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**CORN FLOURS**

# The Nutritional Evaluation of Processed Whole Corn Flours

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A processing method for preparing whole corn flours for human consumption under heat and pressure without the use of lime was developed. A nutritional evaluation was made of samples produced experimentally by this new method to determine the best conditions for preparing a product of maximum nutritive value. Nine processed whole corn flours, prepared under different conditions, were evaluated by means of chemical analyses, microbiological assay of amino acids, and biological experiments with rats. None of the treatments of the flours had any effect on composition and true protein digestibility, but all reduced the solubility of the nitrogen and high pressure reduced the nutritive value of the flour. Processed whole corn flour with higher nutritive value can be prepared by cooking moist corn at 5 p.s.i.g. for 15 or 30 minutes.

In the Central American countries, tortillas made with corn form the basic diet for the majority of the population and, up to the present, have been prepared at home from raw corn by traditional methods (*4*, *5*). Recently, interest has arisen in the industrial production of whole corn flours suitable for home use. Important problems include production costs, physical and organoleptical characteristics, and the nutritive value of the flour.

Numerous investigations (*17*, *18*, *22*, *26*) have shown that experimental animals fed lime-treated corn grow better than animals fed raw corn, probably because of greater niacin availability (*17*) or the absorption of a better pattern of amino acids from lime-treated corn (*5*, *26*). Pearson and coworkers (*25*) found that simple boiling of maize released bound niacin and gave a product causing rat growth responses equal to those obtained from the feeding of lime-treated corn. Harper, Punekar, and Elvehjem (*13*) found, on the other hand, that prolonged boiling was not so good as short-duration alkali treatment of maize in releasing bound niacin and promoting growth. Both groups of authors (*13*, *25*) concluded that the beneficial effect of alkali treatment and of water cooking could not be attributed to the correction or prevention of an amino acid imbalance, but only to release of niacin from an unavailable form.

Taking the preceding experimental findings into consideration, the Instituto Centroamericano de Investigaciones y Tecnología Industrial (ICAITI) developed a method for preparing whole corn flours under heat and pressure without lime. Because heat affects the nutritive protein value of cereal grains and other foods (*19*, *24*), a nutritional evaluation was made of flour samples produced experimentally by this new method in order to determine the best conditions for preparing a product of maximum nutritive value. Successful production of corn flours on an industrial basis could greatly benefit the Central American population, for such flours could at the same time be enriched with vitamins and other essential nutrients (*10*).

### Materials and Methods

A starchy-type, white hybrid corn was used for flour production in a pilot plant of ICAITI. The dry whole corn was steam-cooked at a pressure of 5 or 15 p.s.i.g. (227° and 249° F., respectively) for 15, 30, and 60 minutes at each pressure. The cooked grain was then ground to 100 mesh, and a 75-pound sample from each preparation (six in all) was brought to the INCAP laboratory for chemical and microbiological analyses and biological studies with animals. In addition, three flour samples were prepared using whole corn previously soaked in water to raise the moisture content to approximately 30% and cooked at 5 p.s.i.g. (227° F.) for 15, 30, and 60 minutes.

Using 25 pounds of whole raw corn, two masa samples were prepared by the lime-treatment cooking method described by Bressani *et al.* (4, 5)—one designated as *M*1 was prepared in the laboratory; the other, *M*2, by a person experienced in making corn masa for the preparation of tortillas. These two samples and a commercial one produced in Mexico ("Masa Minsa," Maíz Industrializado, S. A., Mexico), *M*3, served for comparison with the flours prepared in the pilot plant. A fourth sample, *L*-100-2, of ground, white hybrid corn was used.

