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Abstract

Spontaneous lactic acid fermentation is an important process in cereal processing. It is applied to develop and enhance taste and flavour, modify texture and improve the microbial safety of foods. When applied to nixtamalized corn mixed with traditional steeped corn it is expected to further improve the functionality, improve nutritional quality and provide an alternative corn-based ingredient. The objective of this study was to investigate the chemical and functional properties of fermented blends of steeped and nixtamalized corn. A 3 x 5 factorial experimental design with fermentation time (0, 24, 48 h) and blends composition (0:100, 25:75, 50:50, 75:25, 100:0 steeped:nixtamalized corn) was performed. The blends were fermented for the specific times and analysed for pH, titratable acidity, water absorption, texture and viscosity. The pH of all the blends decreased with a corresponding increase in titratable acidity as fermentation time was increased. Decreases in water absorption capacity, texture, colour and cooked paste viscosity were measured in all the blends with increasing fermentation time. The cooled paste viscosity of the blends containing 50:50, 25:75 and 0:100 of steeped:nixtamalized corn showed decreases from 1840 to 780, 650 to 240 and 2240 to 1790 BU, respectively, after 48 h of fermentation. The sample derived from 100% steeped corn, however, showed increases in water absorption capacity, texture and cooked paste viscosity with increasing fermentation time. Nixtamalized corn can be subjected to spontaneous fermentation to produce thin, energy dense gruels of acceptable qualities to solve the low energy density problem of weaning foods prepared from fermented corn.

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Keywords: Corn; Fermentation; Nixtamalization; Chemical properties; Functional properties

1. Introduction

The consumption of corn (Zea mays) in Africa follows a variety of unit operations. These operations provide a means of converting this important staple to several traditional foods (Sefa-Dedeh, 1991). The high dependence on corn as a staple food in tropical Africa, coupled with the low nutritive value of the commodity has led to the investigation of simple traditional methods in the improvement of the nutritional quality of maize-based foods. Fermentation is one of the widely practised unit operations in Africa and it contributes to the development of acceptable texture, flavour and improves the safety of foods (Mbogga, 1988; Mensah, Tomkins, Dras, & Harrison, 1991; Nout, Rombout, & Harelaar, 1989; Odunfa, 1985; Sefa-Dedeh & Plange, 1989). Fermentation has also been identified to significantly improve the nutritional value (protein quality) of corn-based foods and as well reduce their anti-nutritional factors (Mbogga, 1988).

The process of nixtamalization is popular in Mexico and Central America and has been applied to corn for centuries (Bressani, Benavides, Acevedo, & Ortiz, 1990; Serna-Saldívar, Gomez, & Roodney, 1989). It has been reported to lead to increased bioavailability of niacin, improved protein quality, increased calcium and reduction of aflatoxin concentrations in foods (Serna-Saldívar, Knabe, Roodney, Tanksley, & Sproule, 1988; Wall & Carpenter, 1988). Sefa-Dedeh (1991) reported on the combined use of traditional African corn fermentation and the Mexican/South American corn nixtamalization to improve the nutritional quality of corn-based foods as well as to introduce and develop variety of corn processing and utilization in Ghana.
The rationale of this study was to investigate the effects of fermentation on some chemical and functional quality characteristics of nixtamalized corn.

2. Materials and methods

2.1. Materials

Corn (Z. mays) was obtained from a market in Accra. Cowpea (Vigna unguiculata) var Bengpla was obtained from the Crop Research Institute in Ghana. They were stored at 4 °C (relative humidity 65–100%). Lime [Ca(OH)2] laboratory grade, was obtained from BDH Chemicals Ltd., Poole, England.

2.2. Experimental design and sample preparation

A 3 x 5 factorial experimental design with fermentation time (0, 24, 48 h) and proportions of traditional fermented corn dough (0, 25, 50, 75, 100%) respectively was used. The traditional steeped corn was prepared by cleaning and steeping the corn in water for 24 h. The steeped corn was washed and dried. Nixtamal was prepared by boiling whole corn in 1% lime solution for 30 min and steeped in cook liquor for 14 h. The steeped grains were washed thoroughly with water to remove excess lime and mixed with the traditional steeped corn. The composite mixtures were milled using a Disc attrition mill (Model 10–2A, New Delhi) to produce blends of steeped:nixtamalized corn with the following composition; 100:0, 75:25, 50:50, 25:75 and 0:100%, respectively.

