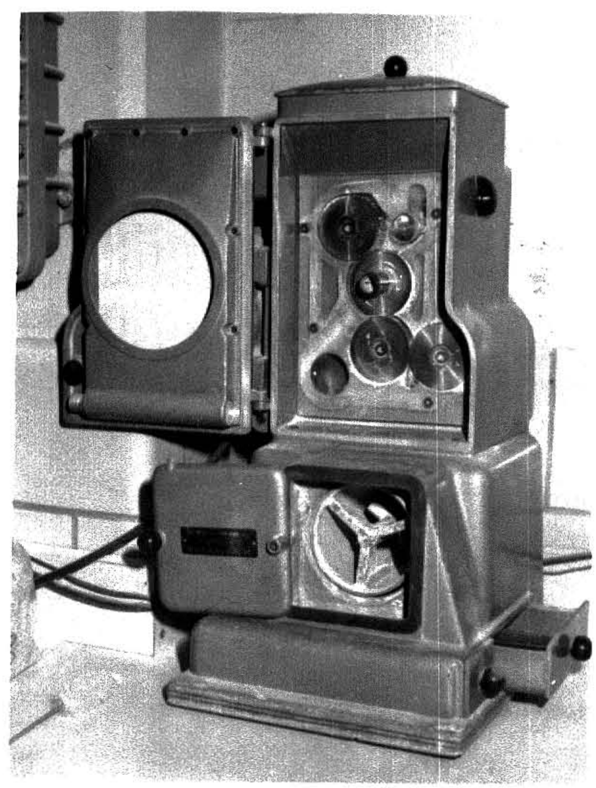

Ross





rugations/inch, a differential of 1.5:1, and the roll gap was varied with consecutive reduction steps. For example whole grain millet was ground until 99% of the millet meal passed through a 35 mesh screen. The roll gap of the second mill stand was set at 0.01 in. for the first reduction. The stock was again sifted on a 35 mesh screen and the overs reground. This process was repeated with gradual reduction in the roll gap until 99% of the stock passed through the 35 mesh sieve.

Whole grain millet was also ground until 99% of the millet meal passed through a 42 mesh screen. The grain was reduced as described above, except for the size of the sieve used.

B. Hobart Coffee Grinder (Fig. 3) - There are several settings on this attrition type mill which allows the stock to be ground to various levels of fineness. Settings #5 and #9 were used to grind pearl millet and achieve a medium (i.e. 40% to 60% was >65 mesh) and coarse (i.e. 60% or more >65 mesh) distribution respectively.

C. Quadrumat Junior Experimental Roller Mill (Fig. 4) - The mill employs 4 rolls which provide three breaks. The first break utilizes rolls #1 and #2 with differential of 2.3:1. Roll #1 has 12 corrugations/inch and runs at 1240 RPM. Roll #2 has 25 corrugations/inch and runs at 540 RPM. The second break employs rolls #2 and #3 with a differential of 2.22:1. Roll #3 has 37 corrugations/inch and runs at 1200 RPM. The third break is between rolls #3 and #4 with a differential of 2.22:1. Roll #4 has 40 corrugations/inch and runs at 540 RPM. The fines are separated through a rotating sieve, 64GG, at the base of the mill and the coarse fraction is reground.

D. U D Cyclotec Abrasion Mill (Fig. 5) - The severe abrasive action of this mill reduces whole grain millet to a fine powder with a single pass. This mill employs high speed centrifugal force which abraids the grain against an abrasive disc. A 1 mm mesh sieve allows only the finely ground meal to discharge.

E. Alpine Pin Mill (Fig. 6) - This mill has a severe impact-type grinding action. Four concentric rows of rotating pins move past four concentric rows of stationary pins at 14000 RPM. Whole grain millet was reduced to a fine powder with a single pass.

Separation of the Sample

After grinding the particle size distribtuion was determined by separation on the Alpine Sifter (Fig. 7). The meals were characterized arbitrarily as % >65 mesh, % between 65-100 mesh, % <100 mesh, to indicate coarse, medium, and fine particles, respectively.

Baking Method

The following represents the roti baking method established as the standard in subsequent testing. This method was developed using the millet cultivar 2090 x 7107 milled on the U D Cyclotec Abrasion Mill (Fig. 8A-F).

1. Mix 50 g millet flour with 37 ml tap water (74% absorption)

Figure 5. U D Cyclotec Abrasion Mill, upper

Figure 6. Alpine Pin Mill, lower

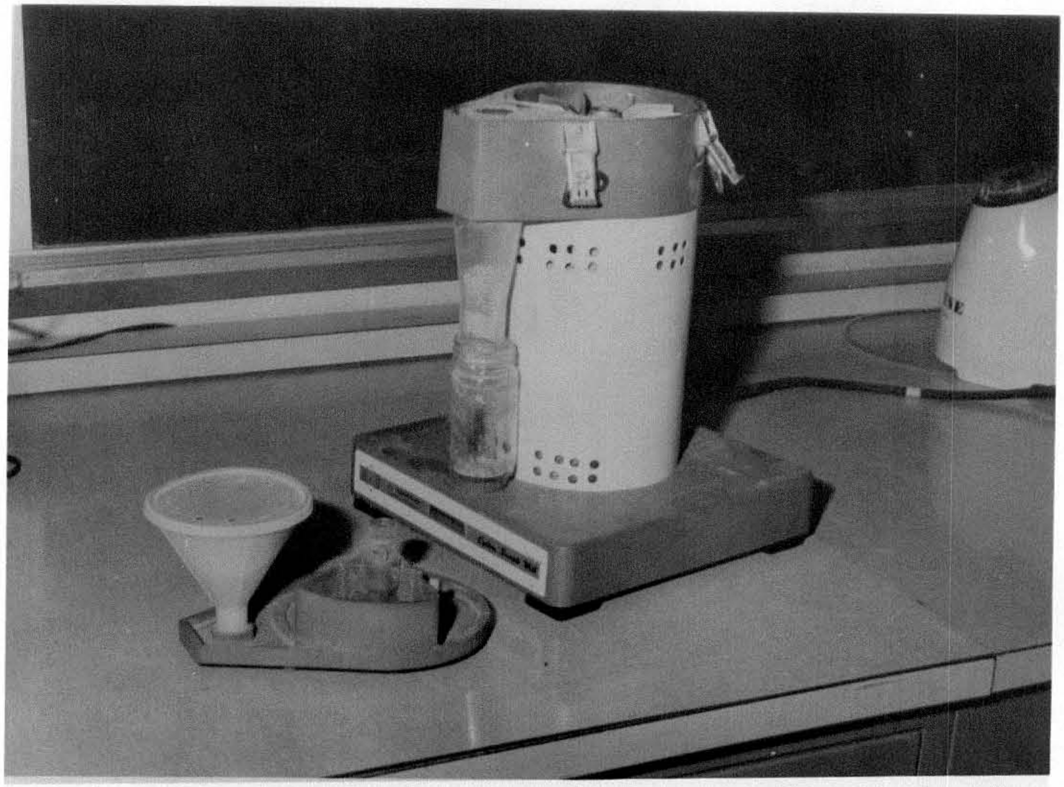
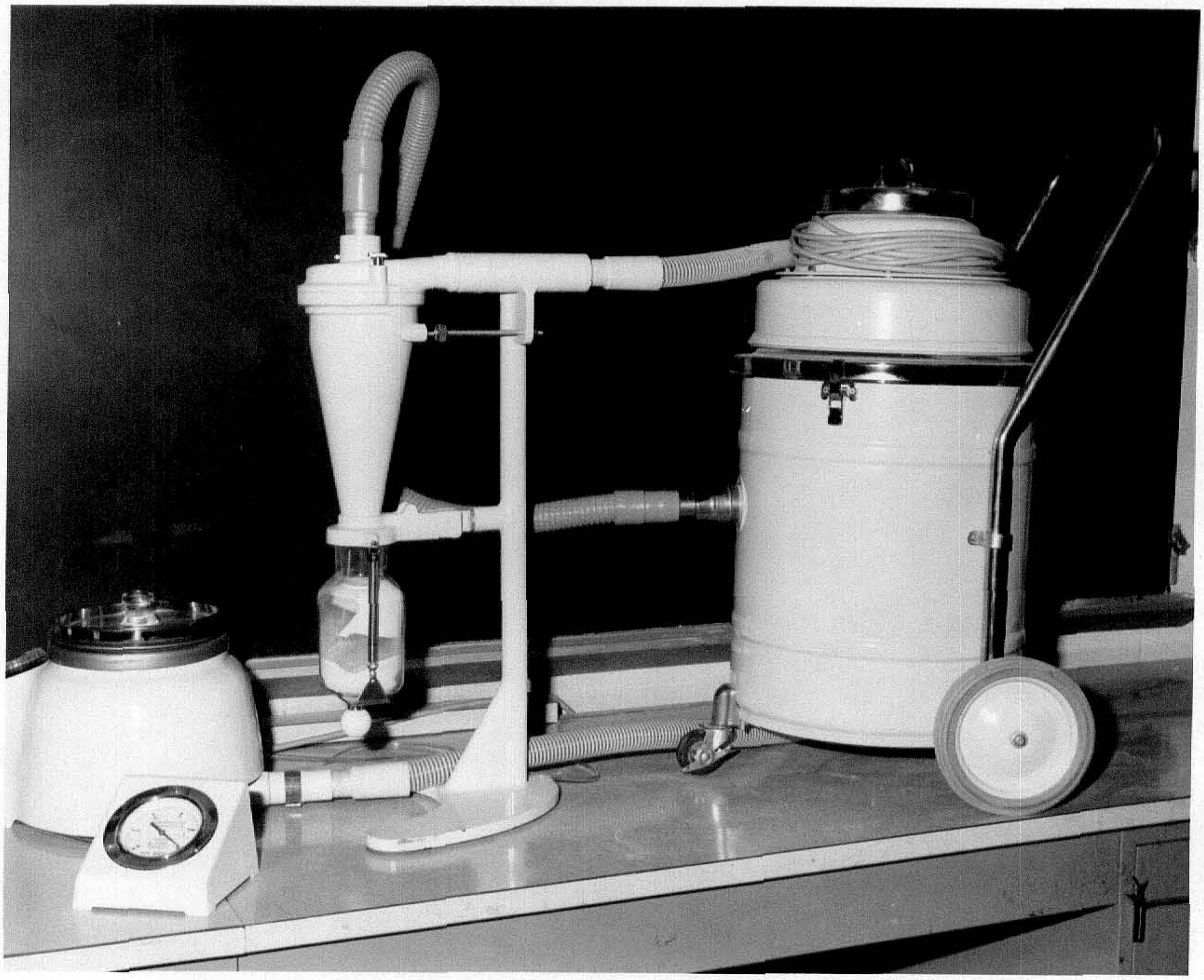


Figure 7. Alpine Sifter



using a spoon to achieve uniform consistency.

