Utilization of High-Lysine Corn for the Manufacture of Ogi using a New, Improved Processing System

E. O. I. BANIGO[1], J. M. deMAN, and C. L. DUITSCHAEVER, Department of Food Science, University of Guelph, Guelph, Ontario

ABSTRACT

High-lysine (*opaque-2*) corn (HLC) has been evaluated for the manufacture of ogi using a new approach to the existing traditional ogi process. It was dry-milled into whole corn and dehulled corn flours, mixed with requisite amounts of water, cooked, inoculated with a mixed culture of pure lactobacilli and yeasts, and finally fermented. Ogi porridge prepared from the fermented product was organoleptically very acceptable. In the preliminary studies, whey protein concentrate was incorporated into the mixtures to provide a good substrate for the lactic acid bacteria. It had no significant effect on the rate of acid production of the organisms finally selected for ogi fermentation and was discontinued in subsequent studies. The most successful combination of organisms was found to be *Lactobacillus plantarum, Streptococcus lactis*, and *Saccharomyces rouxii*, and incubation temperature was 32°C. for 24 to 28 hr. There was a threefold increase in titratable acidity with HLC and normal corn ogi samples over the entire fermentation cycle of 28 hr. Brabender amylograph viscosity measurements of all samples revealed that ogi fermentation markedly increased the swelling and thickening characteristics of the starch component of HLC and normal corn flours. Cooking of the corn flour-water mixture increased the rate of acid production of the organisms. Direct steam injection cooking was found to be the more effective and would be preferred in a larger scale operation. Analyses of corn flours and ogi samples indicated no nutrient losses during processing. It was concluded that the new ogi processing system is nutritionally superior to the existing traditional process.

Since an improved essential amino acid pattern in the protein of corn due to the presence of the *opaque-2* mutant gene was discovered by Mertz et al. (1,2), several reports on the nutritional use of high-lysine (*opaque-2*) corn (HLC) have been published (3–12). Corn proteins are deficient in lysine and tryptophan but these amino acids are found in increased concentration in HLC (1,2,5). Some of the published reports deal with comparative studies on proteins of normal corn and HLC (8–11), dry- and wet-milling properties of HLC (7,12), and its use in vegetable protein-rich foods (5)—arepas of Colombia and Venezuela (6) and tortillas of Mexico and Central America (3). There is, however, no published information on the use of HLC for the manufacture of traditional cereal foods of West Africa, notably, ogi (13–15) and kenkey (16,17) of Nigeria and Ghana, respectively. These fermented cereal foods are consumed extensively in both countries.

Because of its excellent protein quality (11), HLC has great nutritional potential in predominantly corn-consuming areas of the world. To ensure its ready acceptance among those for whom it is intended, HLC must be processed into familiar foods by techniques similar to existing ones.

The present contribution deals with the utilization of HLC for the manufacture of ogi.

In Nigeria, cereals are processed in a variety of ways including roasting, boiling, milling, fermentation, or combinations of these (15). Ogi is prepared by the fermentation of corn, sorghum, or millet, followed by wet-milling, wet-sieving, and boiling (13,15). A flow-sheet of the present traditional preparation of ogi is given in Fig. 1A. Ogi porridge has a smooth texture perhaps similar to a

---

[1]Present address: Institute of Applied Science and Technology, University of Ibadan, Ibadan, Nigeria.
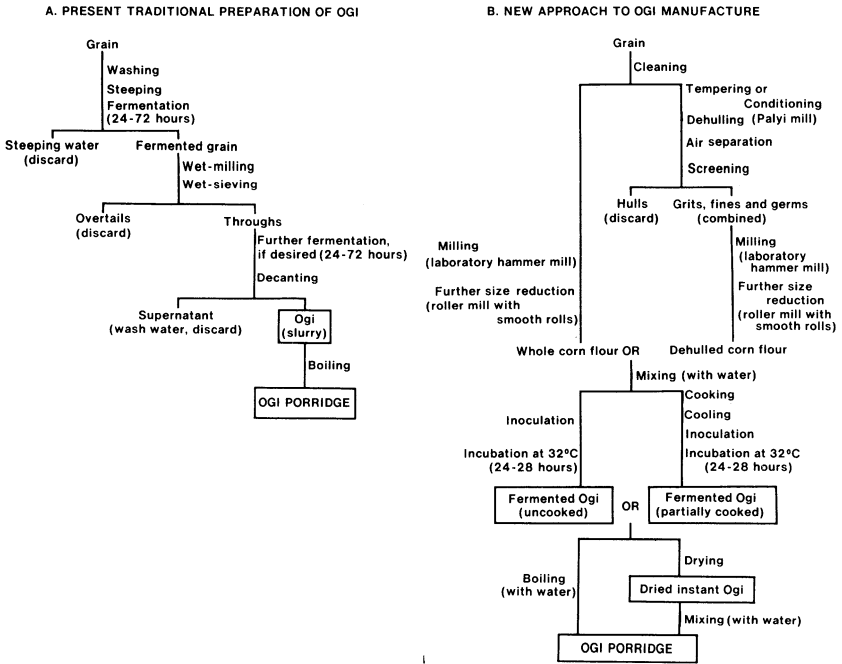
Fig. 1. Flow sheet for ogi manufacture.

hot blanc-mange and a sour taste reminiscent of yogurt. It is by far the most important traditional food for weaning infants, and the major breakfast cereal for adults (15).

Previous studies by Banigo and others (13,15) indicate considerable losses in nutrients and material during traditional ogi processing with normal corn. Much of the loss occurred in the wash water, some in the steeping water and as overtails usually discarded or used as feed. There are, however, no published reports of similar studies on the effect of traditional ogi processing on nutrient and material balance of HLC. In related comparative studies on the wet-milling properties of HLC and normal corn, Watson and Yahl (12) showed that HLC yielded more than three times as much soluble "protein" as the normal hybrids. Higher yields of steep-water and milling solubles, and higher protein content than with normal corn, were also recorded with the solubles fractions of HLC. It was therefore concluded that nutrient and material losses of HLC will far exceed those reported for normal corn (13,15) with the traditional preparation of ogi as outlined in Fig. 1A.