Moisture, nitrogen, ether extract, crude fiber, ash, calcium, and fat acidity contents of the samples were determined by known methods (1). The starch and free sugar content were determined by the anthrone reagent method of Clegg (6). Phosphorus analysis was carried out colorimetrically by using the method of Fiske and Subbarow (9) as modified by Lowry and López (20). The iron content was determined by the colorimetric method of Jackson (16) and Moss and Mellon (23); the thiamine content by the thiochrome method of Hennessy and Cerecedo (14), and the riboflavin content by the fluorometric method of Hodson and Norris (15). Niacin was determined microbiologically with *Lactobacillus arabinosus* 17-5 and Difco media (Difco Laboratories, Detroit, Mich.). Nitrogen extraction and fractionation were carried out as described by Bressani and Scrimshaw (5).

The first biological trial was carried out with 72 young, female white rats (Charles Rivers Laboratories, Brookline, Mass.) divided into 12 groups of six animals each, all groups having the same average initial weight. They were housed in individual all-wire cages with raised screen bottoms. Food and water were supplied *ad libitum*. Individual weight gains and the amount of food consumed were measured every 7 days for a total of 35 days. The 12 experimental diets contained: 90% whole, ground corn masa or processed whole corn flour, 4% mineral mixture (Hegsted Mineral Mixture, Nutritional Biochemical Corp., Cleveland, Ohio), 1% cod liver oil (Mead Johnson, Evansville, Ind.), and 5% cottonseed oil, supplemented with 5 ml. per 100 grams of a vitamin solution to reach the vitamin levels used by Manna and Hauge (21).

The second biological study was carried out with 78 adult female rats (Charles Rivers Laboratories, Brookline, Mass.), using a protein-depletion technique. During a 4-week period, all were fed a protein-free diet made up of 86% starch, 5% minerals, 5% cottonseed oil, 2% cod liver oil, and 2% cellulose, plus a vitamin supplement as described previously. After losing 25% of their initial weight, the animals were distributed by weight among 13 groups of six rats each. The animals were handled as described for the first trial. The experiment lasted 14 days during which weight gains and food consumption were tabulated every 7 days.

The protein digestibility of all the flour samples was determined in a third biological experiment, using adult male rats of the Wistar strain from the INCAP colony, housed in individual metabolism cages. The same rations were fed to the animals for 7 days; in each period, the first 3 days were for adaptation and during the other 4, feces were collected. To obtain endogenous fecal nitrogen values for true digestibility calculations, all the rats were given the protein-free diet. All feces were weighed after dehydration, finely ground, and then analyzed for nitrogen by the micro-Kjeldahl method.

## Results

**Chemical Composition.** Moisture, protein, ether extract, crude fiber, and ash contents of the 13 samples are

**Table I. Moisture, Protein, Ether Extract, Crude Fiber, Ash, Calcium, Iron, and Phosphorus Content of Masas and Corn Flours**

| Code and Treatment | Moisture, % | Protein, % | Ether Extract, % | Crude Fiber, % | Ash, % | Calcium, Mg./100 G. | Iron, Mg./100 G. | Phosphorus, Mg./100 G. |
|---|---|---|---|---|---|---|---|---|
| *M*1, masa | 11.3 | 9.54 | 4.32 | 1.64 | 1.98 | 451 | 3.8 | 303 |
| *M*2, masa | 10.5 | 9.72 | 4.58 | 1.60 | 1.43 | 135 | 2.4 | 313 |
| *M*3,[a] masa | 10.9 | 8.32 | 4.07 | 2.58 | 1.83 | 293 | 4.2 | 278 |
| *L*-100-2, raw corn | 10.4 | 9.49 | 4.25 | 2.25 | 1.43 | 6.6 | 3.1 | 323 |
| *L*-101-2, 5 p.s.i.g., 15 minutes, dry | 9.7 | 9.44 | 4.53 | 2.37 | 1.50 | 6.7 | 3.1 | 332 |
| *L*-102-2, 5 p.s.i.g., 30 minutes, dry | 10.0 | 9.28 | 4.02 | 2.37 | 1.45 | 6.5 | 2.9 | 324 |
| *L*-103-2, 5 p.s.i.g., 60 minutes, dry | 11.6 | 9.25 | 4.41 | 2.32 | 1.49 | 6.1 | 2.6 | 318 |
| *L*-104-2, 15 p.s.i.g., 15 minutes, dry | 9.9 | 10.07 | 4.17 | 2.30 | 1.47 | 6.1 | 2.9 | 325 |
| *L*-105-2, 15 p.s.i g., 30 minutes, dry | 10.0 | 10.09 | 4.37 | 2.45 | 1.50 | 6.1 | 2.8 | 316 |
| *L*-106-2, 15 p.s.i.g., 60 minutes, dry | 11.3 | 9.72 | 4.33 | 2.46 | 1.48 | 5.4 | 2.7 | 341 |
| *L*-108-2, 5 p.s i.g., 15 minutes, moist | 12.1 | 9.50 | 4.28 | 2.24 | 1.47 | 7.2 | 3.5 | 309 |
| *L*-109-2, 5 p.s.i.g., 30 minutes, moist | 12.2 | 9.13 | 4.13 | 2.29 | 1.49 | 7.3 | 2.8 | 347 |
| *L*-110-2, 5 p.s.i.g., 60 minutes, moist | 11.8 | 9.06 | 4.24 | 2.08 | 1.43 | 7.5 | 2.6 | 324 |