2. Roll the dough into a ball and place the ball in a zip-lock plastic bag for 60 min at room temperature.
3. Remove the doughball from the bag and place on a board covered with dusting flour. Lightly dust the dough (Fig 8A).
4. Roll the ball gently in all directions with a wooden rolling pin unitl it is 5 to 7 mm thick and approximately round. Place rolling pin on 3 mm spacing bars and, using them as a guide, continue to roll gently until the dough is 3 mm thick. Intermittant use of dusting powder on the surface may be neccessary to control sticking and tearing of the dough (Fig. 8B).
5. Using a round guide, approximately 7 in. in diameter, cut the dough into a circle and discard excess dough (Fig. 8C).
6. Separate the roti from the cutting board by gently sliding small amounts of flour under the roti using a spatula. Once the roti is loosened, carefully slide it onto your hand, with the aid of the spatula, and transfer quickly to the hot plate with the surface that was on the cutting board up. That surface should be lightly dusted with meal. Avoid any cracks or breaks in the dough. If this transfer proves difficult, loosen the roti as described and invert the entire board allowing the roti to fall directly onto the hot plate (Fig. 8D).
7. The hot plate is preheated to $200^{o}C \pm 3^{o}$ and is ungreased. With a spatula, gently press inward on the roti edges to prevent the escape of steam through small cracks.

Figure 8A. Prepared roti dough, upper left

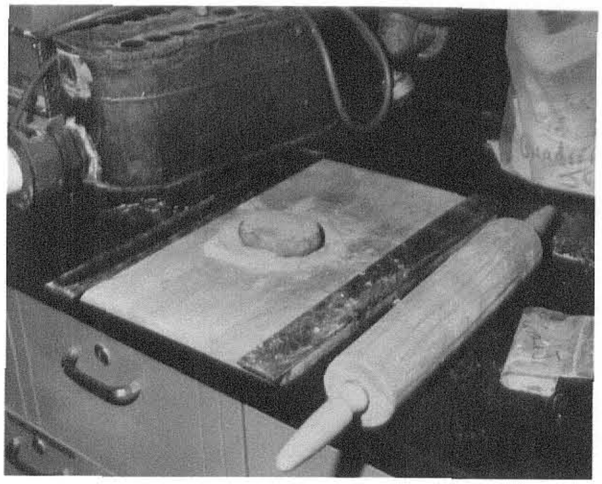
Figure 8B. Dough is rolled between two 3 mm bars, upper right

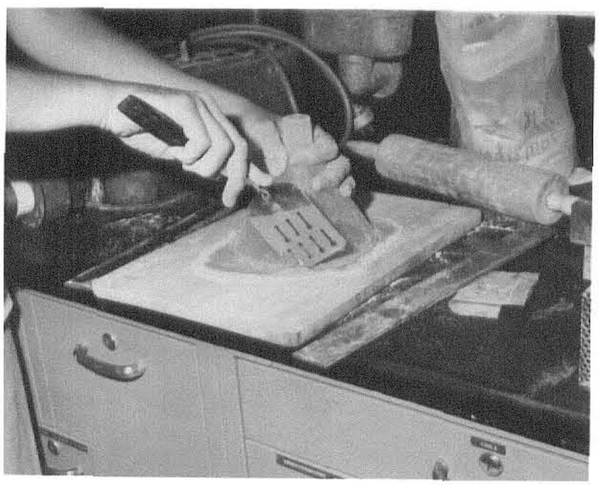
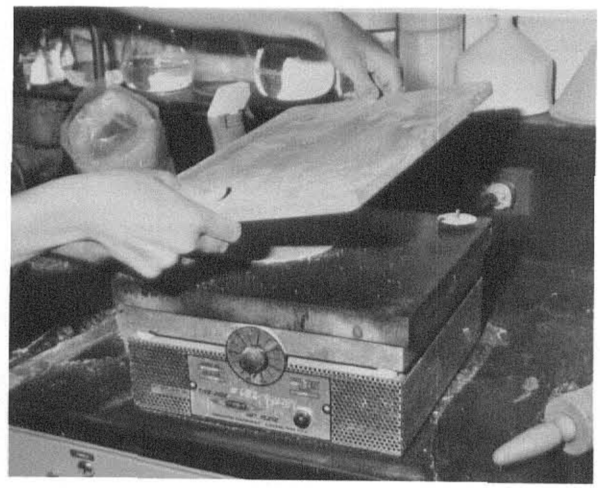
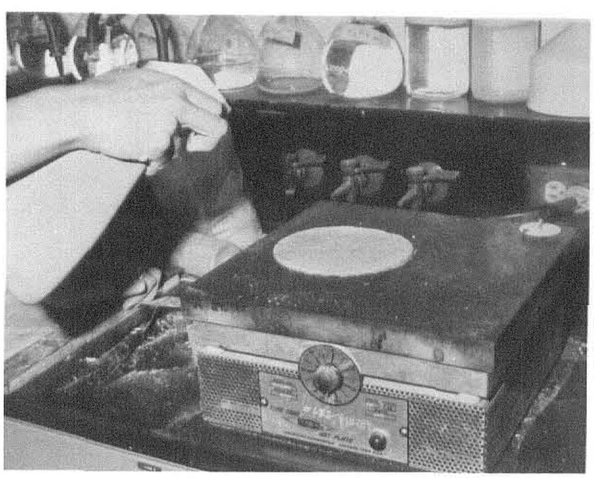
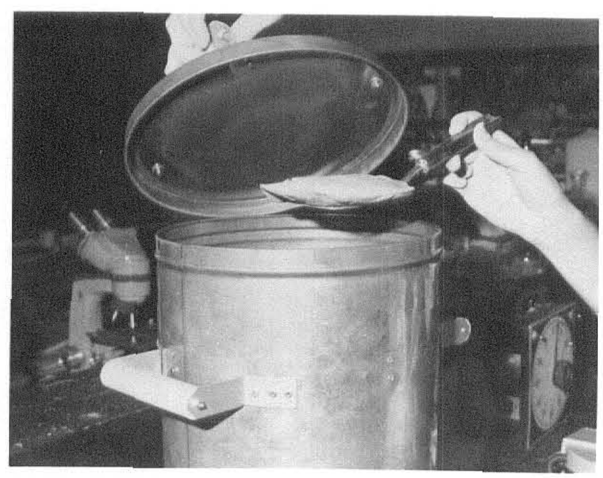
Figure 8C. Dough is cut to 7" diameter, middle left

Figure 8D. Dough is transferred to 200°C hot plate, middle right

Figure 8E. Dough is sprayed lightly with water before flipping it the first time, lower left

Figure 8F. Roti is puffed in 350°C tandoor after 6 min cook time on the hot plate, lower right



8. Bake on side 1 for 90 seconds. During the last 15 sec apply an even mist of water (approximately 3 mls) over the roti's exposed surface (Fig. 8E).
9. Flip the roti and bake 90 seconds on side 2.
10. Again flip the roti and bake for 90 seconds on side 1.
11. Again flip the roti and bake for 90 seconds on side 2.
12. Transfer the roti to the simulated tandoor, heated to about 350^{o}C, with the side 2 up and close the lid. Heat for about 30 seconds or until completely puffed (Fig. 8F).

Separation of Water Solubles

Water solubles were separated from millet meal by mixing 60 g meal with sufficient water (ea. 100 ml) to make a slurry. The slurry was centrifuged for 10 min at 1600 RPM and the supernatant decanted. The insoluble residue was spread on an aluminum tray and air dried. Fully dried chunks of meal were then passed through smooth rolls of the Ross Experimental Mill with the roll gap set at 0.005 in. to reduce the meal to its original fineness.

Damaged Starch

Percent damaged starch was determined using AACC method 76-30A.

Scanning Electron Microscopy of Millet Meal

Millet meal was prepared by grinding whole grain millet on the U D Cyclotec Mill and the Quadrumat Junior Roller Mill. Double sticky tape on an SEM stub was dusted with these meals and coated with gold-palladium prior to being viewed on the ETEC scanning electron microscope at an accelerating voltage of 20 kv.

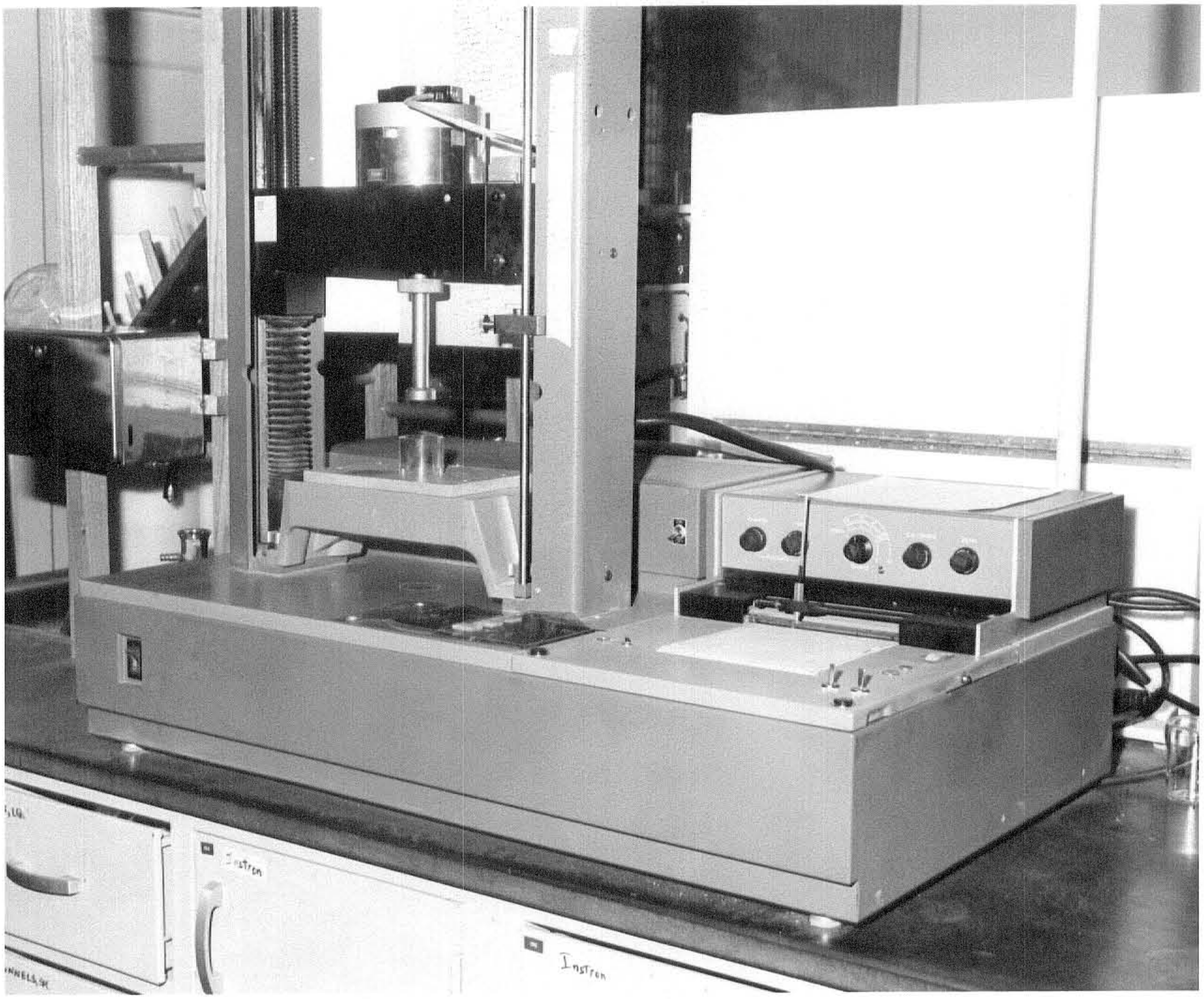
Instron Stress Relaxation Curves

Stress relaxation data for millet doughs was obtained with the Instron Universal Testing Machine Model 1132 (Fig. 9). Millet doughs were prepared as previously described. Dough samples were evenly packed in a plexiglass cell (37 mm in diameter and 25 mm high). The dough was compressed at a rate of 0.25 cm/min. The plunger was 35 mm in diameter allowing approximately 1 mm clearance between the plunger and the cell wall.

