Millet Processing for Improved Stability and Nutritional Quality Without Functionality Changes

G. N. BOOKWALTER, S. A. LYLE, and K. WARNER

ABSTRACT

Whole millet adjusted to 15% moisture was gradually heated to 97°C over 12 min by passing through a steam-jacketed paddle conveyer to inactivate lipid enzymes. Both processed and unprocessed millet were milled to 50% and 80% extraction flours. The 80% flour contained germ fractions, which resulted in much higher protein, lipid, thiamine, riboflavin, niacin, iron, zinc, available lysine, and protein efficiency ratios than the 50% flour. After 49°C storage, peroxide and fat acidity values were lower and flavor scores higher for processed than for unprocessed millet flours. No differences between processed and unprocessed flours were found in birefringence, water absorption and solubility, viscoamylograph values, or in their use in several traditional foods.

INTRODUCTION

Millet is the name applied to small-seeded annual grasses that were probably first cultivated in Asia or Africa. Major millet types are Panicum miliaceum (proso), Pennisetum americanum (pearl), Eleusine coracana (finger), and Setaria italica (foxtail). In the United States and western Europe, millets are grown primarily for hay and pasture or as components of wild birdseed and chick feed mixtures. However, millets are used chiefly as food grains in Africa, eastern Europe, China, India, and other Asiatic countries. Hulled millet grains, either whole or cracked, are cooked into porridge called kasha in Russia and Poland. Ground millet is made into a thin pancake known as kisra in Sudan (Perten, 1983). Flours for millet can be used to partially replace wheat flour in breads, cookies, and pasta products (Badi et al., 1976; Lorenz and Dilsaver, 1980). In Senegal, millet flour is steam-cooked to prepare couscous and consumed as porridge with vegetables and a meat sauce.

Millets can be stored for long periods without substantial quality changes if the kernels remain intact (Kaced, 1982). However, quality rapidly deteriorates after millet is ground into meal (Varrano-Marston and Hoseney, 1983); hydrolytic and oxidative changes occur in lipids (Carnovale and Quaglia, 1973; Lai and Varrano-Marston, 1980). Poor storage quality has been attributed largely to hydrolytic changes associated with the action of lipolytic enzymes (Thiam, 1977).

Ground millet storage stability is improved by dry-milling processes that remove the major lipid-containing portions of the grain (i.e., the germ and covering layers) from the endosperm. Abdelraham et al. (1983) produced low-fat grits from pearl millet that had extended storage life, but yield was only 61%. It has been shown that storage stability of other cereals and oilseeds can be improved by heat-processing methods that inactivate lipid enzymes (Bookwalter, 1983). Cereals and oilseeds can be partially or fully cooked in extruder or roll cookers to inactivate hydrolytic and oxidative enzymes to improve storage stability. Substantial improvement in yield and nutritional quality can be achieved by heat-processing. However, these procedures cause drastic changes in physical characteristics that limit their use in traditional food applications.

The objective of this research was to investigate processing whole millet grain to inactivate deleterious lipid enzymes without changing functionality in order to retain stabilized germ fractions and increase nutritional quality.

MATERIALS & METHODS

Materials

White proso millet (Panicum miliaceum), used in this study, was commercially grown in South Dakota. Millet was screened to remove dust, other grains, weed seeds, and other foreign materials.

Thermal processing equipment

Millet was transported through a continuous two-stage steam-jacketed paddle conveyer (Fig. 1) at a controlled rate of about 60 lb/hr (27 kg/hr). Each stage was 6 ft (1.83m) long and equipped with a 6 in (15.24cm) diameter screw. Screws were linked together with a chain belt driven by a variable speed motor. Millet, with or without added water, was metered into the upper conveyer and exited either at the sample port between conveyers or at the lower conveyer port. Temperatures up to 110°C could be obtained by controlling jacket steam pressure and/or holding time.

Dry milling

Two different pairs of Allis Chalmers corrugated rolls (152 mm × 152 mm) were used to reduce whole millet with and without temper water to desired particle sizes. One pair of rolls with 2.5:1 differential speeds contained 16 corrugations per 2.54 cm while the other pair had 1.5:1 differential speeds contained 24 corrugations per 2.54 cm. A laboratory sifter containing various U.S. Standard screens and an aspirator were used to separate milled particles into medium and fine grits, flours, germ, hulls, and shorts prior to either remilling or separating into final products.

Physical tests

Viscosity properties of cooked millet flours at 9% solids were characterized by a Brabender Visco-Amylograph. Birefringence was determined by microscopic observation under polarized light. Color comparisons were made both visually and by measurement with a Hunterlab Model D-25-3 color difference meter. Methods for determining water absorption index and water solubility index have been described by Conway (1971).