[a] "Masa Minsa," Maís Industrializado, S. A., Mexico.
Figures are results of two independent determinations.

**Table II. Total Soluble Carbohydrates, Free Sugars, Starch, Fat Acidity, Thiamine, Riboflavin, and Niacin Content of Corn Flours**

| Code and Treatment | Nitrogen-Free Extract,[a] % | Sugars, % | Starch, % | Fat Acidity[b] | Thiamine, Mg./100 G. | Riboflavin, Mg./100 G. | Niacin, Mg./100 G. |
|---|---|---|---|---|---|---|---|
| *M*1, masa | 71.22 | 1.52 | 69.93 | 0.11 | 0.23 | 0.08 | 0.90 |
| *M*2, masa | 72.17 | 1.87 | 66.40 | 0.45 | 0.24 | 0.08 | 1.51 |
| *M*3, masa | 72.30 | 1.65 | 74.29 | 0.95 | 0.34 | 0.11 | 1.63 |
| *L*-100-2, raw corn | 72.18 | 2.47 | 60.26 | 5.07 | 0.39 | 0.11 | 1.76 |
| *L*-101-2, 5 p.s.i.g., 15 minutes, dry | 72.46 | 2.60 | 69.72 | 0.60 | 0.39 | 0.12 | 1.78 |
| *L*-102-2, 5 p.s.i.g., 30 minutes, dry | 72.88 | 2.38 | 68.90 | 0.57 | 0.38 | 0.12 | 1.86 |
| *L*-103-2, 5 p.s.i.g., 60 minutes, dry | 70.93 | 2.39 | 72.60 | 0.59 | 0.28 | 0.12 | 1.87 |
| *L*-104-2, 15 p.s.i.g., 15 minutes, dry | 72.09 | 2.43 | 71.36 | 0.59 | 0.28 | 0.12 | 1.92 |
| *L*-105-2, 15 p.s.i.g., 30 minutes, dry | 71.59 | 2.42 | 70.63 | 0.57 | 0.22 | 0.13 | 1.89 |
| *L*-106-2, 15 p.s.i.g., 60 minutes, dry | 70.71 | 2.16 | 70.76 | 0.59 | 0.22 | 0.15 | 1.85 |
| *L*-108-2, 5 p.s.i.g., 15 minutes, moist | 70.41 | 2.62 | 72.75 | 0.53 | 0.38 | 0.11 | 1.84 |
| *L*-109-2, 5 p.s.i.g., 30 minutes, moist | 70.76 | 2.64 | 72.04 | 0.53 | 0.34 | 0.11 | 1.88 |
| *L*-110-2, 5 p.s.i.g., 60 minutes, moist | 71.39 | 3.11 | 70.89 | 0.53 | 0.36 | 0.11 | 1.87 |

[a] Nitrogen-free extract calculated by difference.
[b] Milligrams KOH/100 grams of sample.
Figures are results of two independent determinations.

presented in Table I. Moisture content differences were small, but the three moist corn flours prepared at 5 p.s.i.g. had slightly higher values. The differences in protein content also were small, although samples *M*1 and *M*2 contained around 1.5% more protein than the raw corn and processed corn flours. Sample *M*3, prepared from a different corn, had the lowest protein content. The ether extract content varied only slightly between samples. Samples *M*1 and *M*2 contained around 35% less crude fiber than the rest of the samples. The lime-treated flours had 15 to 20% more ash than the processed corn flours and raw corn.