In the present study, a different approach to processing HLC into ogi has been adopted. Essentially it consists of dry milling, inoculation, incubation, and boiling (Fig. 1B).

MATERIALS AND METHODS

Yellow HLC, soft-endosperm variety, was obtained from the U.S. Yellow normal corn was obtained from commercial sources in Chatham, Ontario, Canada. These corn hybrids were processed into whole and dehulled corn flours

(Fig. 1B). Freeze-dried whey protein concentrate (WPC) used in the initial study
was obtained from Silverwood Industries Limited, London, Ontario, and had
the following composition: total solids, 93.8%; protein, 61.3%; lactose, 24.2%;
and ash, 4.9%.

Organisms

The following organisms were obtained as lyophilized cultures: *Lactobacillus
plantarum* NRRL B-531 and *Saccharomyces rouxii* NRRL Y-2547, courtesy of
USDA Northern Regional Research Laboratory. *S. cerevisiae,* courtesy of John
Labatt Ltd., London, Ontario; *Streptococcus lactis* No. 18, supplied by Chr.
Hansen's Laboratory, Milwaukee, Wis.; and *L. casei,* from the Department of
Microbiology, University of Guelph, Guelph, Ontario. Yogurt culture SW was
developed in this department by Duitschaever (18).

Methods of Cultivation

Yogurt and *S. lactis* cultures were maintained and transferred every other day
in sterilized, 2% homogenized milk. *L. plantarum* and *L. casei* were grown at
32°C. in TYG-broth (2% tryptone, 9.5% yeast extract, 0.2% glucose, 0.4%
KH_2PO_4 and transferred every week. *S. rouxii* and *S. cerevisiae* were maintained
on yeast broth (5% dextrose, 0.3% yeast extract, 0.2% KH_2PO_4, 0.1% KH_2PO_4,
and 0.2% $(NH_4)2$ HPO_4 added after sterilization) in a shaking-
water bath at 32°C. for 24 hr. All cultures were freshly cultivated each time
before inoculation. Aliquots of the broth cultures were centrifuged at $12,100 \times g$.
for 20 min. with a Sorvall superspeed RC2-B automatic refrigerated centrifuge,
supernatant removed by suction, and sediment redispersed in a known volume of
sterile water for inoculation. Cultures maintained in milk were added directly.

Dry-Milling of HLC

Brekke et al. (7) have described the processing of soft endosperm HLC into
products of acceptable fat content with conventional dry-milling equipment.

Whole HLC flour was prepared by grinding cleaned whole grains of HLC with
a laboratory hammer mill (0.024-in. mesh screen), manufactured by Weber Bros.
and White Metal Works Inc., Chicago, Ill. The particle size of the resulting
product was further reduced to the fineness of flour by milling with an
experimental roller mill (smooth rolls) manufactured by Allis-Chalmers
Manufacturing Company, Milwaukee, Wis.

Normal whole corn flour was prepared in a similar way. Total recovery of
whole corn flours (HLC and normal corn) was 98%.

Dehulled HLC flour was prepared by tempering, dehulling, air-separating,
screening, and milling the combined grits, germs, and fines fractions (Fig. 1B).
Nine percent (w./w.) cold water was added to 50 lb. of HLC; the two were
thoroughly mixed and allowed to stand for 25 min. This was followed by a
further adding 3% (w./w.) cold water, mixing, and standing for 30 min. The
tempered grains were dehulled with the Palyi compact mill (19). The hulls were
aspirated off and then screened. The various fractions except hulls were
recombined and milled into flour in the same way as whole corn flours.

Total recovery of dehulled HLC flour was 77%.

Fermentation

In the preliminary experiments, 97 and 94 g. dehulled corn flour, 3 and 6 g.

whey powder (representing approximately 3 and 6% of the total solids, respectively) were separately mixed with 88 ml. sterile water and 6 ml. of freshly cultivated yogurt culture (SW) under sterile conditions. These were incubated in a water bath at 43° C. for 8 hr. and at 22° C. for 16 hr. The pH was measured at two-hourly intervals with a Radiometer Model 26 pH meter. In subsequent experiments, 48.5 g. corn flour, 1.5 g. whey powder, and 44 ml. sterile water were mixed and inoculated with 3 ml. SW. The control was made up of 50 g. corn flour, 44 ml. sterile water, and 3 ml. SW.

The partially cooked samples were of the same composition as the uncooked equivalent just described, except that 99 ml. sterile water was used. The samples were cooked in a steam bath for 20 min. with stirring, cooled to 22° C., inoculated, and incubated.

Several combinations of lactobacilli and yeasts, with or without whey powder, were evaluated at their various optimum growth temperatures. A combination of L. plantarum, S. lactis, and S. rouxii was found to be the most successful as judged by rate of acid production, organoleptic qualities, and economics of raw materials. The method finally selected was as follows: 50 g. whole or dehulled corn flour was mixed with 44 ml. sterile water in a 250-ml. beaker, followed by 3 ml. of S. lactis culture and 1 ml. each of redispersed cultures of L. plantarum and S. rouxii. These proportions were maintained throughout this study, except that 99 ml. sterile water was used in the partially cooked samples. The inoculated samples were then transferred into stoppered jars and incubated at 32° C. for 24 to 28 hr. At four-hourly intervals, the pH was measured and the titratable acidity evaluated as described by Banigo and Muller (13,14).

Some of the fermented ogi samples were freeze-dried for further analysis.

The dry weight of cells in each milliliter of S. rouxii and L. plantarum cultures and total colony counts of all three cultures (S. rouxii, L. plantarum, and L. lactis) using appropriate growth media were determined.

