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Development and Characterization of Low Viscosity Porridge (*Koko*) Flour by Co-Fermenting with Millet Malt

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Abstract

Koko is popularly used as a complementary food across much of West Africa. It is used for infant feeding, and it is made by cooking thin slurries of fermented cereal (usually maize, sorghum or millet) dough. Due to viscosity constraints, *koko* usually has low solids content (≤ 10 g/100 g), and consequently contains inadequate energy to support the child's nutritional requirements.

The objective of this study was to develop and evaluate (malt enzyme) prehydrolyzed fermented maize dough for *koko* that could contain higher than 10 g/100 g solids and still be liquid enough to be fed to infants. Maize was steeped for 24 hours, milled and mixed with millet malt flour. The moisture content was adjusted to 40 g/100 g to form dough, which was left to ferment spontaneously for specific time intervals. Fermentation was stopped by either freezing or dehydration in an air oven. The experiment followed a 4×4×2 full factorial design for malt addition (0, 1, 2 and 3%), fermentation time (0, 6, 12 and 24 hours) and dough type (frozen and dehydrated). Indices that were monitored in the fermenting dough included pH, titratable acidity, brix, reducing sugars, and amylograph pasting characteristics.

Malt and fermentation time influenced titratable acidity, pH, brix and reducing sugars content. Rapid changes in the titratable acidity and pH occurred as malt level increased. The brix and reducing sugars content increased tremendously in the dough that was co-fermented for 24 hours with 3% malt addition to 15% brix and 1393mg reducing sugars/100 g respectively. The apparent viscosity of *koko* made from this dough (at 15g/100g solids) was below 1000cP at 50°C. Co-fermenting the dough with malt increased the pasting temperature, reduced the peak viscosity and lowered the set back viscosity. Dehydrated flour, made from co-fermenting corn dough with cereal malt will provide high solids, low viscosity complementary food for infants.

Keywords: Malt; *Koko*; Energy; Viscosity; Maize; Fermentation

Introduction

Maize is a very important cereal all over the world in terms of production and consumption, but in tropical Africa its importance is even more emphasized because of its application in a wide array of traditional staples including complementary foods. One such complimentary food is *Koko*, a popular traditional porridge made using fermented maize dough. Millet or sorghum are sometimes used instead of maize. It is very widely used as a complementary food in Ghana and in much of West Africa where it is known by other local names such as *ogi, agidi, uji or akamu* [1, 2]. It has low solids content, usually not exceeding 10% [3] and consequently has low nutrient density [4] and low energy in the range of 84-168 kJ/100 g of prepared food [5]. To meet the energy and nutrient requirements of an infant the child has to consume a large volume of *koko* because of the solids content.

This is not very practical because of children's limited stomach capacities, and results in insufficient intakes of energy and other nutrients. To increase the amount of solids and therefore the energy density of *koko*, cereal malt (usually millet or sorghum) is added prior to or after cooking the fermented slurry into *koko*. Amylases in the malt hydrolyze the starches to produce simple sugars and low molecular weight dextrins. This reduces the water binding capacity of the starches when cooked, with a consequent decrease in product viscosity. In this way, more solids could be added to enable production of high energy density porridges [6-8]. Indeed thick porridges have been liquefied using this technique, and the energy density increased while an acceptably low viscosity was achieved [6].

In the traditional processing of fermented maize dough for *koko*, addition of malted cereal during the fermentation process may allow for a higher solids *koko* that will be sufficiently liquid for a young child to consume and obtain adequate energy and nutrition. The objective of this study was to develop and evaluate the physical and chemical properties of maize dough obtained from co-fermenting with millet malt.

Materials and Methods

Malting of millet

Millet was obtained from the local market at Madina, Accra. It was sorted, cleaned and malted according to the procedure described by Ogu [9]. The grains were thoroughly washed before steeping in clean water at ambient temperature (about 25°C) for 24 hrs. The grains were drained and spread on trays that had been lined with moistened pre-sterilized jute sacks. Water was sprinkled on the grains twice daily, for 3 days. The germinating seeds were turned at 24 hour intervals to avoid excessive matting. After the third day, the sprouted seeds were dried in the air oven (Baird and Tatlock London Ltd, Chadwell Heath Essex, England) at 45°C, overnight and cooled to room temperature. They were devegetated by hand rubbing to break off the dried sprouts and rootlets, and then cleaned and milled using a hammer mill (Size

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8 laboratory mill, Christy and Norris Ltd, Chelmsford, England) to obtain fine malted flour.