The Instron was adjusted to 50 g force/division and a chart speed of 10 cm/min. The peak stress on the dough was arbitrarily chosen to be 2 kg/cm^2, therefore, the stress curve was allowed to increase 4.5 divisions. When the peak force was reached, the cross head was stopped with the plunger in place and the chart paper still running. The stress relaxation was then recorded.

The force at 0.25, 0.5, 0.75, 1.0, 1.25, 1.5, 1.75, and 2.0 min was recorded and these values normalized with respect to the stress relaxation curve. We used the equation $F_o t/(F_o - F_t)$ (min); where F_o is the peak force, t is time, and F_t is the stress relaxation force at a given time (Peleg et al, 1979).

Figure 9. Instron Universal testing machine


Instron
Instron

RESULTS AND DISCUSSION

The procedure developed for the laboratory production of the millet roti was based on studies dealing with wheat rotis and personal communications with researchers from India. This procedure does not necessarily duplicate those rotis made in rural India, which, of course, vary widely from place to place. Our goal was to develop a reproducable procedure that would produce a reasonable roti. We then wanted to use the procedure to study the properties of millet meal important in roti making.

Baking Parameters

Quality guidelines for rotis were arbitrarily set according to those considered desirable in wheat rotis. The following characteristics were considred as important parameters: 1) minimal thickness; 2) uniform puffing; 3) uniformity of texture and color; 4) golden brown surface color with intermittent darker spots where air pockets had formed; 5) adequate internal cooking (chewy rather than raw, gummy, or brittle texture).

The preliminary method developed by Mason and Hoseney (1980) and an American grown cultivar of millet, 2010 x 7107, was used as a starting point for the standardization of rotis. Mason and Hoseney's (1980) method included mixing a dough of millet flour with boiling water, tempering the dough for one hour in a ziplock bag, rolling the dough to a minimal thickness and cutting it to a standard size, i.e. 7 in. diameter. The flattened dough piece was then placed on a greaseless hot plate and baked for six minutes at 200°C. The roti was turned every 1.5 min and the surface facing upward before the first turn was sprayed lightly with 2.5 to 3 ml water using a fine mist spray gun. The cooked roti was then transferred to a tripod ring stand and flamed on both sides using a

Bunsen burner.

According to Desikachar (1977), the use of boiling water was necessary to give the roti dough sufficient cohesiveness (the flour used in Desikachar's study was finer than 60 mesh). To test the conclusion that boiling water was necessary to form a cohesive dough, we prepared dough with water that varied from 30°C to 100°C (in 10°C increments). The resultant roti doughs were not significantly different in handling or cooking quality.

To control the heat applied to the roti during puffing, we devised a simulated tandoor similar to those used in India (Fig. 8F). In a tandoor, a gas heat source is shielded from the cooking area by a metal cover. This allows the heat to be distributed evenly in the cooking area. A wire mesh rack was placed in the tandoor. The roti was placed on this wire mesh rack when being puffed. Puffing occurs fast and uniformly. An even high heat was not attainable with a Bunsen burner.

As the roti was cooked, moisture evaporates from the exposed surfaces. Starch is gelatinized and drying occurs on the surface that is in contact with the hot plate. Water diffuses from this unexposed surface to exposed areas where the moisture evaporates. When the roti is turned, the second side is dried and the moisture from this side moves toward exposed areas of the roti. Spraying the first exposed side with water provides a cooling effect that reduces the amount of moisture lost in baking. The moisture in the inside of the roti vaporizes when subjected to sudden high heat in the tandoor (ca 350°C) and this causes the roti to separate and puff. If, during baking, cracks form on the surface of the roti, a greater amount of water is lost and the roti will not puff evenly or completely.

Effect of Meal Particle Size on the Millet Roti

Whole grain millet, ground to varying degrees of fineness, produced roti doughs with marked differences in handling properties and texture. In addition, the meals of different particle sizes required different water absorptions and cooking time to produce an acceptable roti. Meals ground on the Hobart Coffee Grinder and Ross Experimental Roller Mill to a coarse particle size (40% greater than 65 mesh, Table 2), produced doughs that were noncohesive and difficult to mold. With those coarse meals, cooking time required to produce a roti with a nonstarchy flavor was long. In addition, those rotis did not separate or puff when placed in the simulated tandoor. The finished roti was gritty and dense and had little flexibility (Table 3). The roti's outer surface was excessively brown because of the increased cooking time and lack of bubbling on the surface (the complete surface was in contact with the hot plate throughout the cooking period).

Meals with a fine particle size, such as those produced on the Quadrumat Junior Experimental Roller Mill and the U D Cyclotec Abrasion Mill (Table 2), produced soft cohesive doughs that could be easily molded. A cooking time of 6 min with 3 intermediate turns was adequate. Some vaporization of the water in the roti during cooking caused air pockets or bubbles to form on the surface of the roti. Those slightly raised areas browned and hardened more than the rest of the roti surface allowing for more flexibility in the less hardened areas. When placed into the heated tandoor, these rotis puffed completely, producing a pliable nongritty texture and no raw starch flavor (Table 2).

Effect of Cooking Time on the Millet Roti

Using the meal produced with the U D Cyclotec Abrasion Mill, the

Table 2. Particle Size Distribution[a]

Sample	% >65 Mesh	% 65-100 Mesh	% <100 Mesh
Ross through 35 mesh	40.4	24.6	35.0
Ross through 42 mesh	14.0	33.2	52.8
Hobart Coffee Grinder #5	56.4	17.6	26.0
Hobart Coffee Grinder #9	75.0	12.6	12.4
Pin Mill	21.2	19.2	59.6
UD Mill	8.4	10.8	80.6
Quadrumat Junior Mill	0.0	18.4	81.6

[a]Cultivar 2010 X 7107 was used, milled on different mill types

Table 3. Effect of Meal Particle Size on Roti Quality[a]

Sample	Mixing & Handling	Puffing	Texture	Color	Taste
Ross through 35 mesh	Semi-cohesive; molds with difficulty	Incomplete	Fairly flexible; gritty	Excessive browning	Raw starch
Ross through 42 mesh	Cohesive; molds easily w/some surface cracking	Varied	Flexible; fairly gritty	Fair	No raw starch
Hobart Coffee Grinder #5	Semi-cohesive; difficult to mold	None	Nonflexible; gritty	Excessive browning	Raw starch; earthy
Hobart Coffee Grinder #9	Non-cohesive; will not mold	None	Nonflexible; very gritty	Excessive browning	Raw starch; earthy
Pin Mill	Cohesive; molds easily	Complete	Flexible; soft	Good	No raw starch
UD Mill	Cohesive; molds easily	Complete	Flexible; soft	Good	No raw starch
Quad. Jr. Mill	Cohesive; molds easily	Complete	Flexible: soft	Good	No raw starch

[a]Cultivar 2010 X 7107 was used

optimum cooking time and temperature was determined. Variables studied included the cooking time before turning, the temperature of the hot plate, and the total cooking time (Table 4).

A roti baking for 3 min on each side with only one turn after the first 3 min, yielded a product that was hard and cracked on the outside and gummy inside. Furthermore, when those rotis were placed in the simulated tandoor no puffing occurred. Rotis cooked at 200°C, with a series of turns at 1.5 min intervals, were pliable with a silky surface. When placed in high heat, these rotis puffed quickly and evenly.

Rotis cooked less than 6 min were sticky inside and had a raw starch flavor. Increasing the cooking time above 6 min yielded rotis that were hard and dry, and did not puff completely.

Optimum cooking time also varied with changes in surface temperature of the hot plate. Hot plate temperatures less than 200°C required a longer cooking time to produce a roti with no raw starch flavor. These rotis tended to be dry inside and out and puffed unevenly when placed in the simulated tandoor. Hot plate temperatures above 200°C cooked the outside of the roti very rapidly causing the roti surface to dry and crack. The insides of these rotis were sticky and had a raw starch flavor. Puffing of these rotis was limited due to escape of the water vapor from the cracked surface.

Effect of Mixing Time on the Millet Roti

The effect of mixing time on the handling properties of roti dough and final quality of the roti was studied (Table 5). Mechancial mixing was tested by combining cultivar 2090 x 7107, (Ground on the U D Mill) with water and mixing for periods varying from 30 sec to 20 min in the 50 g bowl of the Brabender Farinograph. The dough tended to become

Table 4. Effect of Varying Cooking Time and Temperature on Rotis[a]

Total Cook Time	Time Between Turns	Temperature Of Hot Plate in ^{o}C	Puffing	Texture	Color	Taste
6 min	1.5 min	$150^{o}C$	Complete	Flexible; sticky inside	Light	Raw starch
8 min	2.0 min	$150^{o}C$	Complete	Slightly flex-ible, sticky inside	Dark	Raw starch
6 min	1.5 min	$175^{o}C$	Complete	Flexible; sticky inside	Light	Raw starch
8 min	2.0 min	$175^{o}C$	Complete	Flexible; sticky inside	Dark	Raw starch
10 min	2.5 min	$175^{o}C$	Cracked edges; varied	Nonflexible; sticky inside	Dark	Raw starch
6 min	1.5 min	$200^{o}C$	Complete	Flexible	Varied; good	No raw starch
8 min	2.0 min	$200^{o}C$	Complete	Slightly flex-ible, edges hard	Dark	No raw starch
4 min	1.0 min	$225^{o}C$	Complete	Slightly flex-ible; sticky	Excessive-ly dark	Outside overdone; inside raw

[a]Cultivar 2010 X 7107 was used, milled on UD mill

Table 5. Effect of Varying Mixing Time on Rotis[a]

Time Mixed	Mixing & Handling	Puffing	Texture	Color	Taste
30 sec	Not well mixed--water not entirely incorporated				
60 sec	Mixed well; rolls easily	Complete	Flexible; soft	Good	No raw starch
90 sec	Slightly sticky; molds w/extra dusting flour	Complete	Flexible; soft	Good	No raw starch
3 min	Slightly sticky; molds w/extra dusting flour	Complete	Flexible; soft	Good	No raw starch
5 min	Sticky; molds w/extra dusting flour	Complete	Flexible; soft	Good	No raw starch
10 min	Sticky; molds w/extra dusting flour	Complete	Flexible; soft	Good	No raw starch
20 min	Sticky; molds w/extra dusting flour	Complete	Flexible; soft	Good	No raw starch

[a]Cultivar 2010 X 7107 was used, milled on UD mill

sticky with increased mixing time, but after tempering for 1 hr the dough lost much of its sticky characteristic.

Doughs that were mechanically mixed for 1 min produced roti doughs that were similar in handling properties to the hand mixed doughs. Stickly doughs, produced by "over-mixing", were more difficult to mold, but the final roti was comparable to rotis made from hand mixed doughs.