Larger Scale Process

Cooking of the corn flour-water slurry by direct steam injection under constant stirring with a Hobart mixer was evaluated. This was followed by inoculation, incubation in stainless-steel containers at 32°C. for 28 hr., and drying on a steam-heated drum dryer. Prior to drum-drying, the total solid content of the cooked samples was adjusted with water to about 12% in a king-size Waring Blendor. The solid content of uncooked samples was adjusted to about 16 to 18% in the same manner.

Ogi porridge was prepared by boiling the uncooked or cooked fermented samples with the appropriate amount of water. Alternatively the drum-dried products were mixed with hot water with constant stirring to give ogi porridge. The total solid content of ogi porridge was about 10%.

Proximate Analysis

Protein was determined with a conversion factor of N × 6.25. Moisture, ash, fat, and fiber contents were determined on all samples according to AACC methods (20).

Amino Acid Analysis

Analyses of various corn and ogi samples for amino acid content was carried out as described in previous reports by Banigo (13) and Banigo and Muller (15).

Brabender Amylograph Viscosity

The samples were evaluated by measuring their Brabender amylograph viscosity. This test has also been described by Mottern et al. (6), Anderson et al. (21), and Yasunaga et al. (22). The amylogram was determined with a concentration of 11.8% dry weight basis using the 700 cm. g. cartridge. The standard rate of heating and cooling of 1.5° C. per min. was used at both normal heating and cooling cycles.

RESULTS AND DISCUSSION

HLC was evaluated for ogi manufacture using whole and dehulled HLC flours and mixed cultures of pure lactobacilli and yeasts. This new approach (Fig. 1B) virtually eliminated nutrient and material losses reported by Banigo and Muller (13–15) in the present traditional preparation of ogi (Fig. 1A) (see later). Similar results obtained with normal whole corn flour have been included for comparison.

Except where otherwise indicated, all tables are based on mean values of five replicates.

Whole and Dehulled Corn Flours

Ninety-eight percent of whole HLC and normal corn flours and 77% of dehulled HLC flour were recovered. Watson and Yahl (12) recorded 8.5% of hull in hand-dissected HLC. During dehulling, some of the germs and endosperm grits were firmly attached to the hulls and could not be separated by aspiration or screening. These fractions were discarded with the hull fraction and account for the lower yield of 77% of dehulled corn flour. By visual inspection, dehulled HLC flour was whiter in color than whole HLC and normal corn flours. Whole corn flour was of a higher extraction than corn ogi (13,15).

Flour fineness tests showed that 70.3% of dehulled HLC flour passed through a 10XX screen (1.13-mm. opening), 18.8% was over 10XX and under 70GG screen (0.23-mm. opening), and 10.9% was over 70GG. Of whole HLC flour 67.2% was under 10XX, 15.6% was over 10XX and under 70GG, and 17.2% was over 70GG. Of normal corn flour 45.3% was under 10XX, 17.2% was over 10XX and under 70GG, and 37.5% was over 70GG. These results indicated that dehulled HLC flour was of a higher flour fineness than whole HLC flour. Normal whole corn flour and its HLC equivalent are dissimilar in flour fineness. Apparently, HLC is deficient in horny endosperm when compared with normal dent corn (7). The fineness of the flour is a major factor to be taken into account in the oganoleptic evaluation, especially the mouth-feel of the fermented ogi porridge.

Effect of Organisms on Ogi Fermentation

Effects of several organisms, separately and in combinations, on cooked and uncooked ogi formulations were evaluated at their optimal growth temperatures by titratable acidity determinations (Fig. 2), pH measurements (Tables I–III; Fig. 3), and organoleptically. WPC was added to ogi formulations mainly to provide a good substrate for the lactose fermenting organisms. Results with uncooked ogi (Table I) showed no significant change in pH at the 3 and 6% levels of WPC. The lower level of 3% was maintained in subsequent studies. Inclusion of *S. cerevisiae* in the inoculum of yogurt culture SW and *S. lactis* appeared to

TABLE I. EFFECT OF VARIOUS ORGANISMS ON pH OF UNCOOKED FORMULATION OF OGI[1]

CF	WPC	Water	Other	Organisms in Inoculum	°C.	hr.	°C.	hr.	0 hr.	4 hr.	8 hr.	24 hr.	28 hr.
97	3	88	---	SW	43	8	22	20	5.8	5.1	4.5	4.1	4.1
94	6	88	---	SW	43	8	22	20	5.5	4.7	4.4	4.2	4.1
47	3	44	---	SW + SL + SC	43	8	22	20	5.4	4.6	4.3	nd	4.1
47	1.5	44	1.5 (Su)	SW + SL + SC	43	8	22	20	5.7	4.7	4.6	nd	4.5
48.5	1.5	44	---	SW + SL + SC	43	8	22	20	5.7	4.7	4.6	nd	4.5
48.5	1.5	44	0.2 (YE)	SW + SL + SC	43	4	22	24	5.8	5.6	5.7	nd	5.7
48.5	1.5	44	---	SL + LC	43	8	22	20	5.7	5.7	5.1	nd	4.6
48.5	1.5	44	---	LP	43	4	22	24	5.7	5.6	nd	3.9	3.9
48.5	1.5	44	---	LP + SW	11, 32	20			5.9	4.9	nd	4.2	nd
50	---	44	---	LP	32	24			6.2	6.2	nd	3.9	nd
48.5	1.5	44	---	LP + SL	32	24			5.9	5.0	4.7	4.1	nd
50	---	44	---	LP + SL	32	24			6.1	4.9	4.6	4.1	nd

[1]CF = dehulled corn flour; WPC = whey protein concentrate; SW = yogurt culture SW; SC = *S. cerevisiae;* SL = *S. lactis;* Su = sugar; LC = *L. casei;* YE = yeast extract; LP = *L. plantarum;* nd = not determined.