Co-fermentation of corn dough with malt flour

Maize was steeped in clean water for 48 hours, drained and milled, using a disc attrition mill (Straub Company, Philadelphia, PA, USA). It was mixed with the malted millet flour at 0%, 1%, 2% and 3%, and made into stiff dough by adding enough water to attain 40% moisture. The dough was left to undergo spontaneous fermentation for 0, 6, 12 and 24 hours. The fermentation was stopped by freezing (-18°C) part of the dough and drying part in the air oven (Baird and Tatlock London Ltd, Chadwell Heath Essex, England) at 50°C. Physico-chemical characteristics such as moisture content, pH, titratable acidity, reducing sugars, brix, and pasting characteristics of the products (i.e. frozen and dehydrated dough) were determined. Figure 1 is an annotated flow chart of the process.

Enzyme activity of malt flour

The Dextrose Equivalents Assay as described by the AACC 22-12 [10] was used to determine enzyme activity of the millet malt flour. A standard dextrose curve was constructed and α-amylase activity, (in µg of dextrose equivalents, DE) was calculated.

Determination of physical and chemical indices of pre-hydrolyzed dough

Moisture content determinations were done according to AOAC method number 925.10 [11] in triplicate. The pH of 10% (db) slurries of dough samples was determined using a pH meter (Hanna Instrument pH 210 Microprocessor pH Meter) after calibrating the equipment using standard buffers of pH 4 and 7. The total titratable acidity of the dough was determined as described in AACC methods number 02-31 [10]. The titratable acidity was expressed in terms of lactic acid.

Determination of reducing sugars

The method for sugar determination as described in AACC method 69-80 [10] was used.

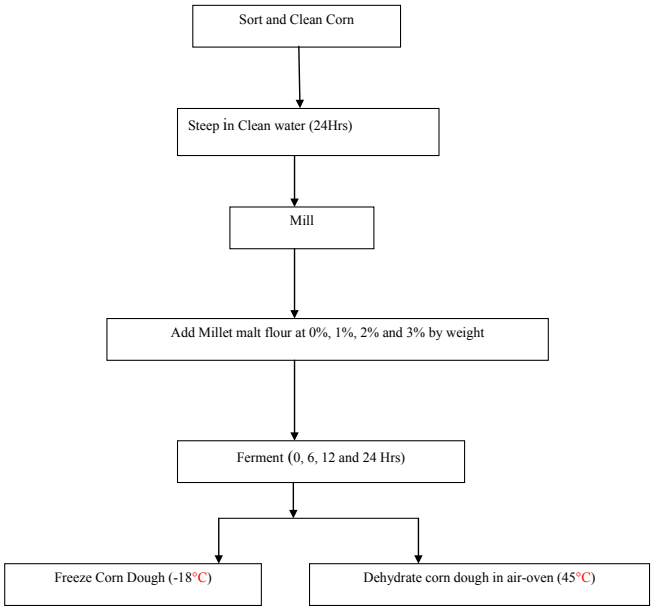

Figure 1: Flow diagram of the enzyme hydrolyzed fermented corn dough process.

Brix of pre-hydrolyzed corn dough

The Abbe Refractometer was used to determine the brix of the samples at 20°C in triplicate.

Pasting characteristics of pre-hydrolyzed corn dough

The pasting characteristics of the pre-hydrolyzed corn dough flour were determined as described by Shuey and Tipples [12] using the Brabender visco-amylograph (Brabender viscograph) equipped with a 700 cmg sensitivity cartridge. The viscosity of the slurries (500 mL, 8% solids)were continuously monitored as they were heated from 25°C at a rate of 1.5°C/min to 95°C and held at 95°C for 30 minutes, cooled to 50°C at a rate of 1.5°C/min and then held for 20 minutes at 50°C. the Brabender viscomaylograph indices (pasting temperature, peak viscosity, viscosity at 95°C and 95°C-Hold, viscosity at 50°C and 50°C-Hold) were recorded.