Hand mixing gave adequate distribution of water in the system and produced doughs that were easy to mold and that produced good quality rotis. When placed in the simulated tandoor, those rotis puffed completely if the water content was optimum.

From this data we concluded that the mixing time was not an important parameter in roti dough quality provided there was sufficient mixing to give an adequate distribution of water.

Water Absorption

Production of a good quality roti is dependent on proper water distribution and consistency within the roti dough. Perhaps the single most important factor in roti dough quality is optimum water absorption. Extent and type of grinding as well as cultivar and area grown tend to be governing factors in the hydration capacity of millet meal (Table 6).

The effect of different water levels on the behavior of the roti doughs during mixing, handling, and baking was studied. As shown in Table 5, for any given cultivar and grind of millet meal, there was one optimum water level. Excess water produced a dough that was sticky, difficult to mold, and tended to stick to the hot plate. The rotis produced from the wet dough were dense and wet and when placed in the simulated tandoor, those rotis would puff unevenly leaving a moist center with a raw starch flavor.

Table 6. Optimum Water Content for Specific Particle Size and Mill Type[a]

Sample	% >65 Mesh	% 65-100 Mesh	% <100 Mesh	Opt H_2O[b]
Ross through 35	40.4	24.6	35.0	76
Ross through 42	14.0	33.2	52.8	74
Pin Mill	21.2	19.2	59.6	70
Hobart #5	56.4	17.6	26.0	--
Hobart #9	75.0	12.6	12.4	--
UD	8.4	10.8	80.6	74

[a]Cultivar 2010 X 7107 was used

[b]Percentage on 100% flour basis

Effect of Cultivar on the Millet Roti

For any given cultivar of millet, ground to equivalent sizes, there is a specific level of water needed to achieve optimum consistency. In comparing different cultivars, all millet samples were ground to a fine powder on the U D Cyclotec Abrasion Mill (Table 7).

The samples showing extreme differences were the cultivars grown in Sudan, labelled Sudan Yellow and Sudan Green. Sudan Green required 78% water to produce a cohesive dough with good molding and cooking properties. At that water level the dough was rubbery and firm, molded easily, and lacked the typical gritty characteristics seen in most millet cultivars.

Sudan Yellow, on the other hand, required only 74% water. It yielded a very soft, sticky dough that produced a good quality product upon cooking. The roti was flexible and puffed completely.

All cultivars tested produced good quality rotis if the meal was ground to sufficient fineness and if optimum absorption was used. Handling properties varied in degrees of stickiness, but the final products were acceptable.

The molding and baking properties of a roti dough improves as the particle size of the meal is reduced. Millet meals with more than 40% greater than 65 mesh (measured on the Alpine sieve) produced poor quality rotis. Meals containing 65% or more by weight, less than 100 mesh, gave acceptable rotis if optimum absorption was used. Those meals containing particles that are in the range 35% - 55% less than 100 mesh, fall into an ambiguous area (Fig. 10).

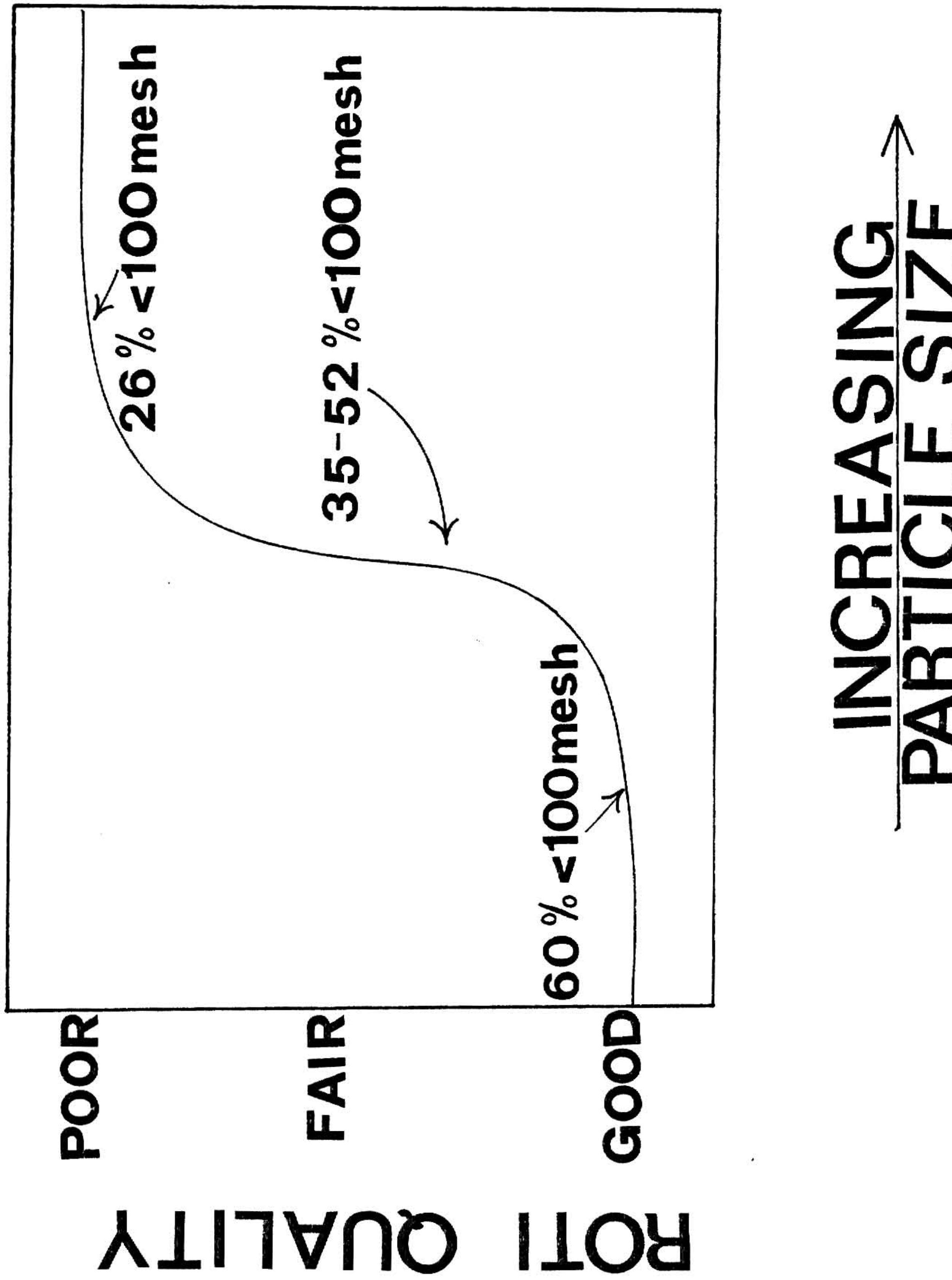
As shown in Fig. 10, good quality rotis can be produced from meals with a large range of fineness. Generally with cereals, as the particle

Table 7. Optimum Water Content for Different Cultivars Ground on the UD Mill

Sample	% H_2O Absorbed[a]	% >65 Mesh	% 65-100 Mesh	% <100 Mesh
1) UD-cultivar 2090 X 7107	74	8.4	10.8	80.6
2) UD-cultivar 79-2017 X 79-4014	72	17.2	20.0	62.8
3) UD-cultivar 79-2161 X 79-4104	76	15.0	16.2	68.8
4) UD-Sudan Commercial	72	8.1	17.2	74.4
5) UD-Sudan Green	78	1.2	10.4	88.4
6) UD-Sudan Yellow	74	0.8	9.2	90.0

[a]Percentage on 100% flour basis

Figure 10. Schematic view of roti quality as influenced by particle size


ROTI QUALITY
POOR
FAIR
GOOD
26 % <100 mesh
35-52 % <100 mesh
60 % <100 mesh
INCREASING PARTICLE SIZE

size is reduced, the percentage of damaged starch in the sample is increased. Damaged starch values for meals ground in a series of mills is shown in Table 8. Starch damage tended to increase with decreased particle size, but, as can be seen with the pin-milled meal, particle size reduction does not necessarily increase starch damage.

There was also no obvious trend in increased water absorption with increased starch damage. The pin mill produced a much finer flour than did the Ross mill, but the optimum water absorption decreased significantly. From these observations, it does not appear that starch damage effects roti quality.

Effect of Separating the Water Soluble Fraction of Millet

The importance of the water soluble fraction of millet meal in roti quality was studied. Water solubles were removed by centrifuging millet meal slurried with water. The supernatant was discarded and the insoluble residue spread on aluminum sheets and air dried. The dried "soluble free" meal was passed through the Ross Experimental Roller Mill and reduced to its original fineness. As a control, soluble-free meal was reslurried with the solubles and then air dried. The soluble materials appeared to have little effect on roti quality. Rotis produced with "soluble free" flour were slightly sticky, but the finished roti was soft and flexible, and puffed completely (Table 9). This data suggests that the soluble fraction in millet meal does not play a major role in the physical properties of the roti. The dough forming properties must, therefore, be an interaction between the insoluble fraction of millet meal and water.

This observation suggests that the interaction between millet meal and water may be similar to that in an inert powder/water system. In this type of a system, the physical interactions between powder particles

Table 8. Starch Damage of Meals[a]

Sample	% Starch Damage	% H_2O abs[b]	% >65 Mesh	% 65-100 Mesh	% <100 Mesh
UD	3.77	74	84.0	10.8	80.6
Quad. Jr. Mill	2.13	76	0.0	18.4	81.6
Ross 7 Passes	2.09	76	14.0	33.2	52.8
Ross 5 Passes	2.05	74	40.4	24.6	35.0
Pin Mill	1.56	70	21.2	19.2	59.6

[a]Produced from cultivar 2010 X 7107, ground on different mills, as it relates to particle size distribution

[b]Percentage on 100% flour basis

Table 9. Effect of the Water Soluble Fraction of Millet Meal on Roti Quality[a]

Sample	Mixing & Handling	Puffing	Texture	Color	Taste
2090 X 7107 UD Mill w/o solubles	Slightly sticky; molded well	Complete	Flexible; smooth	Fair; light	No raw starch; bland
2090 X 7107 UD Mill remixed w/solubles	Sticky; molded fairly well	Complete	Flexible; smooth	Good	No raw starch; off flavor
2090 X 7107 Ross through 42 mesh w/o solubles	Sticky; molded fairly well	Complete	Flexible; smooth	Good	No raw starch
2090 X 7107 Ross through 42 mesh remixed w/solubles	Sticky; molded fairly well	Complete	Flexible; soft	Fair; dark	No raw starch

[a]The meal was produced using cultivar 2010 X 7107 and milled on different mills

and water interface (Weyl and Ormoby, 1960). Water becomes the continous phase by forming a liquid film which is rigid. Peleg et al (1979) noted that finely ground powders are in close contact with one another forming a series of pores which determine the volume of liquid required to incorporate the water into the film system.

Until now, optimum absorption of water in rotis has been obtained on a trial and error basis, i.e. a series of rotis were prepared varying water content and the rotis were baked, puffed, and judged for quality. Peleg's (1979) study of water absorption in powders, using stress relaxation data from the Instron Universal Testing Machine, illustrated significant changes in powder characteristics with changes in water content. A feasibility study was conducted to ascertain the usefulness of this method in determining the millet meal water ratio on roti dough quality.