Also shown in Table I are values for the calcium, iron, and phosphorus content. The calcium content was significantly higher in samples *M*1, *M*2, and *M*3. Probably because the cooked material was not as well washed, masa *M*1 contained 7000% more calcium and *M*2, 2000% more than raw corn. The latter value agrees with that of previous studies (*4*, *7*). The processed flours did not differ in their calcium, iron, or phosphorus content.

Results of analyses for free sugar, starch, fat acidity, riboflavin, thiamine, and niacin are shown (Table II) together with total carbohydrate content calculated by difference. Samples *M*1, *M*2, and *M*3 showed the lowest quantities of free sugar. The starch content showed some degree of variation among the different samples. No difference was found, however, in total carbohydrate content.

The fat acidity, expressed as milligrams of KOH per 100 grams of samples, was low in all the flours, except that prepared from raw corn. These low values can be attributed to the alkaline and heat treatments which stopped enzymatic activity. No relationship was apparent between fat acidity and cooking time or any other cooking condition. Raw corn had a fat acidity value of 5.07 mg., and the variation in the other samples ranged from 0.11 to 0.95 mg. of KOH per 100 grams of sample.

The thiamine content was lower in the masas and processed corn flours prepared at 15 p.s.i.g. than in the raw corn or industrial dry or moist corn flours prepared at 5 p.s.i.g. It appears, therefore, that lime-treatment and high pressure cooking result in greater loss of thiamine. The riboflavin content was lower in samples *M*1, *M*2, and *M*3 than in raw corn and the industrial whole corn flours. Results indicate that neither cooking pressure nor time affects riboflavin content. The low thiamine and riboflavin values in the lime-treated flour are due to the alkaline cooking and washing given the grain after the lime treatment.

Samples *M*1 and *M*2 contained lower amounts of niacin than the rest of the samples. Examination of the niacin content of the processed flours indicated a tendency toward higher concentration of the vitamin in the samples prepared with higher pressures and longer cooking. Samples prepared at 15 p.s.i.g., however, tended to have lower concentrations of niacin as cooking time increased from 15 to 60 minutes.

Nitrogen, lysine, tryptophan, isoleucine, and leucine content of the samples are shown in Table III. The amino acids content is similar to that reported by other investigators for Central American corn (*2*, *5*). Results indicate that the cooking methods applied to the raw corn caused no change in the content of these amino acids.

Fractionations of the total nitrogen of different corn flour samples are shown in Table IV. Comparison of nitrogen distribution shows that when nitrogen solubility values are expressed as percentage of the total nitrogen of the samples, all of the nitrogen fractions in masas and flours are lower than in raw corn. When individual nitrogen solubility values are expressed as percentage of the total soluble nitrogen, there are no marked differences in the percentage of water-soluble nitrogen among the samples. Masas and flours have slightly lower values for sodium chloride- and alcohol-soluble nitrogen than raw corn, but raw corn has the lowest sodium hydroxide-soluble nitrogen values. Nitrogen solubility is reduced by the cooking temperatures employed, and in general, solubility decreases as cooking time increases, particularly at higher pressures.