Determination of apparent viscosity of *koko*

The Brookfield viscometer (Brookfield Engineering Labs Inc., Stoughton MA, USA), equipped with spindle 4 was used to determine the apparent viscosities of *koko* (15% solids) at 50 and 60°C.

Design of experiments and analyses

The study followed a full factorial design (4×4×2) for fermentation time (0, 6, 12 and 24) malt level (0, 1, 2 and 3 g/100 g) and type of dough (fresh and dehydrated). The general linear models procedures (SAS, 2001) were employed to compare means of the treatment effects. The response variables (pH, titratable acidity, reducing sugars and apparent viscosity) were modeled on the factors (malt level and fermentation time), using response surface regression procedures [13].

Results and Discussion

In this study frozen corn dough was considered fresh, and compared with dehydrated corn dough. The physicochemical indices determined included pH, tritatable acidity, reducing sugars, brix, pasting properties and apparent viscosity of the cooked slurries at 15% solids.

Amylase activity

The activity of the millet malt (enzymes) on the corn starch at 37°C was determined to be 3.11×10-7 mg glucose /min/µml.

pH and total titratable acidity of corn dough

During fermentation of cereals accumulation of organic acids increases the total titratable acids and causes the pH to drop [14]. The pH and acidity of the maize dough varied among the different treatments of fermentation time, malt level and dehydration of the dough (Figures 2 and 3). All three variables had significant effects on pH and titratable acidity (Table 1). However the effect of fermentation on pH and titratable acidity were significantly influenced by the amount of malt that was added in the fermenting dough. When low or no malt was added to the fermenting dough system, lower amounts of titratable acids were formed, and higher pH observed than when higher amounts of malt were added. The significant ($p \leq 0.05$) interaction effects of malt and fermentation time are well demonstrated in the contour plots (Figures 4 and 5) generated from regression models for pH and titratable acidity on fermentation time and level of malt addition (Table 2). The models were adequate (and showed no lack of fit at $p \leq 0.05$) and could explain 87% and 60% of the variations in pH and titratable acidity respectively. The figure for pH (Figure 4) shows there was a general decrease in the pH of corn dough as the levels of malt as well as the fermentation time increased. Higher levels of malt more rapidly increased acidity and decreased pH. This implies that increasing the amount of malt in the corn dough enhanced the souring rate of the dough as indicated

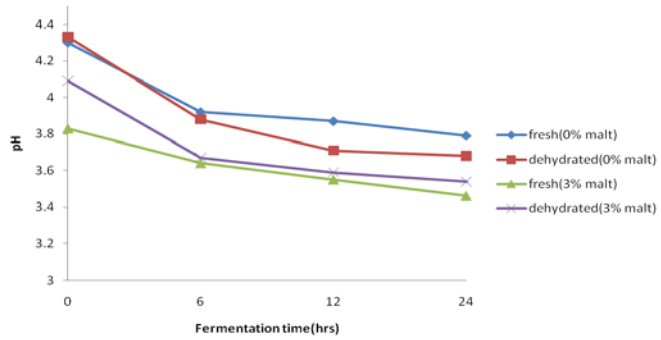

Figure 2: pH as a function of fermentation time (fresh and dehydrated dough).

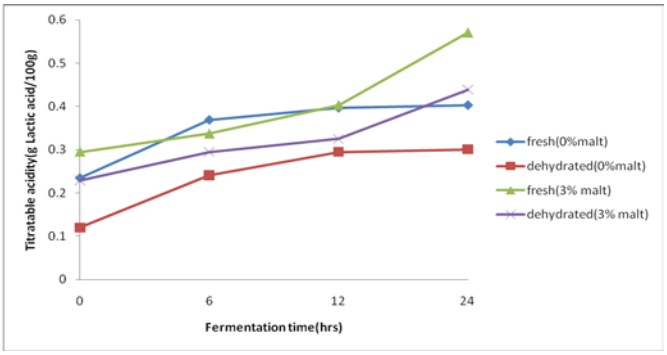

Figure 3: Titratable acidity as a function of fermentation (fresh and dehydrated dough).