The meals produced were mixed with water to form dough of 55% moisture content, fermented for 0, 24 and 48 h, respectively. The pH and titratable acidity of the samples were determined at 0, 24 and 48 h, of fermentation. After fermentation, the dough was dried in an air oven at 50 °C for 16 h to moisture contents between 7 and 10% and the dried samples milled into fine flour using the hammer mill (Christy and Norris Ltd., Chelmsford, England). The flour samples obtained were analysed for the following indices: water absorption capacity (25 and 70 °C), colour, cooked paste viscosity and texture.

2.3. pH and titratable acidity

Ten grams of dried flour was mixed with 100 ml distilled water. The mixture was allowed to stand for 15 min, shaken at 5 min intervals and centrifuged at 3000 g for 15 min using a Denley centrifuge (Model BS4402/D, Denley, England). The supernatant was decanted and its pH was determined using a pH meter (Model HM-30S, Tokyo, Japan). Ten millilitre aliquots (triplicate) were titrated against 0.1 M NaOH using 1% phenolphthalein as indicator. Acidity was calculated as grams of lactic acid/100 g sample using the following equation:

\[
\text{Acidity} = \frac{\text{Normality of NaOH} \times \text{Volume of NaOH used}}{\text{Equivalent weight of lactic acid} \times \text{Weight of sample used} \times \text{Volume of sample}}
\]

2.4. Water absorption capacity

Five grams of sample was weighed into a centrifuge tube and 30 ml of distilled water at temperatures of 25 and 70 °C added. The mixture was stirred and allowed to stand for 30 min and centrifuged using a Denley centrifuge (Model BS4402/D, Denley, England), at 3000 g for 15 min. The supernatant was decanted and the increase in weight noted by weighing. The water absorption capacity was expressed as a percentage of the initial sample weight. The determination was done for duplicate samples.

2.5. Cooked paste viscosity

The viscosities of the samples were determined using AACC method 22–10 (AACC, 1983) with slight modifications. The cooked paste viscosity of 8% slurries in 500 ml water was measured using the Brabender Viscoamylograph (Brabender, Duisburg, Germany), equipped with a 500 cmg sensitivity cartridge. The viscosity of the samples were continuously monitored as they were heated from 25 °C at a rate of 1.5 °C/min to 95 °C, held for 30 min, cooled to 50 °C for 15 min. Brabender Viscoamylograph indices were measured.

2.6. Colour

Calorimetric measurements of the dry flour samples were recorded using a Minolta CR-310 tristimulus calorimeter (Minolta Camera Co. Ltd., Osaka, Japan). The instrument was calibrated with a standard white tile \((L=97.95, a=-0.12, b=+1.64)\). Surface colour differences were minimized by reporting an average of three readings of each flour sample. Psychrometric colour terms, \(L\) (lightness), \(a\) (red-greenness) and \(b\) (yellow-blueness) were recorded.

2.7. Texture

Twelve per cent slurries of the sample flours were cooked into a porridge which was allowed to set to room temperature (25 °C) within a period of 40 min. The texture of the set slurries were determined by using a TA-XT2 Texture Analyser (Stable Micro Systems, Surrey, England), equipped with a back extrusion rig and a compression disc of 45mm diameter. The work
done in back extruding 90 mL of set sample slurry was
determined. The test was replicated five times at a
crosshead speed of 5 m/s and a distance of 35 m. The
force-deformation curve was plotted using the XT.RA
Dimension, version 3.78 computer software (Stable
Micro Systems, Surrey, UK).

2.8. Statistical analyses

The data obtained from the analyses were statistically
analyzed using Statgraphics (Graphics Software System,
STCC, Inc, USA). Comparisons between sample treat-
ments and the indices were done using analysis of var-
iance (ANOVA) with a probability $P \leq 0.05$.