**Table III. Nitrogen, Lysine, Tryptophan, Isoleucine, and Leucine Content of Corn Flours**

| Code and Treatment | Nitrogen G./100 G. | Lysine, G./G. N | Tryptophan, G./G. N | Isoleucine, G./G. N | Leucine, G./G. N |
|---|---|---|---|---|---|
| *M*1, masa | 1.52 | 0.202 | 0.032 | 0.276 | 0.855 |
| *M*2, masa | 1.55 | 0.205 | 0.030 | 0.303 | 0.810 |
| *M*3, masa | 1.33 | 0.213 | 0.033 | 0.298 | 0.912 |
| *L*-100-2, raw corn | 1.52 | 0.192 | 0.032 | 0.289 | 0.860 |
| *L*-101-2, 5 p.s.i.g., 15 minutes, dry | 1.51 | 0.212 | 0.033 | 0.285 | 0.897 |
| *L*-102-2, 5 p.s.i.g., 30 minutes, dry | 1.48 | 0.216 | 0.034 | 0.291 | 0.855 |
| *L*-103-2, 5 p.s.i.g., 60 minutes, dry | 1.48 | 0.220 | 0.036 | 0.294 | 0.841 |
| *L*-104-2, 15 p.s.i.g., 15 minutes, dry | 1.61 | 0.200 | 0.033 | 0.263 | 0.835 |
| *L*-105-2, 15 p.s.i.g., 30 minutes, dry | 1.61 | 0.214 | 0.029 | 0.245 | 0.840 |
| *L*-106-2, 15 p.s.i.g., 60 minutes, dry | 1.55 | 0.207 | 0.030 | 0.264 | 0.823 |
| *L*-108-2, 5 p.s.i.g., 15 minutes, moist | 1.52 | 0.218 | 0.033 | 0.267 | 0.868 |
| *L*-109-2, 5 p.s.i.g., 30 minutes, moist | 1.46 | 0.239 | 0.034 | 0.289 | 0.897 |
| *L*-110-2, 5 p.s.i.g., 60 minutes, moist | 1.45 | 0.217 | 0.030 | 0.282 | 0.872 |

**Table IV. Solubility of Total Nitrogen of Masa Flours, Raw Corn, and Industrial Flours in Water, Sodium Chloride, Ethyl Alcohol, and Sodium Hydroxide**

| | Distribution of Total Nitrogen, % Soluble in | | | | |
|---|---|---|---|---|---|
| Code and Treatment | $H_2O$ | NaCl | EtOH | NaOH | Insoluble |
| *M*1, masa | 10.47 | 3.55 | 6.29 | 16.44 | 63.25 |
| *M*2, masa | 12.35 | 6.69 | 6.17 | 25.21 | 49.58 |
| *M*3, masa | 11.80 | 6.15 | 15.88 | 27.06 | 39.11 |
| *L*-100-2, raw corn | 18.23 | 9.75 | 34.81 | 25.63 | 11.58 |
| *L*-101-2, 5 p.s.i.g., 15 minutes, dry | 12.19 | 5.17 | 23.23 | 25.00 | 34.41 |
| *L*-102-2, 5 p.s.i.g., 30 minutes, dry | 12.09 | 4.55 | 20.38 | 16.69 | 46.28 |
| *L*-103-2, 5 p.s.i.g., 60 minutes, dry | 11.69 | 4.02 | 18.04 | 16.55 | 49.70 |
| *L*-104-2, 15 p.s.i.g., 15 minutes, dry | 12.77 | 4.38 | 16.10 | 17.17 | 49.58 |
| *L*-105-2, 15 p.s.i.g., 30 minutes, dry | 12.29 | 3.78 | 13.25 | 12.50 | 58.18 |
| *L*-106-2, 15 p.s.i.g., 60 minutes, dry | 12.54 | 2.52 | 12.46 | 11.68 | 60.80 |
| *L*-108-2, 5 p.s.i.g., 15 minutes, moist | 15.80 | 5.22 | 19.84 | 23.51 | 35.63 |
| *L*-109-2, 5 p.s.i.g., 30 minutes, moist | 13.45 | 3.46 | 14.00 | 18.74 | 50.35 |
| *L*-110-2, 5 p.s.i.g., 60 minutes, moist | 15.75 | 3.82 | 12.81 | 15.32 | 52.30 |