Source	df	pH	TTA	SUGARS	BRIX
Malt	3	0.9369*	0.0574*	4432858*	368.198*
Ferment	3	3.4538*	0.3785*	1337625*	122.031*
Dough	1	0.0651*	0.1957*	11704	0.510
Malt × Ferment	9	0.0548*	0.0569*	1360116*	97.594*
Malt × Dough	3	0.1181*	0.0053*	14078	0.698
Ferment × Dough	3	0.2286*	0.0016	2380	0.031
R^2 (adj)		97.71%	95.62%	95.84	96.64%

* denotes statistically significant difference at p≤ 0.05.

Table 1: ANOVA summary of physicochemical indices of corn dough.

by the reduction in the pH. This is probably because as the amount of malt in the corn dough was increased, more enzymes (α-amylases) were available for starch hydrolysis into fermentable sugars. The figure for titratable acidity (Figure 5) shows there was a general increase in the titratable acidity of corn dough as the level of malt increased and fermentation time also increased. Stepwise multiple regression analyses showed that fermentation time had greater influence on the pH and acidity of the dough than malt content. Fermentation contributed the largest variations (59.8 and 69.8% respectively) for pH and acidity than malt which contributed 7.98 and 15.96% respectively to the variations of pH and acidity respectively.

Reducing sugars and brix of corn dough

The reducing sugars content and percent brix were not significantly (p≤0.05) different in the fresh and dehydrated corn dough. As fermentation proceeded, there was a gradual decrease in reducing sugars (and brix) in the dough systems that did not have malt (Figures 6 and 7) probably because the fermentable sugars served as a source of

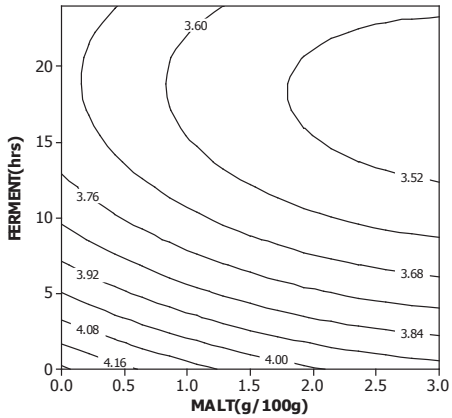

Figure 4: Effects of fermentation and malt on the pH of corn dough.

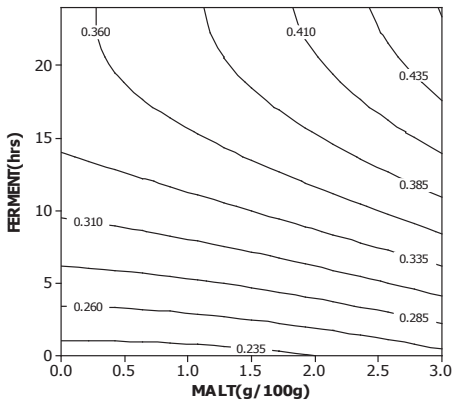

Figure 5: Effects of fermentation and malt addition on the titratable acidity of corn dough.

PARAMETER	REGRESSION COEFFICIENTS			
	pH	TTA	SUGARS	BRIX
Constant	3.6032*	0.3503*	913.089*	10.6953*
Malt	-0.1260*	0.0346*	310.449*	2.8286*
Ferment	-0.2337*	0.0845*	144.085*	1.5000*
Malt*Malt	0.0492*	0.0094	-8.719	-0.3516*
Ferment*Ferment	0.2152*	-0.0369*	-134.121*	-0.8333*
Malt*Ferment	0.0248	0.0197	182.189*	1.6786*
R^2 (adj)	67.81%	85.80%	75.14	69.54%

* denotes statistically significant difference at p≤ 0.05

Table 2: Parameter estimates of the corn dough flour characteristics.

energy for the lactic acid bacteria [1]. On the other hand, in the corn dough that was co-fermented with malt reducing sugars increased tremendously with increasing fermentation time. This suggests that the starch hydrolyzing enzymes (α-amylases) in the malt may have effectively converted the corn dough starches into more than enough substrate for the fermenting microbes.

Co-fermenting corn dough with malt significantly increased the brix and reducing sugars content (Tables 1 and 2).The effects of fermentation on sugar content of dough was influenced by the amount of malt that was incorporated in the fermenting dough system. Lower amounts of sugars were recorded when low or no malt was added. On the other hand, higher amounts of malt in the corn dough increased the sugars content (Figures 6 and 7).