Fig. 1—Continuous two-stage steam-jacketed paddle conveyer.
MILLET PROCESSING FOR IMPROVED QUALITY...

Table 1—Peroxidase activity and fat acidity values of stored unheated and heat-processed whole and cracked millet

<table>
<thead>
<tr>
<th>Thermal treatment (°C)</th>
<th>Peroxidase activity</th>
<th>Fat acidityb, whole</th>
<th>Fat aciditiyb, cracked</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unheated</td>
<td>Positive</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>68.9</td>
<td>Positive</td>
<td>62</td>
<td>96</td>
</tr>
<tr>
<td>80.0</td>
<td>Positive</td>
<td>41</td>
<td>73</td>
</tr>
<tr>
<td>88.9</td>
<td>Positive</td>
<td>35</td>
<td>45</td>
</tr>
<tr>
<td>98.9</td>
<td>Negative</td>
<td>46</td>
<td>37</td>
</tr>
</tbody>
</table>

*Tempered to 15.0% moisture

<table>
<thead>
<tr>
<th>Thermal treatment (°C)</th>
<th>Peroxidase activity</th>
<th>Fat acidityb, whole</th>
<th>Fat aciditiyb, cracked</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unheated</td>
<td>Positive</td>
<td>50</td>
<td>70</td>
</tr>
<tr>
<td>68.9</td>
<td>Positive</td>
<td>62</td>
<td>96</td>
</tr>
<tr>
<td>80.0</td>
<td>Positive</td>
<td>41</td>
<td>73</td>
</tr>
<tr>
<td>88.9</td>
<td>Positive</td>
<td>35</td>
<td>45</td>
</tr>
<tr>
<td>98.9</td>
<td>Negative</td>
<td>46</td>
<td>37</td>
</tr>
</tbody>
</table>

*Tempered to 15.0% moisture

Analytical tests

Peroxidase was determined by the method of Bergmeyer et al. (1974) based on color development by decomposition of hydrogen peroxide with guaiacol as hydrogen donor. Peroxidase and fat acidity analyses were carried out according to AACC (1976) methods. Peroxides were measured on extracted fat while fat acidity was determined directly. Vitamins, minerals, and protein efficiency ratios were assayed by AOAC (1980) methods. The method of Rao et al. (1963) was used to measure available lysine.

Food application

Millet flours were evaluated for their suitability by preparation of couscous. Agglomerated particles were formed by blending millet flour with 60% total water during 5 min mixing on low speed in a Hobart mixer. The agglomerates were then stirred occasionally to provide uniform steam cooking until tender. Cooking proceeded over 25 min or until disappearance of raw cereal flavor.

Storage stability

Stability tests were made on heat-processed and unprocessed millet flours. Products were packaged in glass containers with screw closures and stored at 49°C for 2 months. Controls were held at -18°C. Withdrawals from storage were made after 0, 1, and 2 months. The samples were evaluated for changes in peroxide values, fat acidity, available lysine, and flavor.

Sensory evaluation

Millet flours were evaluated as 10% gruels after 7 min cooking. Flavor and odor were assessed by a 12-member trained panel. As previously described for soybean products (Warner et al., 1974, 1983), panelists scored overall flavor quality on a 10-point scoring scale with 1 = bad and 10 = excellent. Statistical evaluations were made on the data after completion of each taste panel series. Analysis of variance, regression analysis (Snedecor and Cochran, 1980) and Duncan's multiple range test (Duncan, 1955) were used to assess experimental results.

RESULTS & DISCUSSION

Thermal processing

Exploratory tests were carried out with the continuous two-stage steam-jacketed paddle conveyer (Fig. 1). Whole millet enzymes were inactivated, as indicated by the peroxidase test, by this processing method. Heat-treatment was most effective after prior addition of water to raise moisture content to 15.0%. Processing was carried out with pass-through times between 4 to 12 min to achieve 68.9° to 98.9°C (Table 1). Peroxidase remained active except with millet heated to 98.9°C. Whole millet, both unheated and heated over 68.9° to 98.9°C, was divided into two portions; one was cracked by coarse grinding and the other was not cracked. Fat acidity values, an indicator of lipase activity, were lower in whole than in cracked millet, both before and after storage. Significantly lower (5% level) fat acidity values were associated with processing at 88.9° and 98.9°C. Lowest fat acidity values and negative peroxidase activity were associated with the 98.9°C heat-treatment. Additional research showed that peroxidase could be inactivated by heat-treating millet containing 15.0% moisture during 12 min heating to attain 97°C.