**Biological Trials.** The growth, feed, and protein efficiencies of young rats fed diets prepared with the various corn flours are shown in Table V. Feed efficiency is defined as average food consumed per average weight gained, and protein efficiency as average weight gained per average protein consumed. Also shown are weight gains of adult female rats in a depletion-repletion experiment. The processed, moist whole corn flours cooked at 5 p.s.i.g. induced an average weight gain of 58 grams; lime-treated samples resulted in an average gain of 55 grams. Processed, dry whole corn flours cooked at 5 p.s.i.g. induced an average weight gain of 53 grams, while the raw ground corn and the flours prepared at 15 p.s.i.g. showed weight gains of 47 and 45 grams, respectively. Feed and protein efficiencies followed generally the same pattern as weight gains, with the exception of the better values obtained with the lime-treated corn flours. These results indicate that the lime-treated corn flours, particularly *M*2, have a better nutritive value than the other samples, with sample *L*-109-2 (5 p.s.i.g., 15 minutes, moist corn) in second place. Processed whole corn flours prepared at 15 p.s.i.g. were inferior. The growth response of protein-depleted rats fed the different flours was not, in general, in agreement with that of the young growing rats. Grouping the results according to pressure treatment, however, gives a better correlation between the results of the two experiments. Sample *M*1, tested only in the protein repletion experiment, resulted in a weight gain of 41 grams in 14 days.

Variance analysis (Table VI) showed that the differences in weight gain of rats fed different flours were significant. The statistical breakdown of the 11 degrees of freedom in the flours into controls, lime-treated corn *M*2, *M*3, and raw corn; treatments and control *vs.* treatments indicated further that the significant differences in weight gain were due to the various treatments applied to the corn. The effects of pressure treatment reached statistical significance at the 1% level as did the effects of cooking time and the interaction of pressure × cooking time. Of the 13 flours studied, dry corn prepared at 15 p.s.i.g. for 60 minutes was the poorest and moist corn prepared at 5 p.s.i.g. for 15 minutes was the best as judged by weight gains of the rats.

Results of statistical analyses for both feed and protein efficiencies are also presented in Table VI. Differences observed in both efficiencies among groups were highly significant mainly because of the difference observed for the controls and the effects of the various treatments. These differences between controls and treatments were significant for protein only. In all cases, the effects of pressure and cooking time were significant. The interaction of pressure × cooking time was also significant for both feed and protein efficiency. Ranking the flour samples in groups according to treatments indicated that the descending order in nutritive value was as follows: lime-treated corn flours, moist corn flours prepared at 5 p.s.i.g., dry corn flours prepared at 5 p.s.i.g., raw corn flour, and dry corn flour, prepared at 15 p.s.i.g. Results of the repletion of protein-depleted rats were similar to those obtained with young rats (Table VI); however, adult rats were not as sensitive to the treatments as young rats as evidenced by the statistics at the 5% level.

The protein digestibility coefficients of corn flours indicated that the preparations of the different flours had no apparent effect on protein digestibility, with the possible exception of sample *M*2 which had a slightly lower value than the others. The average of five digestibility coefficients for the lime-treated flours was 88.5% and for raw corn 91.0%. Digestibility coefficients for the processed corn flours were as follows: dry corn prepared at 5 p.s.i.g., 90.4%; dry corn at 15 p.s.i.g., 92.5%; and moist corn at 5 p.s.i.g., 92.5%.

## Discussion

This study indicates that it is possible to produce processed whole corn flours that are similar in nutritive value to lime-treated corn flours and superior to raw corn flours. There are, however, several chemical and biological differences among the different flours.