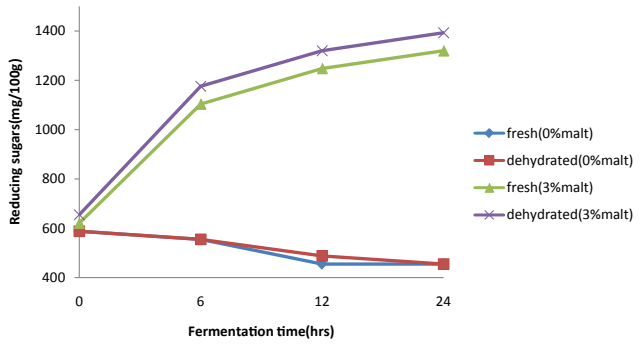

Figure 6: Reducing sugars as a function of fermentation time (fresh and dehydrated dough).

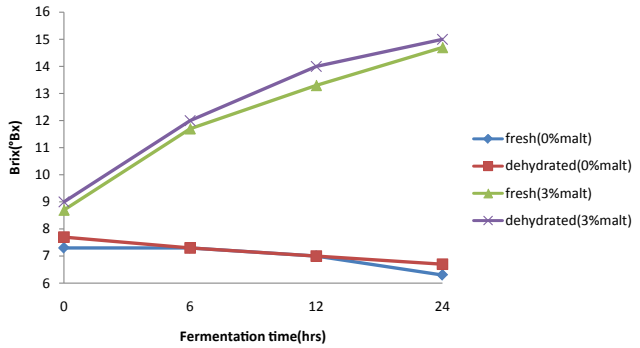

Figure 7: Brix as a function of fermentation time (fresh and dehydrated dough).

The effects of fermentation time and malt addition on reducing sugars and brix are demonstrated in the contour plots (Figures 8 and 9) generated from the regression models (Table 2). Higher levels of malt rapidly increased the reducing sugars content of the dough. Indeed while it was possible to attain or exceed 15% brix when malt was added at 3% level in the dough and co- fermented for about 20 hours, it was not possible to obtain greater than 8% brix when fermentation was done with little or no malt added to the dough (Figure 9).

Apparent viscosity of *koko* made using pre-hydrolyzed corn dough

The apparent viscosity of *koko* made using dough that was not fermented and had no malt in it was very high even at 60°C, and it further increased upon limited (6 hours) fermentation (Figure 10). On the other hand the viscosity of *koko* made using dough obtained by co-fermenting with malt dropped, and further decreased with fermentation time, and increasing levels of malt addition at both 50°C and 60°C (Figures 10 and 11).

The observed effects of pre-hydrolyzing corn dough on viscosity are significant and have important implications for *koko* as a complementary food. The regression model (Table 3) for apparent viscosity on fermentation time and malt level was fairly adequate (R-squared=83.6). The effects of malt level on the apparent viscosity of the *koko* made using pre-hydrolyzed corn dough depended on how long the dough was fermented. Longer fermentation times and higher malt levels achieved the greatest liquefaction of the *koko*. The apparent viscosity of *koko* made using dough that was co-fermented for 24 hours with different levels of malt is shown in figure 12. The figure clearly demonstrates that it is possible to achieve low viscosities (less than 1000 cP) *koko* with solids content of 15 g/100 g. Most mothers feed their children on *koko* with viscosities ranging from 600-1500 cP at 45-60°C (unpublished data from preliminary survey work). Thus co-fermenting corn dough with cereal malt will provide dough that could be used for *koko* with high enough solids content (15%) to meet the nutritional requirements of the infant child.

Pasting characteristics of pre-hydrolyzed corn dough

Typical parameters usually obtained from the Brabender amylograph to describe the pasting characteristics of a given starch source include the pasting (or gelatinization) temperature, Peak viscosity, Viscosity at 95°C, Viscosity at 95°C after holding for 30 minutes, Viscosity at 50°C and Viscosity at 50°C after holding for 20minutes [12]. Table 4 provides the pasting indices for the dough at the various treatments of varying malt concentration and fermentation time.