The Effect of Moisture on Stress Relaxation

An American grown cultivar of millet, 2090 x 7101, was ground on the U D Cyclotec Abrasion Mill and its optimum absorption determined through preparation of rotis. A series of doughs was mixed varying water content from 4% below optimum to 4% above optimum in 2% increments. Table 10 shows that the slope of the normalized curves of the wet powders were significantly smaller than those of the normalized curves of the dry powders. The y-intercepts were in close proximity causing the graph to assume a fan shape (Fig. 11).

The wet dough demonstrates more liquid properties from a rheological point of view (Peleg 1979). The observed change in slope indicates that wet dough is more deformable and better able to reflect physical changes due to internal flow and rearrangement of liquid bridges (Fig. 12).

The dry dough, on the other hand, is more resistant to deformation

Table 10. Effect of Varying Water Content in Roti Doughs, on Slope and Y-intercept of a Normalized Stress Relaxation Curve[a]

Sample	% Abs.[b]	Slope	Y-Intc.
UD -4% H_2O	70	1.389	0.398
UD -2% H_2O	72	1.256	0.270
UD Optimum H_2O	74	1.153	0.210
UD +2% H_2O	76	1.131	0.210
UD +4% H_2O	78	1.100	0.116

[a]Made with cultivar 2010 X 7107, milled on UD Mill

[b]Percentage on 100% flour basis

Figure 11. Effect of varied water levels, in roti doughs, on normalized stress relaxation curves

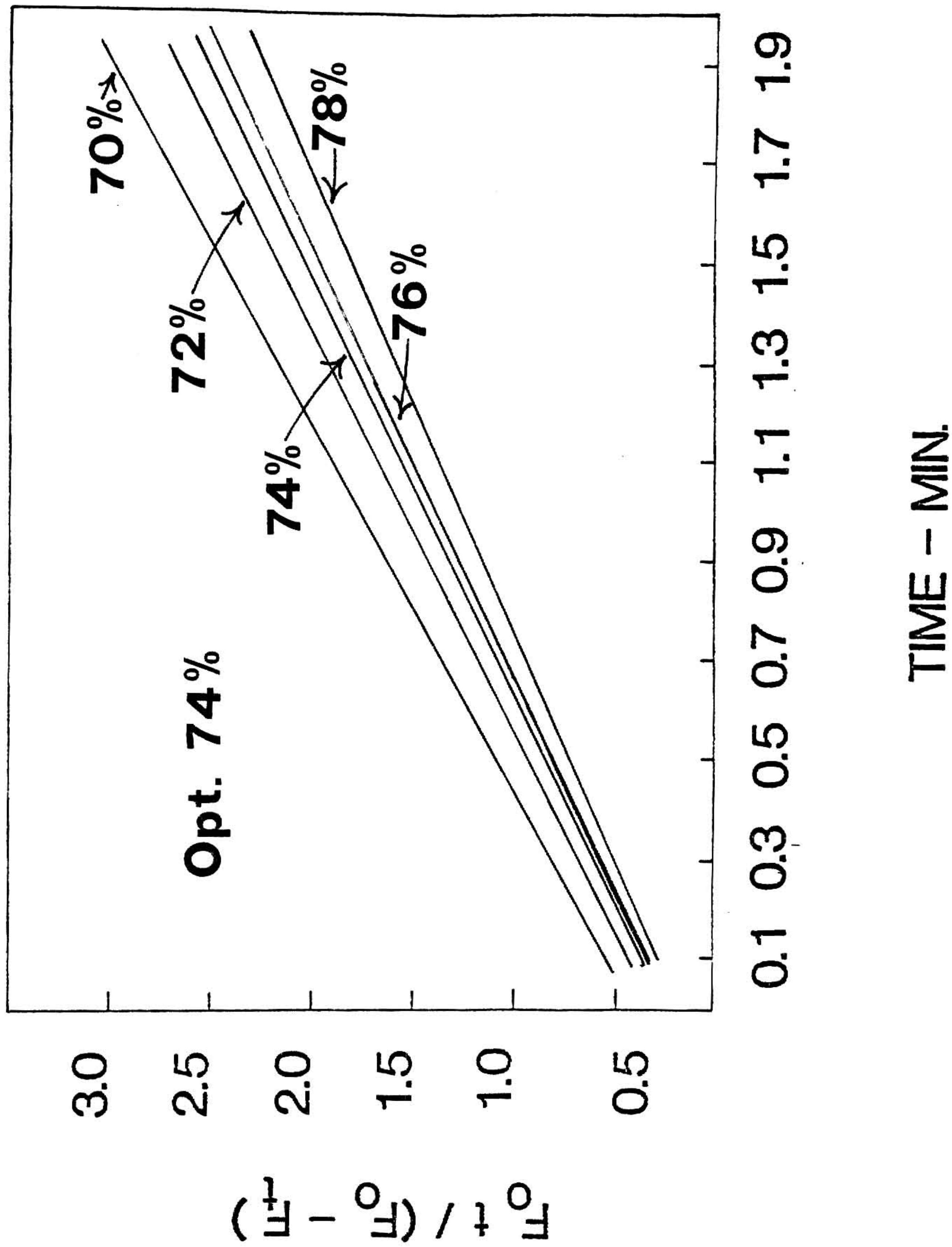
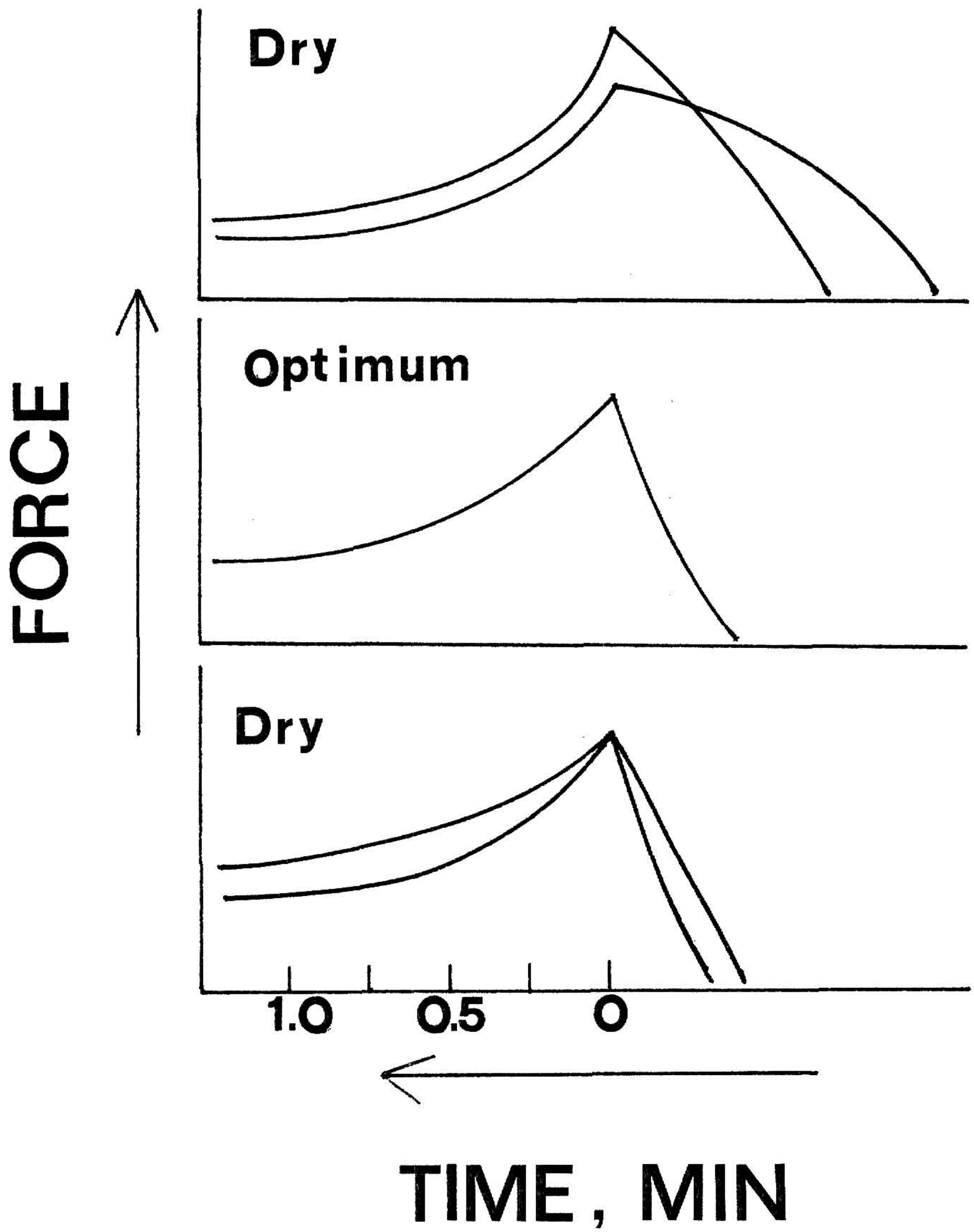

Opt. 74%
70%
72%
74%
76%
78%
0.1 0.3 0.5 0.7 0.9 1.1 1.3 1.5 1.7 1.9
TIME – MIN.
3.0
2.5
2.0
1.5
1.0
0.5
$F_o t / (F_o - F_t)$

Figure 12. Effect of varied water levels, in roti doughs, on actual stress relaxation curves


Dry
Optimum
Dry
FORCE
1.0
0.5
0
TIME, MIN

as well as the relaxation changes that occur under given stress. The flow properties, due to liquid bridging, are reduced and the compacted particles demonstrate more solid properties.

The Effect of Particle Size on Stress Relaxation

American grown millet, cultivar 2090 x 7101, was ground to give various levels of fineness. Coarsely ground meals were produced on the Hobart attrition mill and progressively finer fractions were produced on the Ross Experimental Roller Mill, Alpine Pin Mill and U D Cyclotec Mill. Each sample was mixed with 74% water (which was optimum for the most finely ground meal i.e. that meal ground on the U D Cyclotec Mill) and the normalized curve of stress relaxation (Fig. 13) was compared.

In this test, the slope of the lines were similar, whereas the y-intercepts increased with increasing particle size (Table 11). Peleg's normalization of the stress relaxation curve made it possible to compare data between materials, but it did not eliminate the influence of physical parameters within a given sample (Peleg et al, 1979). As seen in Table 7, those millet meal samples vary not only in particle size, but also in starch damage. And, as seen in Figs. 14A and 14B, the scanning electron micrograph demonstrates differences in the particle shape and surface properties in two of the samples.

The Effect of Cultivar Change on Stress Relaxation

Seven varieties of millet, grown at the Hays and Minneola Kansas Agricultural Experimental Stations, and one commercial Sudanese cultivar, were milled on the U D Cyclotec Abrasion Mill. Fineness of these meals was tested on the Alpine Sifter and found to be similar (Table 12).