**Table V. Weight Gains of Rats, and Protein and Feed Efficiency Ratio**

| Code and Treatment | Trial 1: Av. weight gain,[a] g. | Trial 1: Efficiency Ratio: Feed[b] | Trial 1: Efficiency Ratio: Protein[c] | Trial 2: Protein repletion expt. wt. gain, g. |
|---|---|---|---|---|
| *M*2, masa | 57 ± 7.6[d] | 6.9 | 1.65 | 43 ± 13.0 |
| *M*3, masa | 53 ± 9.8 | 8.5 | 1.56 | 55 ± 11.9 |
| *L*-100-2, raw corn | 47 ± 12.2 | 8.5 | 1.38 | 55 ± 11.0 |
| *L*-101-2, 5 p.s.i.g., 15 minutes, dry | 50 ± 12.7 | 7.9 | 1.51 | 58 ± 12.4 |
| *L*-102-2, 5 p.s.i.g., 30 minutes, dry | 58 ± 8.4 | 7.9 | 1.52 | 46 ± 9.6 |
| *L*-103-2, 5 p.s.i.g., 60 minutes, dry | 54 ± 10.1 | 8.2 | 1.46 | 50 ± 7.5 |
| *L*-104-2, 15 p.s.i.g., 15 minutes, dry | 59 ± 9.6 | 7.9 | 1.40 | 48 ± 10.0 |
| *L*-105-2, 15 p.s.i.g., 30 minutes, dry | 47 ± 11.0 | 8.7 | 1.27 | 49 ± 8.3 |
| *L*-106-2, 15 p.s.i.g., 60 minutes, dry | 31 ± 6.5 | 11.6 | 0.99 | 44 ± 6.5 |
| *L*-108-2, 5 p.s.i.g., 15 minutes, moist | 63 ± 13.2 | 7.6 | 1.54 | 59 ± 16.5 |
| *L*-109-2, 5 p.s.i.g., 30 minutes, moist | 58 ± 11.4 | 7.6 | 1.59 | 62 ± 7.3 |
| *L*-110-2, 5 p.s.i.g., 60 minutes, moist | 53 ± 5.8 | 8.1 | 1.51 | 51 ± 11.1 |

[a] Average initial weight for all groups, 64 grams.
[b] Feed efficiency ratio: average in grams of feed consumed/average in grams of weight gain.
[c] Protein efficiency ratio: average in grams of weight gain/average in grams of total protein consumed.
[d] Standard deviations.

**Table VI. Analysis of the Variance of Results on the Weight Gained by Young Rats and Adult Protein-Depleted Rats**

| Source of Variation | Growth Trial[a]: Degrees of freedom | Growth Trial[a]: Mean square | Mean Square[b]: Feed efficiency ratio | Mean Square[b]: Protein efficiency ratio | Depletion-Repletion Trial[c]: Degrees of freedom | Depletion-Repletion Trial[c]: Mean square |
|---|---|---|---|---|---|---|
| Replications | 5 | ... | 1.5676 | 0.03357 | 5 | ... |
| Groups | 11 | 430.0441[d] | 8.9909[d] | 0.19881[d] | 12 | 248.9572[e] |
| Controls[f] | 2 | 169.3889[a] | 5.8998[d] | 0.14867[d] | 3 | 325.6111[e] |
| Treatments | 8 | 548.9166[d] | 10.6065[d] | 0.21612[d] | 8 | 235.6250[e] |
| Controls vs. treatments | 1 | 0.3749[a] | 2.2489[a] | 0.16060[d] | 1 | 125.6538[a] |
| Pressure | 2 | 750.1667[d] | 14.8346[d] | 0.57579[d] | 2 | 499.5000[e] |
| Times | 2 | 634.7222[d] | 13.3461[d] | 0.13645[d] | 2 | 187.0555[a] |
| Pressures × times | 4 | 405.3888[d] | 7.1226[d] | 0.07613[e] | 4 | 127.9722[a] |
| Experimental error | 55 | 100.5805 | 0.8771 | 0.02118 | 59[b] | 107.1655 |
| Total | 71 | | | | 76 | |

L.S.D.[c] 0.05 for groups of 6, 11.58 grams — −11.96 grams
L.S.D. 0.05 for groups of 18, 6.68 grams — −6.90 grams

[a] No statistical significance.
[b] Loss of one degree of freedom for lack of one figure.
[c] Least significant difference.
[d] Significant difference at the 1% level.
[e] Significant difference at the 5% level.
[f] Lime-treated corn masa, *M*2 and *M*3, and raw corn for growth trial; *M*1, *M*2, *M*3, and raw corn flour for depletion-repletion trial.