3. Results and discussion

3.1. pH

It was noted that the blending of the water-steeped
corn with the nixtamalized corn contributed to the
reduction of the pH of all the blended samples prior to
fermentation (Fig. 1). The pH of all the samples
decreased with fermentation time. The decrease was
more pronounce in the blends containing non-nixtama-
lized corn. The pH of the sample made of 100% nixta-
malized corn was 5.86 after 48 h of fermentation. This is
in contrast to the pH of 4.02–4.57 observed in all the
other samples and may be due to the initial high pH of
the 100% nixtamalized samples. Sefa-Dedeh (1991)
showed that the pH of nixtamalized corn decreased with
fermentation time reaching a value of 4.13 after 72 h.

The decrease in pH observed during fermentation
suggests the presence and activity of lactic acid bacteria
during the spontaneous fermentation of the blends.
Fermentation of traditional corn dough has been
reported to be largely a lactic acid fermentation (Halm,
Lillie, Sorensen, & Jakobsen, 1993). The decrease in pH
with increasing fermentation time is due to the hydro-
lysis of carbohydrates in the sample of dough by lactic
acid bacteria into sugars, alcohols and organic acids.
The low pH obtained after fermentation of nixtamalized
corn blends is important because the product may have
the microbial safety characteristics associated with the
traditional fermented corn dough.

Analysis of variance of the data indicated that, the
fermentation time and composition of the corn blends
significantly ($P \leq 0.05$) affected their pH. Multiple range
analysis on the effect of the fermentation time, revealed
that samples fermented for 24 and 48 h were distinctly
different ($P \leq 0.05$) from the unfermented blends.

3.2. Titratable acidity

The samples containing water-steeped and nixtamala-
zied corn in the ratio of 0:100 and 25:75 were alkaline
and no acidity were measured in these samples at the
beginning of fermentation (Fig. 2). The titratable acidity
in all samples increased with fermentation time. After

![Fig. 1. Effect of fermentation time on pH of steeped:nixtamalized
corn blends.](image)

![Fig. 2. Effect of fermentation time on titratable acidity of stee-
ped:nixtamalized corn blends.](image)
48 h of fermentation samples containing a high concentration of water-steeped corn had relatively high accumulation of acid. The acid production accompanying fermentation of corn dough contributes to the development of sour taste. Sourcing of corn dough during fermentation is an important and desirable attribute in Ghana (Sefa-Dedeh & Plange, 1989). The detection of acidity in fermented blends of steeped and nixtamalized corn dough therefore provides an added advantage in the acceptability of these blends.

Souring of dough has been linked to lactic acid fermentation during which lactic acid and other organic acids are produced (Plahar & Leung, 1982). Several researchers including Nout, Hautucist, van de Haar, Markes, and Rombouts (1988), have reported that lactic acid fermentation exhibits antimicrobial effects on pathogenic microorganisms due to the presence of acid. Fermentation can therefore be applied to steeped:nixtamalized corn blends to produce safe, acceptable foods, which possess all the nutritional improvements nixtamalization imparts.

Apedo (1988) also reported that titratable acidity of mixtures of alkalized and non-alkalized corn meals increased with fermentation time. Titratable acidity of the blends decreased with increasing level of nixtamalized corn in the blend (Fig. 2). This may be due to the fact that some of the acid produced during fermentation is used in neutralizing the alkali in the blends with nixtamalized corn.

Analysis of variance of the data showed that the blend composition and the fermentation time had significant effects ($P \leq 0.05$) on the titratable acidity of the blends. Multiple range analysis on the effect of fermentation time revealed that, each fermentation time (0, 24, 48 h) produced a distinctly different ($P \leq 0.05$) sample with respect to acidity of the blends. Further analysis showed that the fermented 100% steeped corn and a blend of 75:25 steeped: nixtamalized corn had similar titratable acidity.

### 3.3. Water absorption capacity

The water absorption capacity at room temperature (25 °C) of all the blends, except the 100% nixtamalized corn decreased with fermentation time till 24 h and increased slightly after that time [Fig. 3(A)]. The 100% nixtamalized corn on the other hand exhibited a different trend of water absorption with fermentation time. The water absorption was relatively high and increased slightly at 24 h of fermentation and decreased to a value close to its initial water absorption capacity after 48 h of fermentation.