Each cultivar was mixed with 74% water and the stress relaxation

Table 11. Effect of Meal Particle Size in Roti Doughs, on Slope and Y-intercept of a Normalized Stress Relaxation Curve[a]

Sample	Particle Size	Slope	Y-Intc.
UD 2090 X 7107	80.6%<100 mesh	1.153	0.210
Pin Mill 2090 X 7107	59.6%<100 mesh	1.277	0.471
Ross through 42 mesh 2090 X 7107	52.8%<100 mesh	1.273	0.646

[a]Made with cultivar 2010 X 7107, milled of different mill types

Table 12. Particle Size Distribution[a] of 7 Cultivars of Millet

Sample	% >60 Mesh	% 60-100 Mesh	% <100 Mesh
79-2201 X 78-7024 (11)	12.04	16.48	71.48
79-2017 X 79-4014 (12)	17.20	20.00	62.80
79-2216 X 78-7024 (17)	12.14	20.08	67.82
79-2161 X 79-4104 (20)	15.00	16.20	68.80
79-2157 X 78-7024 (21)	11.80	17.74	70.38
79-2148 X 79-4104 (23)	11.06	17.18	71.51
79-2059 X 79-4104 (25)	11.24	17.16	71.60
Commercial Sudan Millet	8.10	17.20	74.40

[a]Determined with the Alpine sifter

Figure 13. Relationship between meal particle size and normalized stress relaxation curves. All meals were mixed with 75% water.

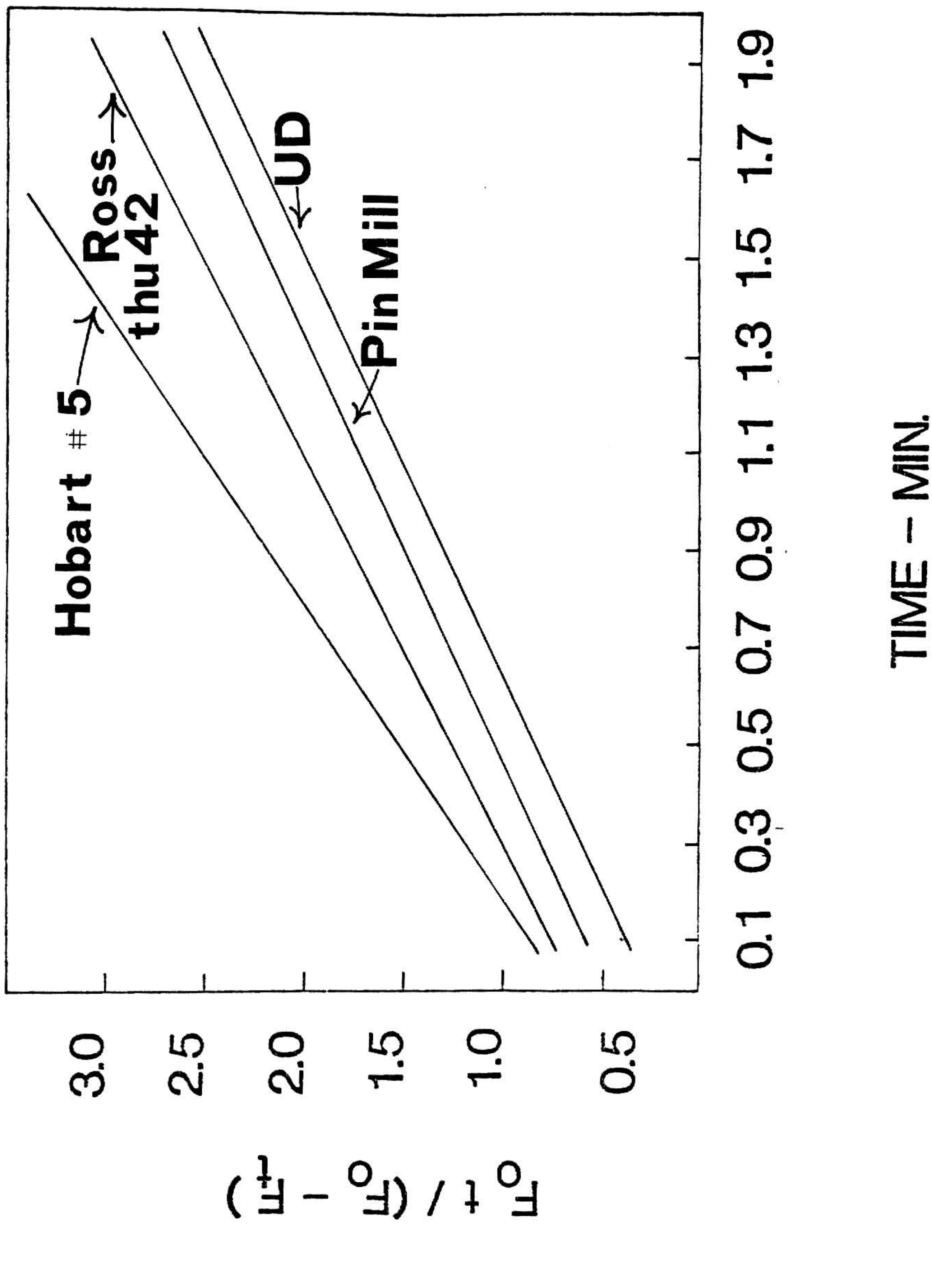
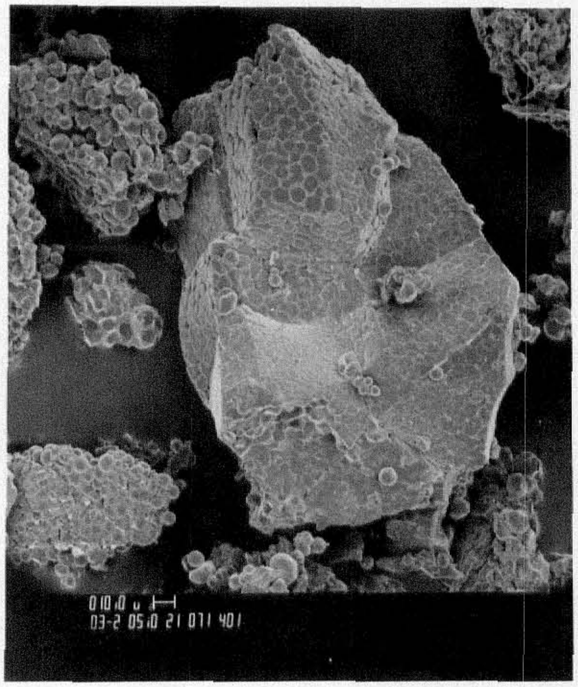
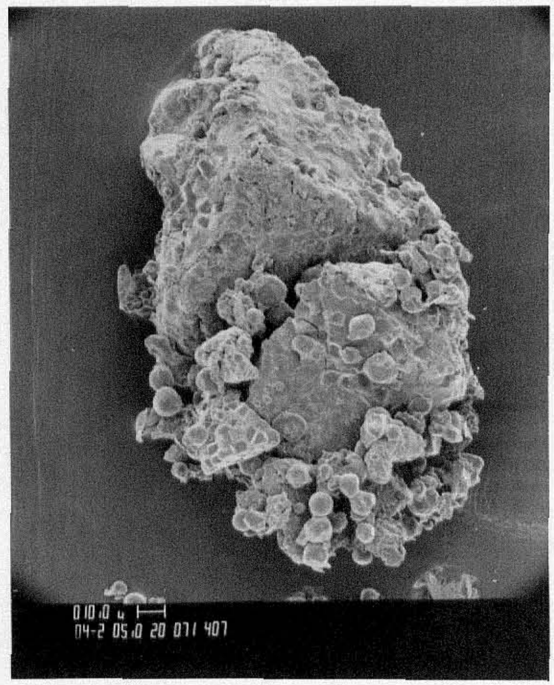

Hobart # 5
Ross thu 42
UD
Pin Mill
3.0
2.5
2.0
1.5
1.0
0.5
0.1 0.3 0.5 0.7 0.9 1.1 1.3 1.5 1.7 1.9
TIME – MIN.
$F_o t / (F_o - F_t)$

Figure 14A. Scanning electron micrograph of millet meal ground on the Quadrumat Junior Mill, left

Figure 14B. Scanning electron micrograph of millet meal ground on the U D Cyclotec Mill, right





pattern was recorded on the Instron, The normalized curves of the seven varieties formed a fan-shaped graph (Fig. 15) with differing slopes and similar y-intercepts.

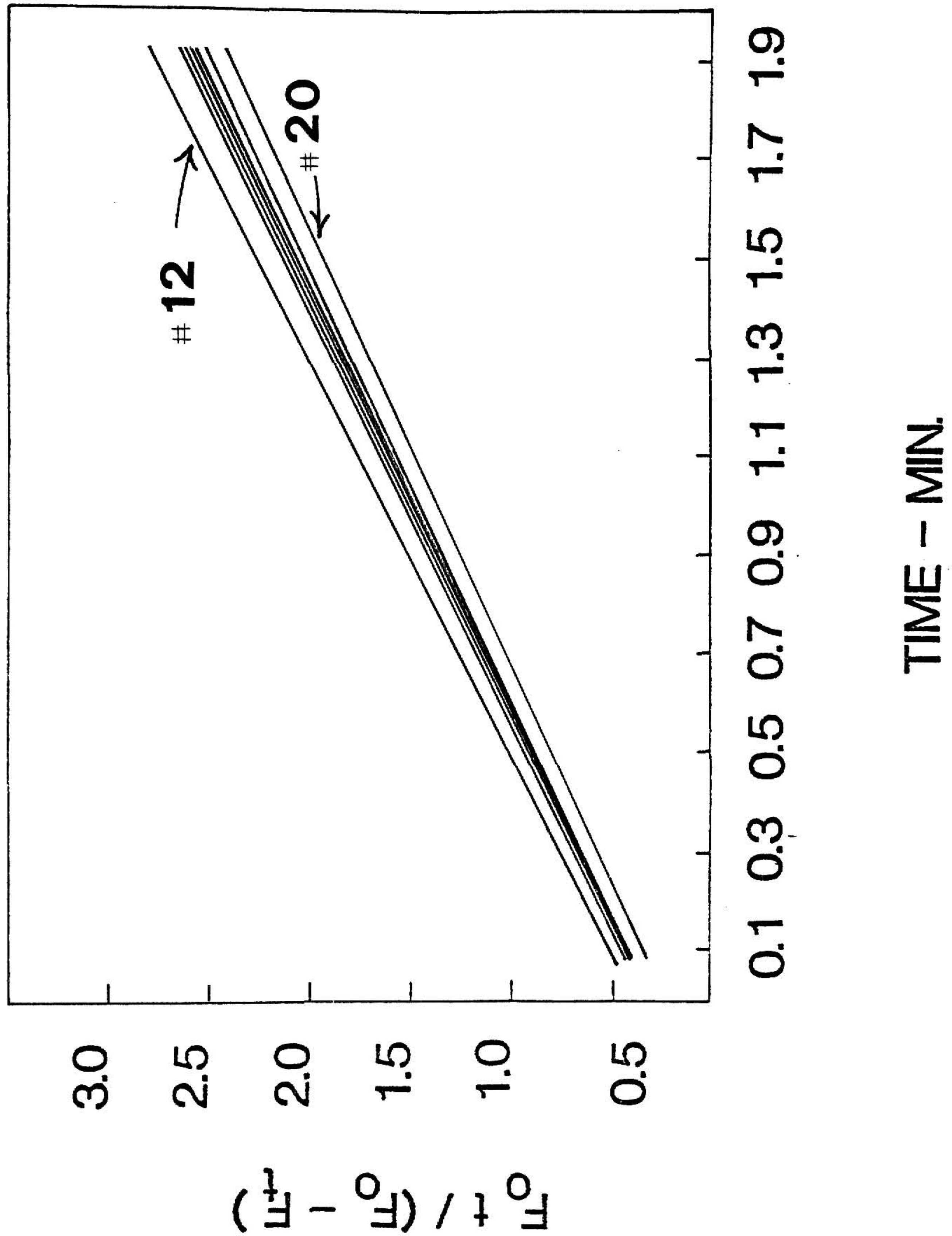
The two cultivars at the extreme ends of the 'fan' were tested by varying water levels and obtaining separate stress relaxation curves for each cultivar. Each cultivar produced a fan-shaped graph similar to that described under "Effect of Moisture on Stress Relaxation" (Figs. 16 and 17).