Dry milling

Milling studies were conducted to provide two product types: one containing minimum germ (low-fat) and the other maximum germ (high-fat). Both types were prepared with the milling system shown in Fig. 2. Each type involved four breaks with corrugated rolls. First and second break rolls contained 16 corrugations/2.54 cm, while third and fourth contained 24 corrugations/2.54 cm. Openings for 1st, 2nd, 3rd, and 4th break rolls were set at 0.1016, 0.0508, 0.0254, and 0.0127 cm, respectively. Each break was sifted through U.S. Standard screens ranging from #12 to #50, followed by three aspira­tions (Fig. 2) to separate milling fractions. Medium and fine grits and fines were combined for food use, while bran and shorts were combined for feed. Germ fractions could be diverted to either food or feed use, depending on objectives. A low-fat flour was obtained by adjusting millet moisture to 22%, milling within 30 min, followed by air drying. A high-fat flour or germ-containing flour was obtained by milling with no added temper water and limiting inclusion of bran to achieve a high-fat flour with appearance similar to low-fat flour. Product yield was 50% for low-fat and 80% for high-fat flour.

Nutritional aspects

Analyses of unheated and heat-processed low-fat and high-fat flours, along with an unprocessed whole millet flour, are shown in Table 2. Inclusion of germ fractions in high-fat flours resulted in significantly higher protein, fat, ash, and crude fiber values than in low-fat flours. Higher protein and fat levels demonstrated the nutritional advantage of germ retention, and heat-treatment had no adverse effect on levels of these nutrients. Analytical values for whole millet showed the effect of retaining all of the germ and hull as noted by lower proteins and much higher crude fiber, ash, and fat analyses. However, retaining all of the hull, as in whole millet, adversely changed product appearance from a dull yellow to an unpleasant gray. Vitamin, mineral, and available lysine values and protein efficiency ratios for the various flours are listed in Table 3. The beneficial effect of germ retention was reflected by sig-
significantly higher (5% level) thiamine, riboflavin, niacin, available lysine and protein efficiency ratios in high-fat and whole millet than in low-fat flours. Heat-treatment was shown to have no adverse effect on these nutrients. Iron and zinc levels were also significantly higher in high-fat and whole millet than in low-fat flours. Bran components also are high in minerals such as iron and zinc as reflected by higher ash values (Table 2).

Physical properties and food application

Table 4 shows physical characteristics of unheated and heat-processed high- and low-fat and whole millet flours. These products were indistinguishable by microscopic evaluation for birefringence as well as by water absorption and Brabender initial viscosity values. The slightly higher water solubility values of high-fat flours were associated with higher solubles derived from higher protein and fiber content. Higher Brabender viscosity values at 95°C for low-fat flours were associated with higher starch content (Table 2). These data showed that heat-treating millet to 97°C, as described to inactivate lipid enzymes, was not vigorous enough to alter starch and other characteristics that could severely change viscosity, water absorption, water solubility, or other functional properties. Differences in Hunter L, a, b values of high- and low-fat flours were negligible, which was in agreement with their similar visual appearance. However, whole millet flour had the lowest ‘L’ and a much lower ‘b’ value than the low- or high-fat flours. The dull gray visual appearance and Hunter color values of ground whole millet demonstrated the adverse effects of high bran content. These properties certainly will limit the usefulness of ground whole millet.

The performance of various unheated- and heat-processed millet flours was evaluated in couscous; results are shown in Table 5. Heat-processed flours required 5 min less time to prepare cooked agglomerated particles than unprocessed flour. Couscous prepared with heat-processed millet flours were of higher quality than those from unheated flours as evidenced by more fluffy, discrete, uniform, and more tender particles. Couscous prepared with unprocessed millet was slightly sticky, and particles were larger than 4 mm, non-uniform and gritty. Normal cereal cooked flavor was designated for all couscous preparations. Color of the various couscous was similar except for the slightly lighter colored product made with heat-processed high-fat millet flour.

Storage stability

The effect of heat-processing on stored millet flours is shown in Table 6. Although all peroxide values were within acceptable limits, those of high-fat were significantly lower than of low-fat millet. Higher values for low-fat millet were associated with the air-drying step that followed high moisture tempering to facilitate degermination. Extremely low peroxide values in the high-fat products demonstrate their very low susceptibility to autoxidation. Fat acidity values of unprocessed millet flours were significantly higher, both before and after storage. Slightly lower fat acidity of low-fat flours was associated with degermination. These data demonstrate the effectiveness of the 97°C heat-treatment to inactivate lipase, which minimizes fat hydrolysis.

Table 7 shows mean flavor scores of stored unheated and heat-processed millet flours. There were significant (5% level) flavor declines in both unheated high- and low-fat flours after storage at 49°C for 2 months. These flavor changes in both unprocessed millet flours were associated with significant increases in fat acidity values (Table 6). High lipase activity has previously been associated with bitter flavor development due to fatty acid hydrolysis.
concluded that hydrolytic rancidity. However, there were no significant
flavor changes in heat-processed high- or low-fat millet flours
which illustrates the beneficial effect of this treatment.