Pasting temperature

The corn dough pasting temperature increased with increasing malt concentration (Table 4). That is, the higher the concentration of malt in the corn dough, the higher the cooking temperature, and probably the longer it will take to cook. On the other hand increasing fermentation time lowered pasting temperatures (Table 4). This observation may be linked to the influence of sugars on the pasting temperature as established by some research reports. Sudhakar [15] made observations about the effects of sugar on the gelatinization temperature and cold

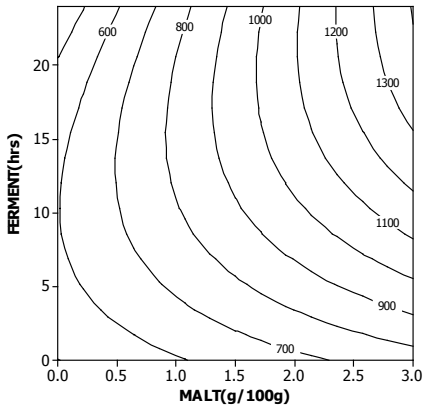

Figure 8: Effect of fermentation and malt on the reducing sugar content of corn dough.

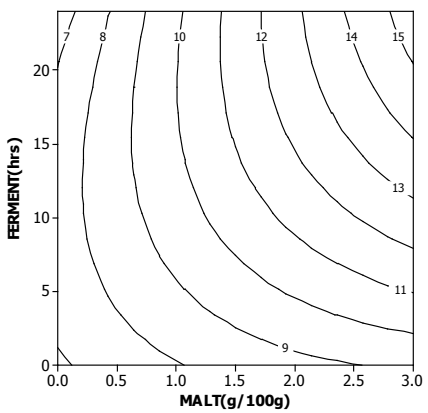

Figure 9: Effect of fermentation and malt on the brix of corn dough samples.

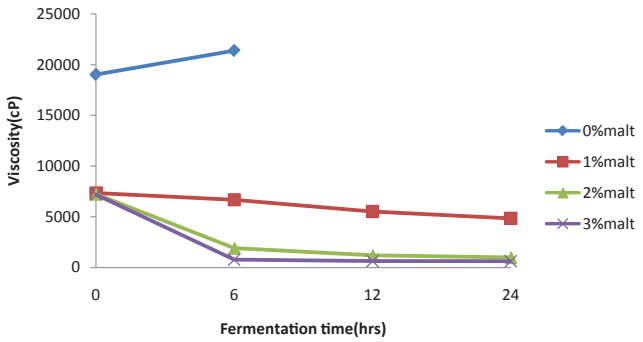

Figure 10: *Koko* viscosity (15% solids) as a function of fermentation and malt concentration at 60°C.

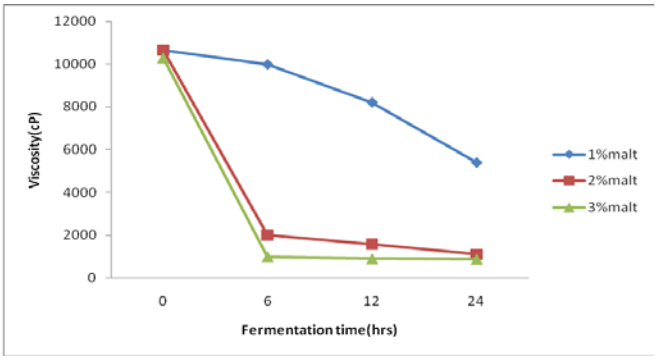

Figure 11: *Koko* viscosity (15% solids) as a function of fermentation and malt concentration at 50°C.

PARAMETER	REGRESSION COEFFICIENTS
Constant	2869.7*
Malt (%)	-8634.7*
Ferment (hrs)	-3605.5*
Temperature (hrs)	-1074.4*
Malt * Malt (hrs)	6782.4*
Ferment (hrs)*Ferment (hrs)	3504.9*
Temperature (°C)*Temperature (°C)	227
Malt (%)*Ferment (hrs)	-1028.7*
Malt (%)*Temperature (°C)	580
Ferment (hrs)*Temperature (°C)	714.1*
R^2 (adj)	83.6%

* denotes statistically significant difference at p≤ 0.05.

Table 3: Regression analysis of apparent viscosity of the corn dough samples.

paste viscosity of corn starch. It therefore implies that, increasing malt concentrations significantly increase the pasting temperatures of corn dough by increasing the sugars level through starch hydrolysis. Fermentation decreased the sugars content, and therefore lowered the pasting temperature.