Optimum absorption was determined experimentally by production of rotis at varying moisture levels. When superimposed, the normalized stress relaxation curves of differing cultivars at optimum absorption fell within a narrow range with regard to slope and y-intercept (Fig. 18). When comparing these cultivars to varieties grown in Sudan and those American grown cultivars studied earlier, it was found that all varieties tested had an optimum absorption that fell within this range of slope and y-intercept.

This aspect of the study could prove useful in the determination of optimum absorption for any given millet cultivar. The Instron stress relaxation method of depicting differences in millet meal/water interaction provides a good evaulation of the characteristics of individual millet properties. By controlling specific parameters, such as type of grinding action, particle size, moisture, and cultivar of the millet, the normalized stress relaxation curves can be used to indicate a range of moisture optimum.

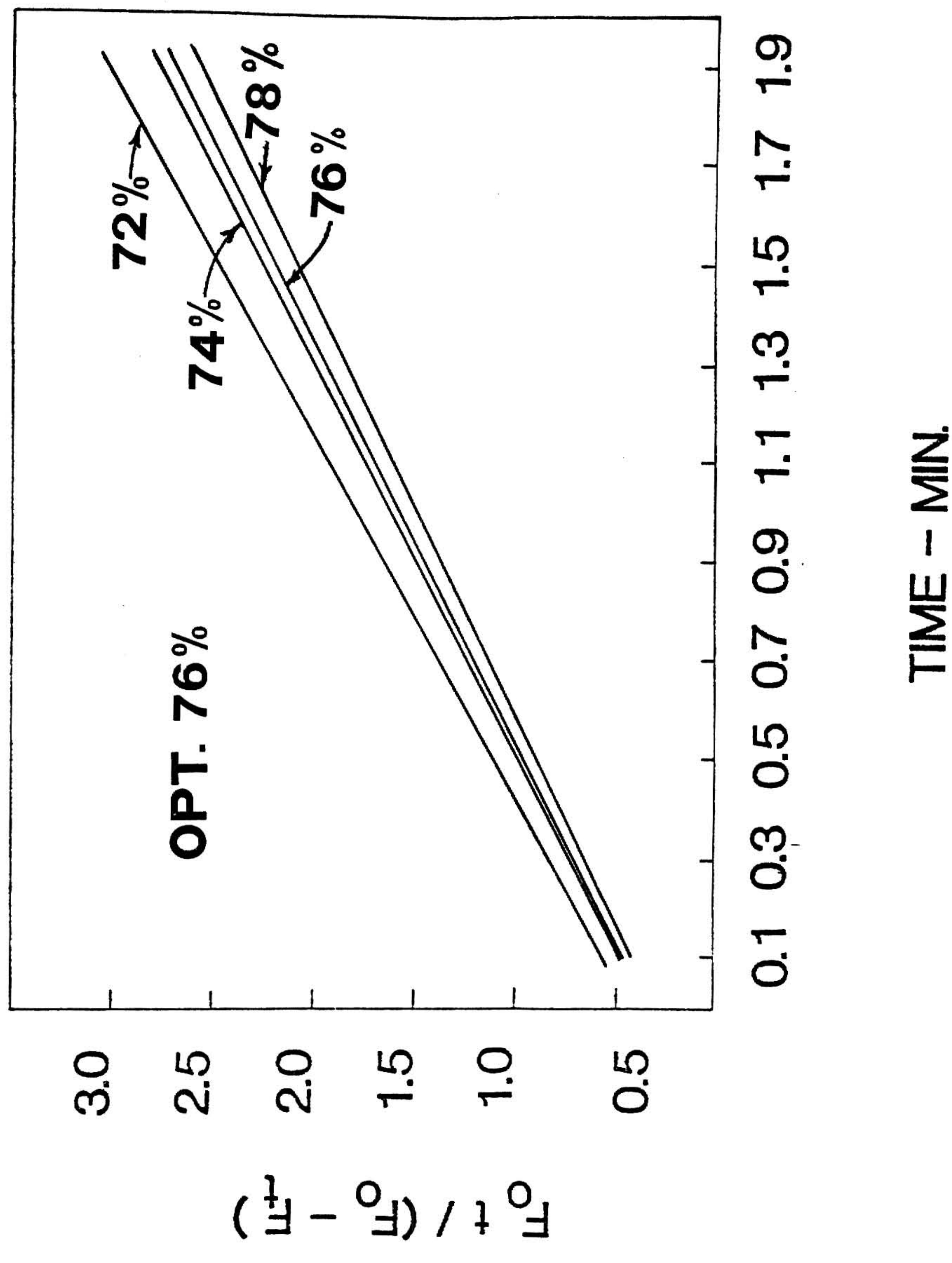
It was also found that the slope of the stress-relaxation line was affected mainly by the water absorption. In general, the y-intercept was affected more by the particle size of the meal. Coarse particles usually

Figure 15. Normalized stress relaxation curves of 7 different millet cultivars mixed with 74% water.



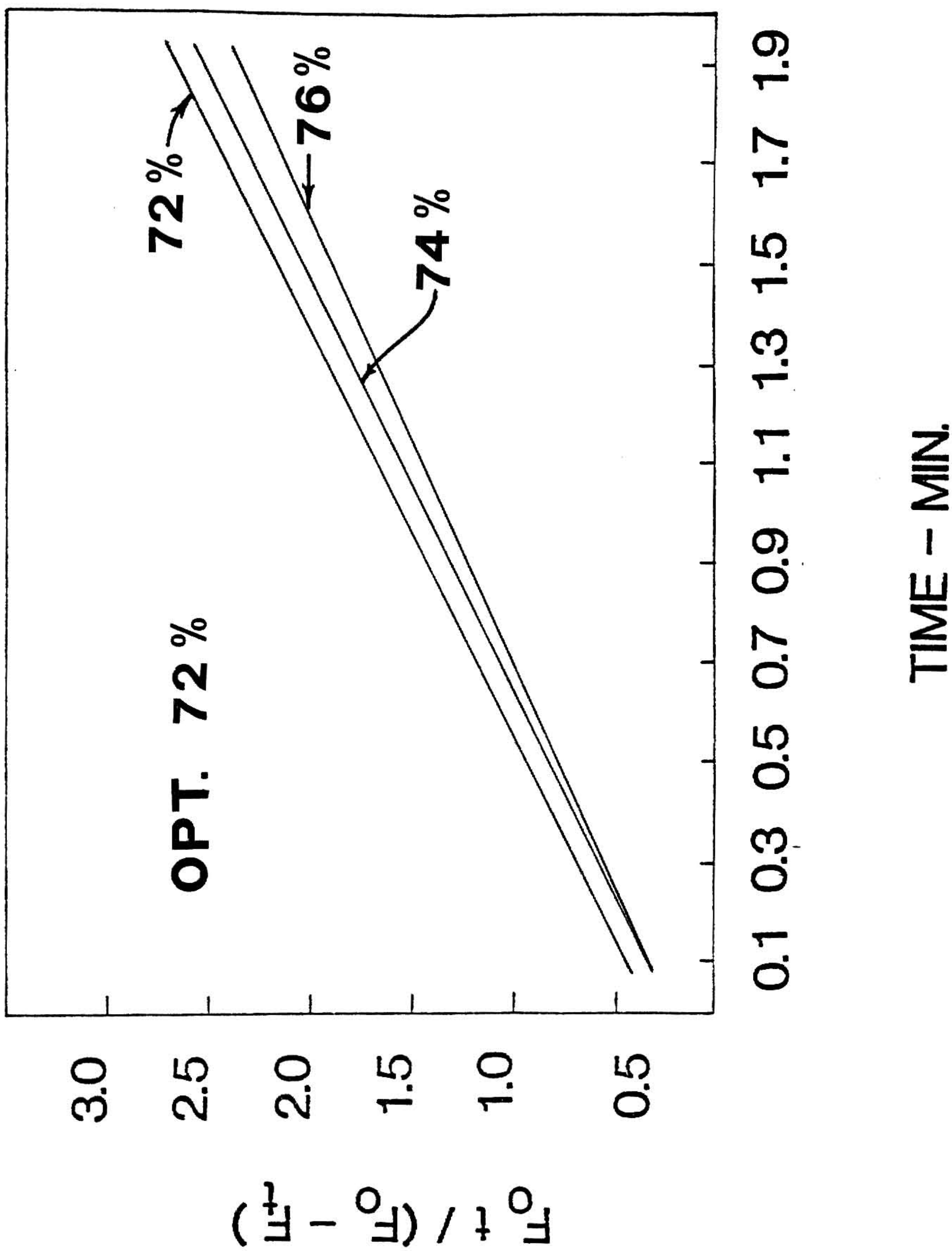
3.0
2.5
2.0
1.5
1.0
0.5
0.1 0.3 0.5 0.7 0.9 1.1 1.3 1.5 1.7 1.9
TIME - MIN.
#12
#20
Fo t / (Fo - Ft)

Figure 16. Normalized stress relaxation curve of cultivar #12 at varying water levels. 76% water was optimum.