TABLE II. EFFECT OF VARIOUS ORGANISMS ON pH OF COOKED FORMULATION OF OGI[1]

CF	WPC	Water	Other	Organisms in Inoculum	°C.	hr.	°C.	hr.	0 hr.	4 hr.	8 hr.	24 hr.	28 hr.
48.5	1.5	99	---	SW	43	8	22	20	5.7	4.7	4.1	nd	nd
50	---	99	---	SW	43	8	22	20	6.1	4.3	4.3	nd	nd
47	3	99	---	SW + SL	43	8	22	20	5.4	4.2	3.9	nd	3.7
47	1.5	99	1.5(Su)	SW + SL + SC	43	8	22	20	5.6	4.5	3.9	nd	3.9
48.5	1.5	99	---	SW + SL + SC	43	8	22	20	5.5	4.4	4.0	nd	4.0
48.5	1.5	99	0.2(YE)	SW + SL + SC	43	4	22	24	5.7	4.9	4.6	nd	4.6
48.5	1.5	99	---	SL + LC	43	8	22	20	5.6	5.6	4.4	nd	4.3
48.5	1.5	99	---	LP	43	4	22	24	5.8	5.6	nd	3.8	3.7
48.5	1.5	99	---	LP + SW	43	4	32	20	5.9	4.8	nd	4.0	nd
50	---	99	---	LP	32	24			6.1	6.1	nd	3.8	nd
48.5	1.5	99	---	LP + SL	32	24			5.8	4.8	4.5	4.0	nd
50	---	99	---	LP + SL	32	24			6.0	5.1	4.7	3.9	nd

[1]Abbreviations as in Table I.

TABLE III. COMPARATIVE EFFECTS OF INOCULA CONTAINING
S. CEREVISIAE AND *S. ROUXII* ON pH OF UNCOOKED AND COOKED FORMULATIONS OF OGI

Ogi Ingredients, Proportions			Organisms in Inoculum	Incubation Temp. and Duration		pH of Fermenting Ogi with Time				
CF	WPC	Water		°C.	hr.	0 hr.	4 hr.	8 hr.	20 hr.	28 hr.
50[1]	---	44	LP + SL + SC	32	28	6.1	5.7	4.7	4.5	4.2
50[1]	---	44	LP + SL + SR	32	28	6.1	5.7	4.7	4.3	4.1
48.5[2]	1.5	99	LP + SL + SC	32	28	5.8	5.1	4.5	4.3	4.2
48.5[2]	1.5	99	LP + SL + SR	32	28	5.8	5.2	4.6	4.2	4.0
50[2]	---	99	LP + SL + SR	32	28	5.9	5.1	4.6	4.4	4.2
50[2]	---	99	LP + SL + SR	32	28	5.9	5.3	4.8	4.1	3.9

[1]Uncooked.

[2]Cooked. CF = dehulled corn flour; WPC = whey protein concentrate; LP = *L. planatarum*; SL = *S. lactis*; SC = *S. cerevisiae*; SR = *S. rouxii*.
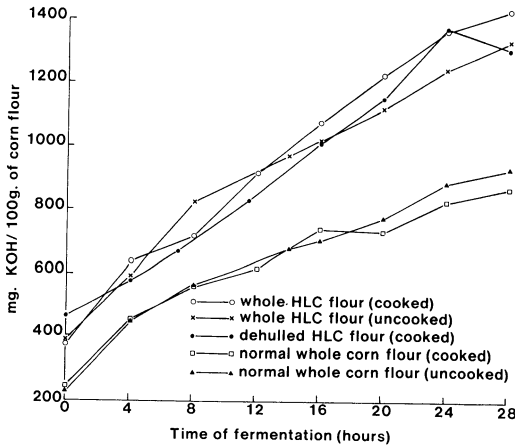

Fig. 2. Effect of fermentation time (hr.) on pH of inoculated fermenting corn flour-water mixtures.

slow down the rate of acid production (Table I). There was no increase in acid production by adding 3% sugar or 0.4% yeast extract to the formulations. A pH of 3.9 was reached after 24 hr. of incubation with *L. plantarum* alone, and was unaffected by 3% WPC addition. The same trend was evident with *L. plantarum* and *S. lactis* inoculum. However, organoleptic qualities (flavor and taste) of ogi fermented by the latter were more acceptable than the former.

A similar trend in acid production by the organisms as noted in uncooked ogi (Table I) was evident in cooked ogi (Table II). There is a significant increase in rate of acid production in cooked ogi formulations. Cooking gelatinizes the starch and makes it easily utilizable by the organisms. Similarly, it sterilizes the formulations, in such a manner that the organisms in the inoculum can grow without much competition from other organisms.

The results (Table III) showed that the final pH of fermented uncooked and cooked ogi formulations inoculated simultaneously with *L. plantarum, S. lactis,* and *S. rouxii* was lower than those inoculated simultaneously with *L. plantarum,*
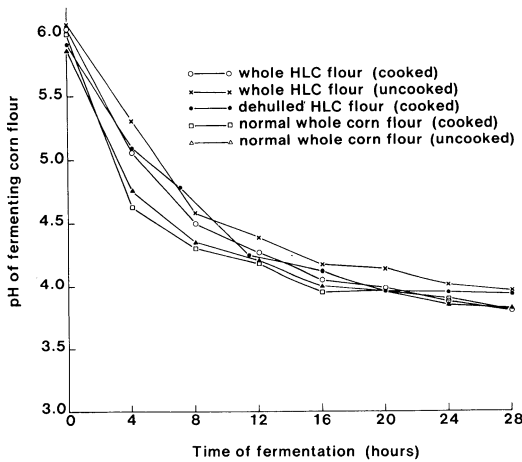
Fig. 3. Effect of fermentation time (hr.) on titratable acidity of inoculated fermenting corn flour-water mixtures.