Peak viscosity

Peak viscosity is measured as the highest value of viscosity attained by the slurry during the heating cycle (25-95°C). It has been shown by Sanstedt and Abbot [16] to be affected by starch concentration. Generally, the presence of malt in the fermented corn decreased the peak viscosities (Table 4 and Figure 14). A drastic reduction in peak

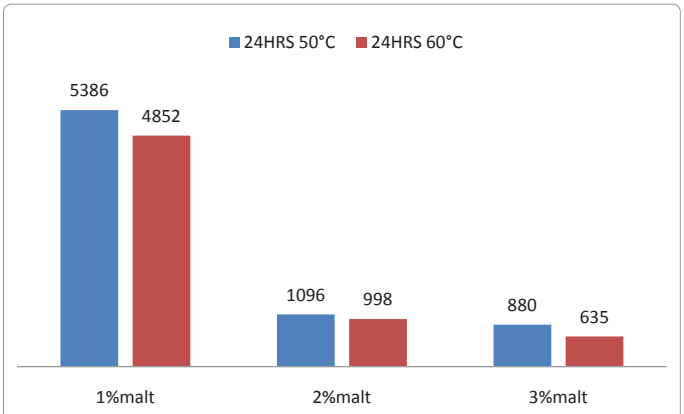

Figure 12: *Koko* viscosity of 24hrs fermented pre-hydrolyzed dough (15% solids) as a function of temperature and malt concentration.

Sample	Amylograph parameter						
Malt (%)	Fermentation time Hr	Pasting temp (C) °C	Peak viscosity (BU) BU	Viscosity at 95 C (BU) BU	Viscosity 95H H(BU) HOLD BU	Viscosity at 50 C (BU) BU	Viscosity at 50 H HOLD(BU) BU
0	0	76.1	465	165	170	260	365
0	6	76.4	430	170	175	270	385
0	12	76.8	540	180	175	275	410
2	0	77.1	510	170	165	245	400
2	6	77.5	410	160	155	205	355
2	12	77.2	440	155	160	195	320
3	0	79.2	480	165	160	235	390
3	6	78.8	400	155	150	220	330
3	12	78.0	345	150	135	180	295

Table 4: Pasting characteristics of the corn dough flour samples.

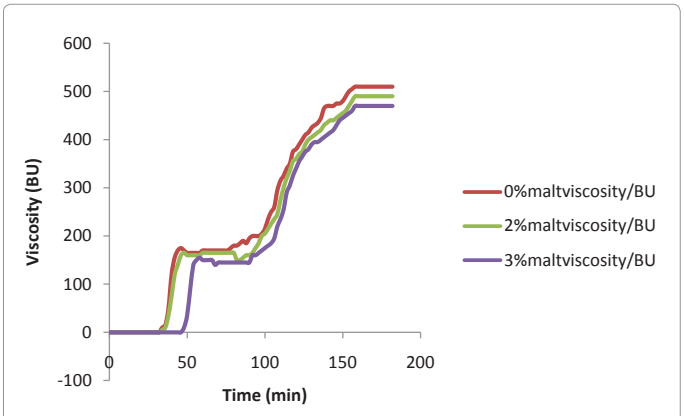

Figure 13: Pasting characteristics of the corn dough flour samples at 0hrs fermentation for varying malt concentrations.

viscosity was observed as malt concentrations increased probably due to increased starch hydrolysis by the increased enzyme (α-amylase) concentration [17]. On the other hand there was a general increase in viscosity as fermentation time increased in the corn dough that did not have malt added (Table 4).

Viscosity at 95°C

Viscosity at 95°C tests the stability of the hot paste under the heating conditions. A high viscosity indicates high paste stability.

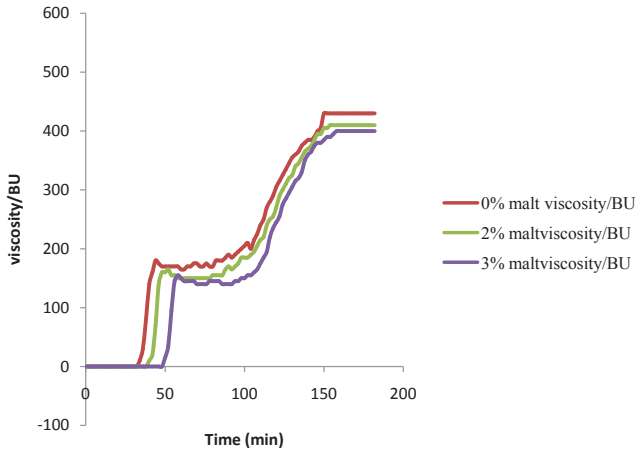

Figure 14: Pasting characteristics of corn dough flour at 6hrs fermentation for varying malt concentrations.