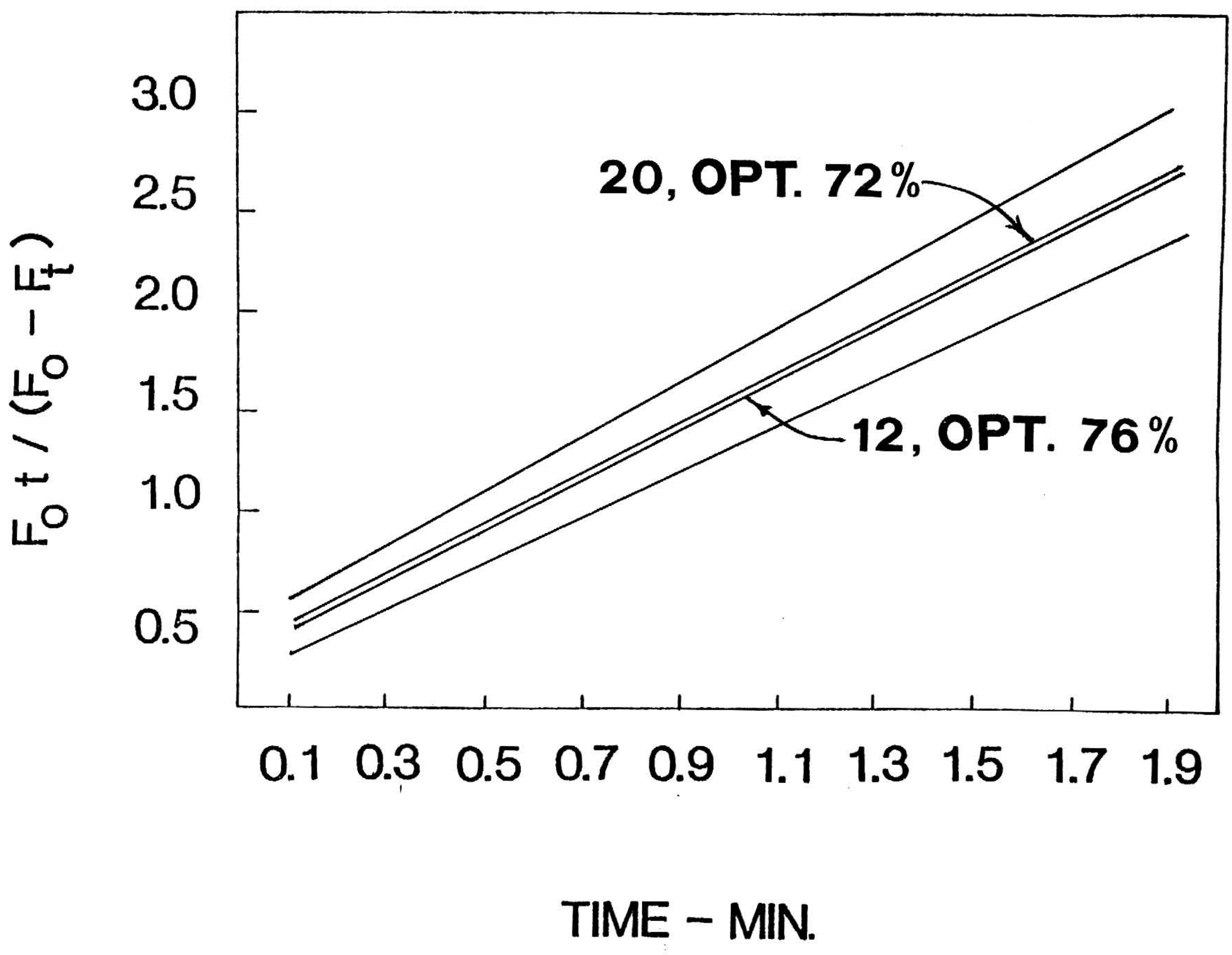
OPT. 76%
72%
74%
76%
78%
0.1 0.3 0.5 0.7 0.9 1.1 1.3 1.5 1.7 1.9
TIME – MIN.
0.5
1.0
1.5
2.0
2.5
3.0
F_o t / (F_o – F_t)

Figure 17. Normalized stress relaxation curve of cultivar #20 at varying water levels. 72% water was optimum.



OPT. 72%
72%
74%
76%
3.0
2.5
2.0
1.5
1.0
0.5
0.1 0.3 0.5 0.7 0.9 1.1 1.3 1.5 1.7 1.9
TIME - MIN.

Figure 18. Optimum absorption for any two cultivars with similar particle distribution produces same normalized relaxation time


20, OPT. 72%
12, OPT. 76%
3.0
2.5
2.0
1.5
1.0
0.5
0.1 0.3 0.5 0.7 0.9 1.1 1.3 1.5 1.7 1.9
$F_o t / (F_o - F_t)$
TIME – MIN.

give a higher y-intercept.

Sorghum and Corn

In preliminary studies on sorghum rotis, it was found that this procedure was useful with appropriate water adjustment. Sorghum tended to require more water to produce an acceptable roti (i.e. 80% - 90% water) (Table 13). Sorghum rotis were, in general, softer and more pliable than millet rotis, and the dough was easier to handle.

The Instron procedure for testing absorption levels proved useful in sorghum roti doughs. Stress relaxation curves for doughs with excess, optimum, and insufficient water produced a typical fan shape on the normalized graphs, though the increments of water used to produce these curves were raised to 3% (from the 2% increments used in millet doughs) to give adequate resolution between the lines (Fig. 19).

Corn masa was also observed in preliminary testing. The amount of water required to produce a good chapatti (tortilla) increased to about 100% (flour basis). The stress relaxation curves followed trends shown in previous work with millet and sorghum, but the increments of water used to produce these curves were raised to 10% to give adequate resolution between the lines.

Millet, masa and sorghum meals were mixed to form doughs of optimum absorption, 74%, 100% and 85% respectively. These doughs were individually freeze dried, then reduced to original size by applying light pressure with a wooden rolling pin. The particle size distributions are similar to those meals before dough preparation (Table 14). This supports the conclusion that forces binding the flour/water system are of a capillary type.

Table 13. Quality of Rotis Made with Sorghum Meals[a]

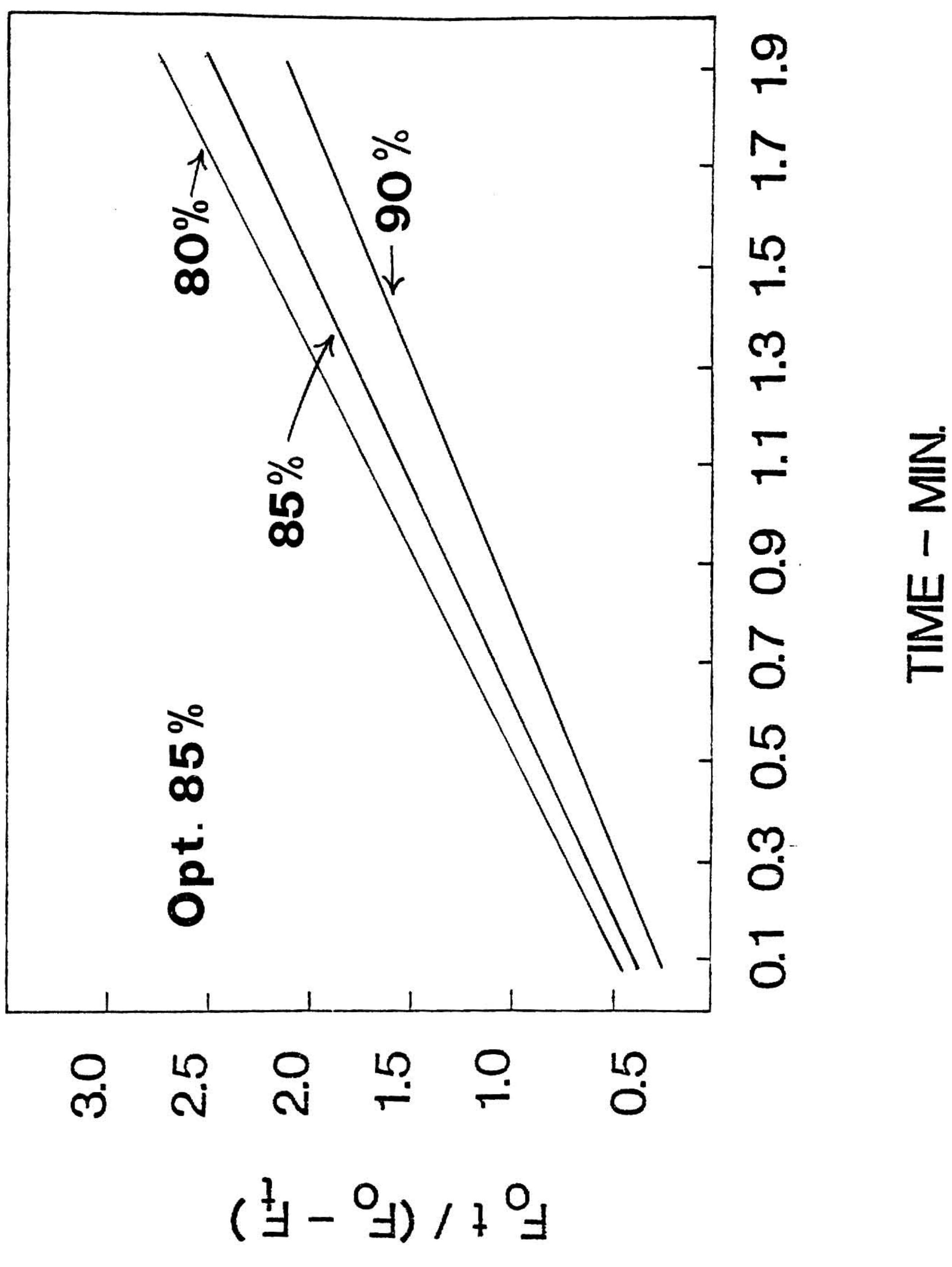
Sample	Optimum % Water[a]	Mixing & Handling	Puffing	Texture	Color	Taste
Danbar	82	Cohesive; molds easily, fairly pliable	Complete	Flexible, soft	Light, intermittent browning	Bland
Safra	85	Cohesive molds easily, fairly pliable	Complete	Flexible, soft	Light, intermittent browning	Bland

[a]Percentage on 100% flour basis

Table 14. Particle Size Distribution for Freeze Dried Doughs

Sample	% >65 Mesh	% 65-100 Mesh	% <100 Mesh
Millet (After)	21.2	26.4	52.4
Millet (Before)	14.0	33.2	52.8
Sorghum (After)	10.8	24.0	65.2
Sorghum (Before)	1.2	15.4	83.4
Corn (After)	56.8	18.0	25.2
Corn (Before)	35.1	36.1	28.9

Figure 19. Normalized stress relaxation curves of varied water content in Dabar sorghum



Opt. 85%
80%
85%
90%
0.1 0.3 0.5 0.7 0.9 1.1 1.3 1.5 1.7 1.9
TIME – MIN.
0.5 1.0 1.5 2.0 2.5 3.0
$F_o t / (F_o - F_t)$

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A PROCEDURE FOR THE PRODUCTION OF MILLET ROTIS

by

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The millet roti (chapatti) is a steam leavened flat bread consumed as a staple food in many parts of India. The objective of this study was to define critical parameters in the preparation of rotis. Various cultivars of millet were experimentally ground and mixed with sufficient water to give a proper dough consistency. These doughs were given a 1 hr rest period and baked at 200°C for 6 min, turning at 1.5 min intervals. The first exposed surface was sprayed lightly with water to reduce moisture loss. The cooked roti was puffed by placing it in a closed metal container at about 350°C.

It was found that meals with smaller particle size produced better rotis. Water absorption in those doughs was shown to be a critical factor in production and the proposed baking test was sensitive to ± 2%. All cultivars of millet tested produced good rotis if the meals were ground to small particle size and optimum absorption was used.

A method of predicting optimum absorption in roti doughs based on stress-relaxation (Instron) was developed. Roti doughs were compressed at 0.25 cm/min until 2 kg/cm^2 was reached and the stress relaxation measured. Force was recorded from this chart at 0.25 min intervals. These values were then normalized to produce a straight line using the decay equation $F_o t/(F_o - F_t)$.

This method enabled us to distinguish among wet, dry, and optimum absorption roti doughs. The procedure also gave differences related to particle fineness of the meals. Optimum absorption for meals with similar particle size distributions were found to produce the same line on a normalized stress relaxation graph.

From those results we can conclude that roti doughs are a simple powder/water system. Cohesion in a roti dough is provided by water holding the powder particles together with capillary type forces.