S. lactis, and *S. cerevisiae,* and that the former group also produced ogi that was more acceptable organoleptically. Therefore, the inoculum finally selected for ogi fermentation comprised *L. plantarum, S. lactis,* and *S. rouxii.*

Comparative Effects of Selected Inoculum on Different Corn Flours

The inoculum comprised two lactobacilli, *L. plantarum* and *S. lactis,* and a yeast, *S. rouxii.* The dry weights of organisms added to every 50 g. of corn flour (as-is) were 1.4 mg. *L. plantarum* and 16.5 mg. *S. rouxii,* and corresponding total colony counts were 5.6×10^8 cells (*L. plantarum*), 1.4×10^8 cells (*S. rouxii*), and 2.3×10^9 cells (*S. lactis*). The dry weight of *S. lactis,* carried in sterilized homogenized milk, was not determined.

The moisture contents of uncooked ogi samples ranged from 52.8 to 53.8%. The pH values were 6.1 to 5.9 at the start of incubation, dropping to 4.1 to 3.9 after 28 hr. of incubation, the longest period of incubation in this study. Similar results obtained with the cooked ogi samples were moisture contents 69.2 to 70.1% and pH values were 6.0 and 5.9 dropping to 4.0 and 3.9 after incubation.

The moisture content of whole HLC ogi cooked by direct steam injection was 75.1%. The initial incubation pH was 6.0 and dropped to 3.8 after incubation. These results indicated that the final pH of the fermented ogi samples, prepared with whole HLC, dehulled HLC, and normal whole corn flours, were essentially similar, but their respective moisture contents after fermentation depended on the amount of water used in the ogi formulations. The moisture content of ogi cooked by direct steam injection was higher than those cooked in a steam bath, as would be expected.

The results (Fig. 3) showed that the pH of the inoculated fermenting corn flour-water mixtures decreased from a high of 6.1 for uncooked whole HLC ogi to a low of 3.8 for cooked whole HLC ogi over the entire incubation period of 28 hr. at 32° C. The same trend of decrease in pH with time of fermentation was evident in all inoculated fermenting corn flour-water mixtures. A pH maximum

of 6.0 decreasing to a minimum of 4.0 after about three days of fermentation in the present uninoculated tradition ogi processing has been reported by Banigo et al. (13,14). A decrease in pH values with time of fermentation was accompanied by a correpsonding increase in titratable acidity of the inoculated fermenting corn flour-water mixtures (Figs. 2 and 3). There was a significant difference in the levels of titratable acidity expressed as mg. KOH per 100 g. of corn flour on a dry-weight basis, of inoculated HLC and normal corn flour-water mixtures. The titratable acidity of HLC ogi samples was considerably higher than those of normal corn ogi samples (Fig. 3). The highest values recorded for both corn hybrids at the start and end of the fermentation cycle were 240 and 830 mg. KOH per 100 g. corn flour (dry basis) for normal corn flours, and 460 and 1,430 mg. KOH per 100 g. corn flour (dry basis) for HLC flours. It is of interest to note that the increase in titratable acidity of fermenting HLC flour is about double that of fermenting normal corn flour. There was about a threefold increase in titratable acidity of both fermenting HLC and normal corn ogi samples over the entire fermentation cycle of 28 hr. with the new ogi manufacturing approach (Fig. 1B). With the present traditional ogi processing (Fig. 1A), a corresponding 1.5-fold increase in titratable acidity after 28 hr. of fermentation has been noted by Banigo and Muller (13,14).

Analyses of Corn, Corn Flours, and Ogi Samples

Results (Table IV) indicated a slight increase of the protein content of all uncooked and cooked ogi samples prepared with whole HLC, dehulled HLC, and normal whole corn flours, indicating that no protein losses occur during processing. The addition of sterilized homogenized milk culture of S. lactis might be another contributing factor to the observed slight increase in protein content.

TABLE IV. COMPOSITION OF CORN, FLOURS, AND OGI SAMPLES[1]

	Moisture	Protein	Fat	Fiber	Ash	Carbohydrate[2]	Cal.[2]
Whole HLC							
Grain	11.4	12.1	3.9	2.6	3.6	72.8	420
Flour	9.5	12.0	5.7	2.1	1.9	78.3	413
Ogi[3]	5.0	12.2	6.1	2.1	1.3	78.3	417
Ogi[4]	4.7	12.5	4.5	2.1	1.7	79.2	407
Dehulled HLC							
Flour	10.5	10.6	5.6	0.9	1.8	81.1	417
Ogi[3]	4.5	10.8	6.1	1.0	1.2	80.9	422
Ogi[4]	4.0	10.9	4.3	0.9	1.9	82.0	410
Normal whole corn							
Grain	11.1	11.3	5.0	1.8	1.5	80.4	412
Flour	8.6	11.0	4.5	1.7	1.7	81.1	409
Ogi[3]	4.8	11.4	5.9	2.0	1.0	79.7	418
Ogi[4]	4.2	11.7	3.5	2.0	1.2	81.6	405

[1]As a percentage on dry basis except moisture.
[2]Calculated.
[3]Uncooked, fermented, and freeze-dried.
[4]Cooked, fermented, and freeze-dried.

TABLE V. AMINO ACID CONTENT OF VARIOUS CORN AND
OGI SAMPLES (g. PER 100 g. SAMPLE ON DRY BASIS)[1]