The water absorption measured at 70 °C did not show much consistent trend. In general, all samples exhibited relatively higher water absorption at this temperature. The non-nixtamalized corn demonstrated a consistent increase in water absorption with fermentation [Fig. 3(B)]. The blending of non-nixtamalized corn with nixtamalized corn caused varying degrees of reduction of water absorption with fermentation time. The data suggests that the nixtamalization process may adversely influence the capacity of macromolecules involved in water absorption (starch, protein, fibre) to absorb water. This can influence other quality indices including swelling and cooked paste viscosity.

![Fig. 3. Effect of fermentation time on water absorption at (a) 25 °C and (b) 70 °C of steeped:nixtamalized corn blends.](image-url)
Statistical analysis showed that the effect of fermenting 100% steeped and 100% nixtamalized corn on water absorption at 70 °C was significantly different \( (P \leq 0.05) \) from that of all the other blends which contained definite amounts of both steeped and nixtamalized corn. These results show that the actual presence of both components of the blends resulted in comparable water absorption capacities, irrespective of their relative amounts in the blends.

3.4. Viscosity

Viscosity is one of the important parameters measured in most starch-based foods. The viscosity of nixtamalized corn is an important quality index during the production of alkaline cooked products. Bedolla and Roodney (1984) reported on the characteristics of instant corn flours for tortillas and snack preparation and concluded that amylograph peak viscosity was one of the objective tests which best predicts tortilla-making quality of dry nixtamalized corn flours.

The Brabender viscoamylographs showed varying effects of fermentation and addition of nixtamalized corn on viscoamylograph indices (Fig. 4). Except for the pasting temperature, the non-nixtamalized corn samples showed increase in all indices with fermentation time (Table 1). The incorporation of nixtamalized corn into the dough caused a general reduction of amylograph characteristics (peak viscosity, viscosity at 95 °C and viscosity at 95 °C-Hold). Cooling the hot paste to 50 °C

![Fig. 4. Amylograph viscosity characteristics of steeped/nixtamalized corn blends. A, 0 h fermentation; B, 24 h fermentation; C, 48 h fermentation; I, 100:0%; II, 75:25%; III, 50:50%; IV, 75:25%; V, 0:100%.](image-url)
and holding for 30 min generally led to an increase in viscosity of the unfermented samples (Table 1). Whilst fermentation led to increase in viscosity at 50 °C and 50 °C-Hold for the non-nixtamalized corn, for the samples containing nixtamalized corn, it led to the reduction of viscosity at 50 °C and 50 °C-Hold.

The increase in viscosity of the non-nixtamalized corn sample with fermentation is the cause of the low energy density problem of weaning foods made from fermented corn. Akpapunam and Sefa-Dedeh (1995) reported that the addition of malted corn resulted in the reduction in amylograph viscosity of corn gruels. The reduction in cooked paste viscosity when nixtamalized corn is fermented with traditionally steeped corn, provides another means of producing safe, thin fermented gruels to address the low energy density problem of fermented weaning foods. The observed decrease in viscosity of nixtamalized corn samples has been documented in an earlier research on fermentation of nixtamalized corn dough by Sefa-Dedeh (1991). He reported that the amylograph cooked paste viscosity of nixtamalized corn dough decreased during fermentation.

3.5. Texture

Nixtamalized corn texture is one of the important quality parameters used in the prediction of the quality of alkaline cooked products. A number of objective tests using various equipment, such as the mechanical stickiness device, described by Ramirez-Wong (1989), have been used for the evaluation of the texture (stickiness) of nixtamalized corn. In the experiment, texture of blends was measured as work required to back-extrude a specific amount of cooked slurry of the blends that had been allowed to cool and set to room temperature (25 °C).

The results showed that apart from the sample derived from the 100% nixtamalized corn, all the others showed comparable texture after 48 h of fermentation (Fig. 5). The blends containing nixtamalized corn showed a general reduction in the work required to do back extrusion with fermentation.