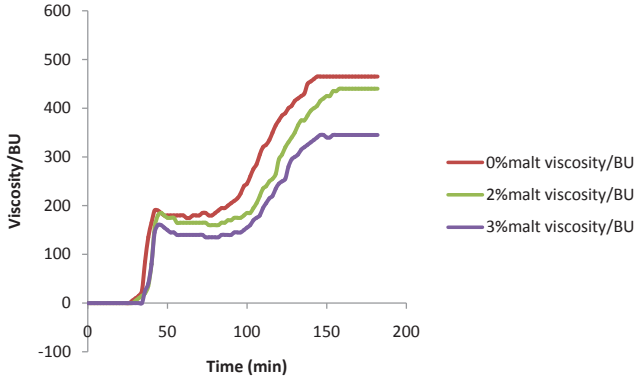

Figure 15: Pasting characteristics of corn dough flour at 12hrs fermentation as a function of malt concentrations.

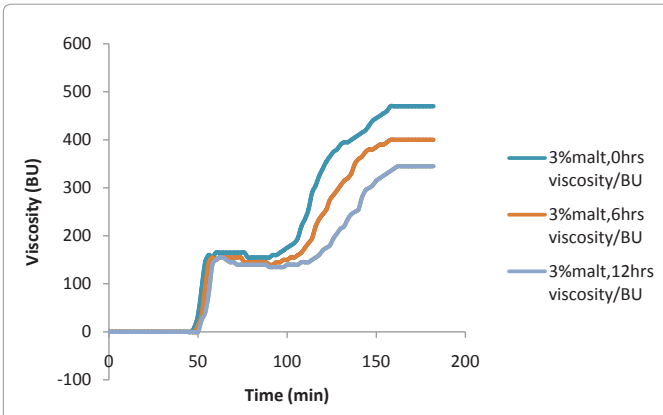

Figure 16: Pasting characteristics of 3% malt corn dough flour as a function of fermentation time.

Lower viscosities at 95°C were observed for the samples containing malt (Table 4). As the concentration of malt increased, the viscosity at 95°C (Figures 13-15) decreased, suggesting that the addition of malt reduces stability of the paste under heating conditions. On the other hand, as fermentation proceeded in dough samples with no malt added, there was an increase in viscosity at 95°C (Table 4 and Figures 13, 14).

Viscosity at 95°C-HOLD

Generally, the addition of malt to the corn dough decreased the viscosity of the resulting gruel at 95°C-HOLD (Figures 13-15), suggesting that co-fermenting corn dough with malt had the effect of weakening the stability of the hot cooked paste. Fermentation had the effect of increasing the viscosity, while malt decreased it. This is further evidence that co-fermenting corn dough with malt will help provide porridges with lower viscosities for their solids content.

Viscosity at 50°C

The viscosity at 50°C is quite revealing with respect to the consistency of *koko* at the average eating temperature. Co-fermentation with malt reduced the viscosity of the gruels even at cooling temperatures (50°C), and the samples recorded lower set- back viscosities than the non-malted samples as fermentation time increased (Figures 13-15).

Viscosity after 20minutes at 50°C

All the samples showed an increase (Figures 13-16) in viscosity at 50°C-HOLD. As fermentation time increased, a drastic increase in viscosity was recorded in the samples with no malt addition while a decrease was recorded in the dough samples with malt.

Conclusion

A critical influence of co-fermenting dough with cereal malt was that a thin cooking *koko* at less than 1000cP could be obtained even at high solids content (15%). Co-fermentation with malt however raises the gelatinization temperature and will therefore prolong the cooking time. Dehydrated dough flour, obtained from co-fermenting corn dough with cereal malt (at 2-3% level) could be developed as a high calorie, low viscosity complimentary food for use by mothers.

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