Lime treatment of the corn lowers the concentration of crude fiber because the seed coat of the grain is broken down (*4*) and is lost when the cooked corn is washed with water. The fiber content in masa *M*3 is high because the cooked corn is not washed during preparation. This may be important from the point of view of the texture and physical appearance of the final product.

Because of the lime, the ash content in the lime-treated corn flour is higher than in the processed whole corn flours. Nutritional surveys carried out by INCAP (*11, 12*) have shown that lime-treated corn in the form of tortillas contributes up to 87% of the daily calcium intake for the rural population of Central America. This finding is important because the consumption of other foodstuffs rich in calcium, such as milk, is extremely low. Furthermore, the high calcium content of the lime-treated corn flours may be an important factor influencing the organoleptic characteristics of the product. The processed whole corn flours, however, can be easily and cheaply enriched with calcium.

The results of this study showing a reduction of thiamine, riboflavin, and niacin contents are similar to those reported by Bressani, Paz y Paz, and Scrimshaw (*4*) for the lime-treated corn flours prepared in Guatemala by the usual method. In striking contrast, the thiamine, riboflavin, and niacin contents of the processed whole corn flours were not significantly lowered by the processing procedure. The fat acidity content, particularly of the lime-treated samples, did not increase because of the method of preparation. The preparation also did not affect the amino acids, except for an 8.9% loss in leucine. When the corn was washed after lime cooking, however, 32.8% of the free sugar was lost.

Biological trials carried out with young and adult rats clearly showed the effects of cooking conditions on the nutritive value of the flours. In all cases, increased pressure and longer cooking periods lowered the nutritive value of the protein of the flours, except in those samples prepared with moist corn. These results agree with those of Liener (*19*) and the National Research Council (*24*).

As in previous studies (*17, 18, 26*), the lime-treated corn flours induced better growth and better feed and protein efficiencies. The industrial, moist corn flours prepared at 5 p.s.i.g. gave similar results, and both were superior to raw corn. Up to the present, there is no satisfactory explanation of these observations. Pearson *et al.* (*25*) demonstrated that boiled corn was as effective as lime-treated corn, which was attributed to the higher availability of niacin in boiled corn.

This study shows that the samples treated by moist cooking induced good growth in the rat, agreeing with the results of Pearson *et al.* (*25*). Similarly, corn with a moisture content of 10%, cooked at 5 p.s.i.g., induced better growth than raw corn. This fact, however, cannot be attributed to a more rapid liberation of niacin because all the diets were supplemented with 5 mg. of niacin per 100 grams of ration, an amount more than adequate to meet the niacin requirements of the rat (*8*). It is doubtful, therefore, that any additional free niacin would affect the growth or the feed and protein efficiencies of the animals.

It has been demonstrated (*3*) through studies in vitro that niacin is equally available from corn and tortillas. If niacin were the responsible factor and if heat were necessary for its liberation, it should follow that all processed corn flours would induce better growth. The results indicate, however, that high pressures are detrimental to corn proteins. The improved growth and protein efficiencies in some of the samples were probably due to the beneficial effects of certain heat treatments on the amino acid balance of the protein of corn in the form of lime-treated corn and some of the processed, whole corn flours.

This study indicates that the processed, whole corn flour *L*-109-2 has the highest nutritive value, followed by flours *L*-108-2 and *L*-110-2. This group of moist corn flours was prepared at 5 p.s.i.g. and cooked for 15, 30, and 60 minutes, respectively. Processed corn flours *L*-101-2, *L*-102-2, and *L*-103-2 ranked second as a group and were prepared by cooking dry corn at 5 p.s.i.g. for 15, 30, and 60 minutes, respectively.

Industrial, whole corn flours have the advantage that they can be easily enriched with minerals, vitamins, amino acids, and protein-rich foods.

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