Amino Acid	Whole HLC			Dehulled HLC			Normal Whole Corn		
	Flour	Ogi[2]	Ogi[3]	Flour	Ogi[2]	Ogi[3]	Flour	Ogi[2]	Ogi[3]
Aspartic acid	0.90	0.84	0.87	0.97	0.79	0.70	0.61	0.62	0.60
Threonine[4]	0.32	0.38	0.30	1.02	1.01	0.94	0.25	0.34	0.29
Serine	0.32	0.45	0.29	0.41	0.41	0.25	0.15	0.44	0.32
Glutamic acid	1.79	1.71	1.73	1.85	1.68	1.47	1.55	2.12	1.96
Proline	0.88	0.91	1.28	0.97	0.91	0.92	0.92	1.04	0.91
Glycine	0.51	0.50	0.57	0.52	0.50	0.43	0.36	0.40	0.37
Alanine	0.70	0.74	0.71	0.71	0.73	0.69	0.77	0.86	0.80
Valine[4] + Cystine[4]	0.61	0.69	0.62	0.66	0.64	0.62	0.53	0.56	0.57
Methionine[4]	0.07	0.11	0.08	0.09	0.06	0.08	0.05	0.10	0.09
Isoleucine[4]	0.39	0.42	0.41	0.40	0.41	0.43	0.41	0.43	0.42
Leucine[4]	0.90	1.01	0.93	0.95	0.97	0.98	1.41	1.46	1.37
Tyrosine[4]	0.23	0.34	0.24	0.30	0.28	0.29	0.25	0.34	0.29
Phenylalanine[4]	0.44	0.49	0.45	0.46	0.46	0.48	0.54	0.57	0.53
Lysine[4]	0.52	0.52	0.54	0.52	0.49	0.58	0.31	0.30	0.31
Histidine[4]	0.30	0.31	0.34	0.32	0.32	0.38	0.28	0.28	0.27
Arginine[4]	0.90	0.88	0.85	0.88	0.84	0.92	0.65	0.64	0.68

[1]Mean of duplicates.
[2]Uncooked, fermented, and freeze-dried.
[3]Cooked, fermented, and freeze-dried.
[4]Essential amino acids.

This new ogi processing system (Fig. 1B) is far more efficient than the existing traditional ogi processing system (Fig. 1A) as regards the retention of protein. Protein is a limiting factor in the diets of the people of most less developed and some developed areas of the world. Banigo and Muller (13–15) have reported losses of up to 50% of the protein of the whole grain on being processed into ogi. The protein content of dehulled HLC flour was lower than that of whole HLC flour indicating losses of some germs and grits in the discarded hull fractions.

An increase in the fat content and a decrease in the ash content of all uncooked ogi samples were evident when compared with those of corn flours (Table IV). With the cooked ogi samples, there was a decrease in fat and ash contents, with the exception of dehulled HLC ogi. The fiber and carbohydrate contents of the corn flours and ogi samples were essentially similar, while those of whole HLC and dehulled HLC flours were dissimilar. As would be expected, the removal of hulls and loss of some germs in the hull fraction during the dehulling and screening stages will result in a much lower fiber content in the dehulled HLC flour.

The total calorie content of all uncooked ogi samples were higher than those of the corn flours, whereas the reverse was true with cooked ogi samples, apparently a reflection on the higher fat content of the uncooked ogi samples.

Amino Acid Composition

Results (Table V) indicated no change in the amino acid content of various corn flours when processed into ogi by this new ogi manufacturing system (Fig. 1B). The amino acid contents of whole HLC and dehulled HLC flours and their respective ogi samples were essentially similar, while those of HLC and normal corn flours and ogi samples were dissimilar. Lysine, the most limiting amino acid of all cereals, was reduced by about 50% when corn, sorghum, and millet were
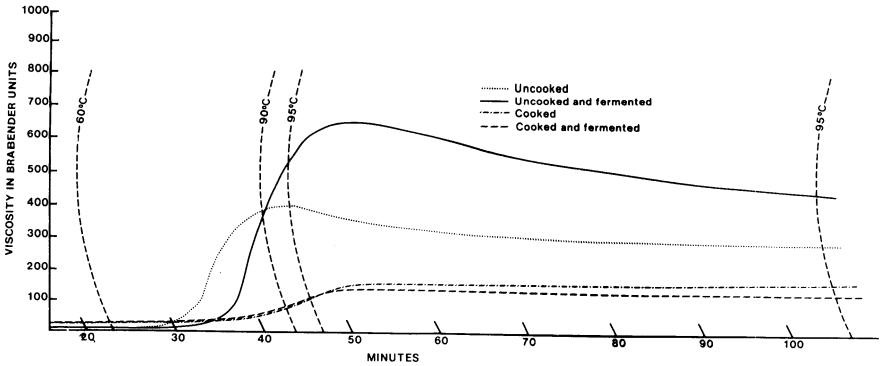
Fig. 4. Effect of new ogi process on Brabender amylograph viscosity of whole HLC flour.
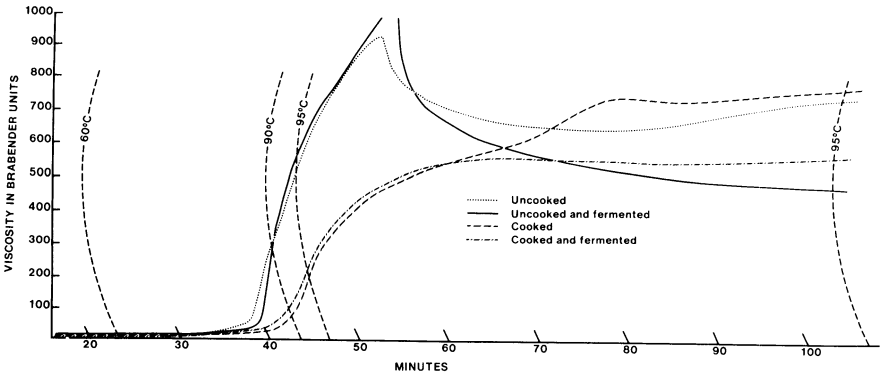

Fig. 5. Effect of new ogi process on Brabender amylograph viscosity of dehulled HLC flour.

processed into ogi by the traditional practice of ogi manufacture (Fig. 1A) (15). From the results reported here (Table V), there was no change in the lysine content of the respective corn samples when processed into ogi by this new system (Fig. 1B). As would be expected, the lysine contents of HLC samples were higher than those of normal corn samples with average values of 0.53 and 0.31 g. per 100 g. sample (dry basis) for HLC and normal corn samples, respectively. Contents of other amino acids in HLC and normal corn samples were about the same.