CONCLUSIONS

HEAT-PROCESSING whole millet at 97°C in a steam-jacketed
conveyor inactivated lipid enzymes and extended storage
life. Germ fractions could be retained in the final milled
product to improve both nutritional quality and yield. The degree
and method of heat-processing or the level of retained germ
fractions resulted in no adverse changes in functionality or
performance in selected traditional foods.

REFERENCES

of Cereal Chemists, St. Paul, MN.
process to produce low-fat grits from pearl millet. Cereal Chern. 60: 189.
Association of Official Agricultural Chemists, Washington, D.C.
characterization of starch and use of millet flour in bread making. Cereal
Chem. 53: 733.
Bergmeyer, H.V., Gawehn, K., and Gradal, M. 1974. Enzymes as biochemical
reagents. In “Methods of Enzymatic Analysis,” Bergmeyer, H.V. (Ed.),
Bookwalter, G.N. 1983. World feeding strategies utilizing cereals and other
controlled preservation on the chemical composition of milling
Dev. 5: 27.
University, Manhattan.
Lorenz, K. and Disavver, W. 1980. Rheological properties and food applica-
Pertin, H. 1983. Practical experience in processing and use of millet and
Iowa State University Press, Ames, IA.
Thiam, A.A. 1977. Contribution to the study of the biochemical phenomena
of millet and sorghum flour determination. Tropical Products Institute
egal.
Varriano-Marston, E. and Hoseney, R.C. 1983. Barriers to increased uti-
lization of pearl millet in developing countries. Cereal Foods World 28:
392.
handling of taste panel data. Food Technol. 28: 42.
Warner, K., Mounts, T.L., Rackis, J.J., and Wolf, W.J. 1983. Sensory char-
teristics and gas chromatographic profiles of soybean protein products.
Cereal Chern. 60: 102.
Ms received 10/6/86; accepted 10/27/86.

The authors acknowledge the assistance of M.R. Gumbmann, Western Regional Re-
search Center, AB, USDA, Berkeley, CA, for protein efficiency ratios and to Hoffman-
La Roche, Nutley, NJ for vitamin determinations.

The mention of firm names or trade products does not imply that they are endorsed
or recommended by the U.S. Department of Agriculture over other firms or similar
products not mentioned.

Table 5—Performancea of unheated and heat-processedb millet flour in couscous

<table>
<thead>
<tr>
<th>Millet flours</th>
<th>Preparation time (min)</th>
<th>Agglomeration characteristics</th>
<th>Visual colorb</th>
<th>Texture and flavor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heated, low-fat</td>
<td>20</td>
<td>Fluffy, uniform particles</td>
<td>99.5</td>
<td>Tender, normal cereal</td>
</tr>
<tr>
<td>Unheated, low-fat</td>
<td>25</td>
<td>Sticky, nonuniform particles</td>
<td>99.5</td>
<td>Chewy, normal cereal</td>
</tr>
<tr>
<td>Heated, high-fat</td>
<td>20</td>
<td>Fluffy, normal discrete particles</td>
<td>100</td>
<td>Tender, normal cereal</td>
</tr>
<tr>
<td>Unheated, high-fat</td>
<td>25</td>
<td>Sticky, large particles</td>
<td>99.5</td>
<td>Gritty, normal cereal</td>
</tr>
</tbody>
</table>

a 60% moisture basis
b See “b” of Table 2

c Normal particle size: 2-4 mm dia

d 100 = light tan; 99.5 = tan

e 10-point scoring scale: 1 = bad, 10 = excellent

Table 6—Peroxide and fat acidity values of stored unheated and heat-processedb millet flours

<table>
<thead>
<tr>
<th>Millet flours</th>
<th>Months’ storage at 49°C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Peroxide values (meq/kg fat)</td>
</tr>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Heated, low-fat</td>
<td>15</td>
</tr>
<tr>
<td>Unheated, low-fat</td>
<td>14</td>
</tr>
<tr>
<td>Heated, high-fat</td>
<td>2.2</td>
</tr>
<tr>
<td>Unheated, high-fat</td>
<td>2.2</td>
</tr>
</tbody>
</table>

See “b” of Table 2

Table 7—Mean flavor scoresa of stored unheated and heat-processedb millet flours

<table>
<thead>
<tr>
<th>Millet flours</th>
<th>Months’ storage at 49°C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Heated, low-fat</td>
<td>6.7</td>
</tr>
<tr>
<td>Unheated, low-fat</td>
<td>7.5</td>
</tr>
<tr>
<td>Heated, high-fat</td>
<td>7.2</td>
</tr>
<tr>
<td>Unheated, high-fat</td>
<td>7.2</td>
</tr>
</tbody>
</table>

a 10-point scoring scale: 1 = bad, 10 = excellent
b See “b” of Table 2