A high positive correlation ($r = 0.9396; P = 0.000$) was found to exist between the work require to back-extrude the samples (texture) and the viscosity of 50 °C-Hold. This results showed that the cooled paste viscosity and the texture of the blends vary in the same direction. A high positive correlation ($r = 0.8481; P = 0.0001$) was also found between the texture and water absorption (25 °C) of the blends. It may be said from these results that the effect of fermentation and nixtamalization on the texture, water absorption (25 °C) and cooled paste viscosity (50 °C-Hold) of the blends are similar. Analysis of variance on the data indicated that the effects of blend composition and fermentation time were, however, not significant ($P \leq 0.05$).

3.6. Colour

The process of alkaline cooking produces yellowish products (Serna-Saldivar et al., 1990) whose acceptability is dependent among other factors on the intensity of the colour. The samples with higher percentage of nixtamalized corn had a deeper yellow colour (lower

<table>
<thead>
<tr>
<th>Fermentation time (h)</th>
<th>Proportion of nixtamalized corn (%)</th>
<th>Pasting temperature (°C)</th>
<th>Viscosity (BU)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Peak viscosity</td>
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<tr>
<td>0</td>
<td>0</td>
<td>64.9</td>
<td>540</td>
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<tr>
<td></td>
<td>25</td>
<td>70.9</td>
<td>240</td>
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<tr>
<td></td>
<td>50</td>
<td>72.7</td>
<td>200</td>
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<td></td>
<td>75</td>
<td>73</td>
<td>210</td>
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<td></td>
<td>100</td>
<td>72</td>
<td>260</td>
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<tr>
<td>24</td>
<td>0</td>
<td>73.1</td>
<td>720</td>
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<td>25</td>
<td>76.4</td>
<td>420</td>
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<tr>
<td></td>
<td>50</td>
<td>75.6</td>
<td>160</td>
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<td>130</td>
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<td>74.7</td>
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<td>48</td>
<td>0</td>
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<td>760</td>
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<td>130</td>
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<tr>
<td></td>
<td>100</td>
<td>72</td>
<td>160</td>
</tr>
</tbody>
</table>

Mean values of duplicate analyses, significant at $P < 0.05$. 

Table 1: Viscoamylograph indices of fermented nixtamalized corn samples
L-value) and higher b-values (yellowness) than those which had smaller percentages of nixtamalized corn (Table 2).

For all the samples, the L-values (lightness) increased while the b-values (yellowness) decreased with increasing fermentation time. These results suggest that the process of fermentation breaks down the colour of the blends, producing whiter dough. The effect of fermentation on colour intensity of the samples could be attributed to the changes in pH and titratable acidity resulting from the breakdown of the complex food substances into lower molecular weight carbohydrates including organic acids during fermentation. According to Serna-Saldivar et al. (1990), colour intensity of alkaline cooked products is closely related to carotenoid pigments, flavonoids and pH. Ghanaians are used to traditional corn dough, which generally has an off-white colour. The ability of the fermentation process to reduce the intensity of the yellow colour which is developed as a result of nixtamalization, is therefore an advantage for consumer acceptability of steeped:nixtamalized corn blends.

Analysis of variance of the results indicated that both blend composition and fermentation time had significant effects (\( P \leq 0.05 \)) on the L-value (lightness) of the steeped:nixtamalized corn samples. Multiple range tests on the trends revealed that the effect on the colour of the 100% nixtamalized corn sample was significantly different (\( P < 0.05 \)) from all the other blends. Apart from the 100% nixtamalized corn sample, the effect of the blend composition on the colour of all the blends were comparable. This result may be due to the influence of the steeped corn in these blends acting as a starter during fermentation. On the other hand, the effect of blend composition on 25:75 and 0:100% steeped:nixtamalized corn were also comparable.

4. Conclusion

The blend composition and fermentation time have significant influence on acid production and the development of the characteristic flavour of the nixtamalized and non-nixtamalized corn. The addition of nixtamalized corn to traditional water-steeped corn provides a means of producing safe and thin fermented gruels. Combining the processes of nixtamalization and fermentation provide benefits in product nutritional quality and safety of products derived from them. The effects of nixtamalization and fermentation on texture, water absorption at 25 °C and cooled paste viscosity of the blends were similar.

Acknowledgements

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