It was concluded from these results (Tables IV and V) that the new approach to ogi manufacture (Fig. 1B) is nutritionally superior to the present traditional ogi process (Fig. 1A), especially with regard to the elimination of nutrient losses during ogi processing.

Brabender Amylograph Viscosity

Brabender viscograms of various corn flours and ogi samples at 11.8% concentration on a dry weight basis are given in Figs. 4 through 7.

Maximum viscosity during heating of whole HLC and dehulled HLC flours
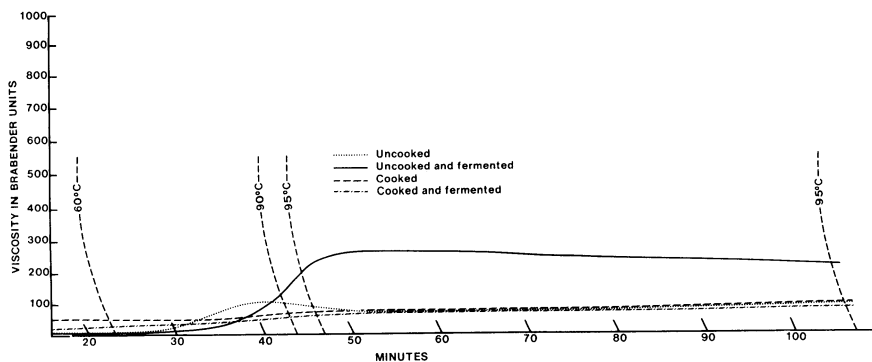
Fig. 6. Effect of new ogi process on Brabender amylograph viscosity of normal whole corn flour.
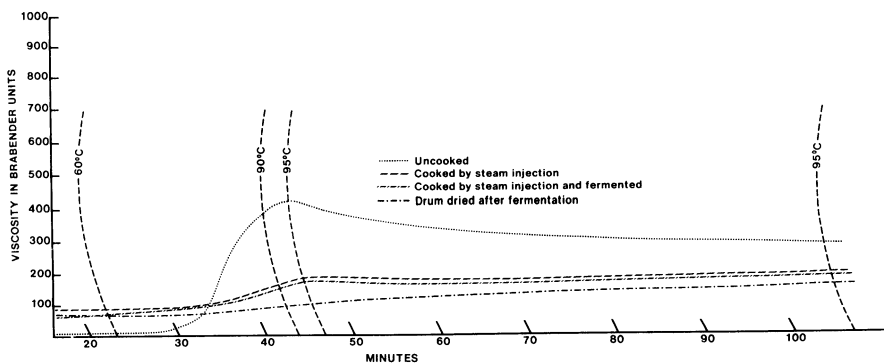

Fig. 7. Effect of new, larger scale ogi process on Brabender amylograph viscosity of whole HLC flour.
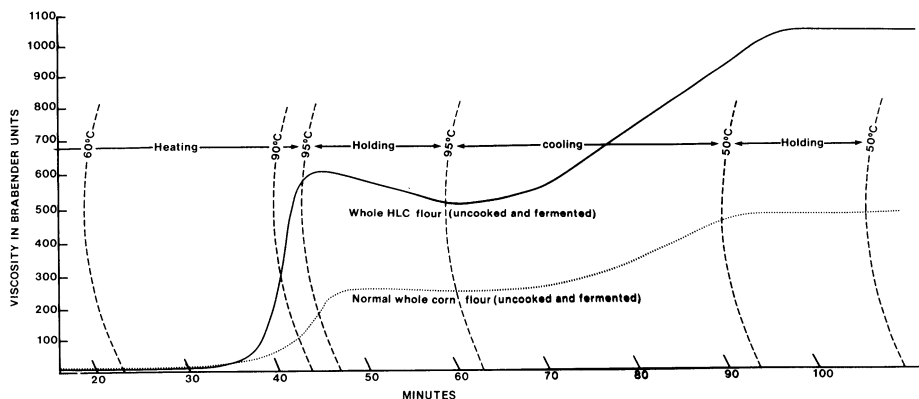

Fig. 8. Comparative changes of viscosity of whole HLC ogi and normal corn ogi with temperature using Brabender amylograph.

TABLE VI. CHANGES IN VISCOSITY OF WHOLE HIGH-LYSINE CORN (HLC)
AND NORMAL WHOLE CORN OGI SAMPLES[1] USING
THE BRABENDER AMYLOGRAPH[2]

Sample	Tg °C.	Mg min.	Vm B.U.	Mn min.	Vr B.U.	Ve B.U.	Mn-Mg min.	Vm-Vr B.U.	Ve-Vr B.U.
Whole HLC ogi[1]	70	30	605	48	515	1,010	18	90	495
Normal whole corn ogi[1]	70	30	260	54	250	460	24	10	210

[1]Uncooked and fermented.
[2]Tg = Temperature of gelatinization; Mg = min. to reach the Tg; Vm = maximum viscosity during heating; Mn = min. to obtain Vm; Vr = viscosity after 16 min. at 95°C. Ve = viscosity on cooling to 50°C.; Mn-Mg =ease of cooking; Vm-Vr= stability of the starch, Ve-Vr = index of gelatinization.

was much greater than that of normal whole corn flour (Figs. 4–6), indicating the relative amounts of raw starch in these flours. Uncooked and fermented ogi samples developed maximum viscosities which were far higher than those of uncooked and cooked flours and cooked and fermented ogi samples (Figs. 4–6). These results indicated that ogi fermentation markedly increased the swelling and thickening characteristics of the starch component of these corn flour suspensions. This observed effect is not well understood. Radley (23) had reviewed the effects of electrolytes on starch swelling, and pointed out that certain ions including acetate increased swelling. The presence of lactic and acetic acids in fermented uncooked ogi samples (13) and not in uncooked and fermented corn flours was thought to be a major factor. A significant change in the gelation period of normal whole corn flour (Fig. 6) and whole HLC flour (Fig. 4), but not dehulled HLC flour (Fig. 5), resulting from ogi fermentation was also indicated.

Cooking of the corn flour-water mixtures before inoculation and subsequent fermentation resulted in significant gelatinization of the starch component of whole HLC flour (Fig. 4), dehulled HLC flour (Fig. 5), and normal whole corn flour (Fig. 6), in that decreasing order. Direct steam-injection cooking (Fig. 7) was shown to be more effective than cooking in a steam bath, as would be expected. The former should be preferred in larger scale operation.

Cooked and fermented ogi has much lower maximum viscosity during the heating cycle than uncooked and fermented ogi (Figs. 4–7). The preparation of the former into ogi porridge will require less time than the latter. Therefore, ogi prepared by direct steam-injection cooking, followed by inoculation, fermentation, and drum-drying (Fig. 7), is a far more convenient food.

Comparative changes of viscosities of uncooked and fermented whole HLC and normal whole corn ogi with temperature are given in Fig. 8 and Table VI. These results, according to the interpretations of Mottern et al. (6), indicated that the temperature of gelatinization and the time taken to reach this temperature were similar but maximum viscosity during heating, time taken to reach maximum viscosity, viscosities after 16 min. at 95°C. and on cooling to 50°C. were dissimilar for both ogi samples. The ease of cooking was less with whole HLC ogi than with normal whole corn ogi. The stability of the starch and index of gelatinization of whole HLC ogi were much higher than those of normal whole corn ogi. A gel-like product known as agidi is prepared from ogi by prolonged cooking and wrapped in leaves (13). From these results, it was concluded that the

agidi qualities of whole HLC ogi were far superior to those of ogi prepared from the normal corn hybrid studied.

Literature Cited

1. MERTZ, E. T., BATES, L. S., and NELSON, O. E. Mutant gene that changes protein composition and increases lysine content of maize endosperm. Science 145: 279 (1964).
2. MERTZ, E. T., VERON, O. A., and NELSON, O. E. Growth of rats fed on opaque-2 maize. Science 148: 1741 (1965).
3. FROST, H. C., and ROBINSON, D. High lysine corn—What lies ahead? J. Amer. Oil Chem. Soc. 48: 407 (1971).
4. YOUNG, V. R., OZALP, I., CHOLAKOS, B. V., and SCRIMSHAW, N. S. Protein value of Colombian opaque-2 corn for young adult men. J. Nutr. 101: 1475 (1971).
5. BRESSANI, R., and ELIAS, L. G. Studies on the use of opaque-2 corn in vegetable protein-rich foods. J. Agr. Food Chem. 17: 659 (1969).
6. MOTTERN, H. H., DE BUCKLE, T. S., and PARDO, C. Protein enrichment of Colombian corn cakes. Cereal Sci. Today 15: 108 (1970).
7. BREKKE, O. L., GRIFFIN, E. L. Jr., and BROOKS, P. Dry-milling of *opaque-2* (high-lysine) corn. Cereal Chem. 48: 499 (1971).
8. PAULIS, J. W., JAMES, C., and WALL, J. S. Comparison of glutelin proteins in normal and high-lysine corn endosperms. J. Agr. Food Chem. 17: 1301 (1969).
9. CHRISTIANSON, D. D., STRINGFELLOW, A. C., BURDICK, D., and INGLETT, G. E. Endosperm fragmentation of ordinary and high-lysine corn. Cereal Chem. 48: 558 (1971).
10. MURPHY, J. J., and DALBY, A. Changes in the protein fractions of developing normal and Opaque-2 maize endosperm. Cereal Chem. 48: 336 (1971).
11. ANONYMOUS. High-pro corn promising. Food Eng. 44(7): 146 (1972).
12. WATSON, S. A., and YAHL, K. R. Comparison of the wet-milling properties of *opaque-2* high-lysine corn and normal corn. Cereal Chem. 44: 488 (1967).
13. BANIGO, E. O. I. An investigation into the fermentation and enrichment of ogi. Ph.D. thesis, University of Leeds, England (1969).
14. BANIGO, E. O. I., and MULLER, H. G. Carboxylic acid patterns in ogi fermentation. J. Sci. Food Agr. 23: 101 (1972).
15. BANIGO, E. O. I., and MULLER, H. G. Manufacture of ogi (a Nigerian fermented cereal porridge): Comparative evaluation of corn, sorghum and millet. Can. Inst. Food Technol. J. 5: 217 (1972).
16. CHRISTIAN, W. F. K. Lactic acid bacteria in fermenting maize dough. Ghana J. Sci. 10: 22 (1971).
17. MULLER, H. G., and NYARKO-MENSAH, B. Studies on kenkey, a Ghanaian cereal food. Food and Microbiological Groups Symposium. J. Sci. Food Agr. 23: 544 (1972).
18. DUITSCHAEVER, C. L. Cultured dairy products. Ontario Department of Agriculture and Food, Publ. 94, Toronto.
19. BANIGO, E. O. I., and DE MAN, J. M. The use of a compact mill in processing cereal grains and oilseeds. In: Short Comm. IX. International Congress of Nutrition (ed. by Arroyo et al.), Mexico; p. 154 (1972).
20. AMERICAN ASSOCIATION OF CEREAL CHEMISTS. Approved methods of the AACC (7th ed.).The Association: St. Paul, Minn. (1969).
21. ANDERSON, R. A., CONWAY, H. F., PFEIFER, V. F., and GRIFFIN, E. L., Jr. Gelatinization of corn grits by roll-and-extrusion cooking. Cereal Sci. Today 14: 4 (1969).
22. YASUNAGA, T., BUSHUK, W., and IRVINE, G. N. Gelatinization of starch during bread-baking. Cereal Chem. 45: 269 (1968).
23. RADLEY, J. A. Starch and its derivatives (4th ed.), p. 183. Chapman and Hall: London (1968).