The Effects of Technological Modifications on the Fermentation of Borde, an Ethiopian Traditional Fermented Cereal Beverage

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Abstract

Four independent experiments were carried out to study the effect of modifying some steps in the technology of the four-phase traditional borde fermentation using malt and a mixture of unmalted cereals. When maize flour was substituted for maize grits in Phase I fermentation, the titratable acidity was greater throughout this phase and decreased after 24 h. Substitution with flour resulted in a higher yield, improved acceptability and extended keeping quality of *borde*. In addition, the wet milling at the last stage of the process could be omitted. When Phase I was omitted from the process, the starting pH at Phase II was much higher than when fermented maize from Phase I was used. Although the pH by the end of Phase II was comparable in both treatments, the *borde* made using fermented maize from Phase I was superior in all sensory attributes. Unmalted ingredients were heat treated in various ways and all methods were found to produce acceptable *borde*. However, *borde* from uncooked ingredients was totally unacceptable. An investigation on the effect of merging some phases of the fermentation showed that it is possible to prepare an acceptable *borde* using a simplified method of production. There were no marked variations in microbial load of *borde* from all the above treatments. It was found possible to shorten the duration and simplify the technology of *borde* fermentation with some variations in acceptability.

Keywords: food processing; traditional fermentation; cereal beverage, borde; Ethiopia

Introduction

Traditional fermentation processes are increasingly attracting the attention of scientists and policy makers as a vital part of food security strategies (van de Sande, 1997). Traditional methods and age-old techniques of food processing are still used in developing countries especially in communities with low-income levels. These countries require food-processing technologies that are technologically appropriate, suitable for their regions and affordable in rural and urban economies. Household-level fermentation is one such indigenous technology that has been developed for a wide range of foods and beverages from an extensive range of raw materials. However, the transformation of home-based arts into modern industries necessitates acquisition of scientific knowledge of the raw materials and processes used (Novellie and De Schaepdrijver, 1986) so that the problems involved in scaling-up can be addressed. In many African countries, cereal-based traditional fermented products (Lorri, 1993; Steinkraus, 1996; Bvochora, 1999 et al; Mahgoub et al., 1999) are consumed both as beverages

and foods. Ethiopian *borde* is one of those types of beverage among others. The recommended research priorities on traditional fermented foods are improving understanding of the fermentation process; refining the processes; increasing utilization of the process and developing local capabilities (BOSTID, 1992).

Borde is produced using traditional fermentation technology from a variety of locally available cereal ingredients. The unmalted cereals and the malt may be from one or a mixture of cereals. The amount, types and combinations of malt (maize, barley, wheat, finger millet) vary within and between households on the basis of availability and preferences of cereals regardless of localities (Abegaz et al., 2002).

•There is only limited published information on the fermentation and microbiology of *borde* in southern and central Ethiopia (Ashenafi and Mehari, 1995; Bacha, 1997). Contrary to both of these reports, however, the traditional processing technology of *borde* in

southern Ethiopia has been shown to have four major phases (Abegaz et al., 2002). This process is time-consuming and inefficient. *Borde* production involves grinding, fermentation, roasting, steam cooking, boiling, cooling, mashing, wet-milling and wet-sieving operations. To improve the fermentation of *borde*, it is necessary to undertake basic studies on its traditional processing technology and quality characteristics. To our knowledge, there is no published information on the effects of various process factors on fermentation and yield of *borde*.

The objective of this work was, therefore, to investigate the effect of modifying selected techniques used in the traditional production of *borde* in an attempt to simplify the technology and reduce loss of residues. The effects of substituting maize grits with flour, fermentation at Phase I, various methods of cooking, and merging some phases of the main fermentation at Phase II, III and IV on acceptability of the product were investigated.

Materials and Methods

Four independent experiments were carried out in duplicate and repeated three times at room temperature (21-25°C) as described in sections 2.1-2.3 below. In all the experiments, *borde* was prepared (at the Awassa College of Agriculture) from malt and a mixture of unmalted cereal ingredients by an experienced brewer using a modified traditional (**MT**) recipe. The modifications were substitutions of: 1) earthenware pot with plastic jar; 2) maize fermented for 48-72 h at Phase I with 24-48 h; and 3) 13-18% malt with 3% (Abegaz *et al.*, 2002; Unpublished results). In addition, substitutions of: 1) flour for maize grits; 2) non-fermented flour for 24-48 h fermentation at Phase I (omission of Phase I); 3) only one or two merged phases instead of three main fermentation phases (Phase II, III and IV); and 4) the combination of roasting, steaming and boiling with only one type of heating in the whole process were carried out in the present work. The main equipment used were plastic jars, metal plate and pan, grinding stone, bowls and sieve (1 mm pore size). Samples for analysis were collected at 6 h intervals and/or the beginning and end of each phase. The microbial load, pH, titratable acidity (TA) and acceptability of *borde* were evaluated.

Treatment and proportion of ingredients

Borde was prepared using unmalted maize (Zea mays), sorghum (Sorghum bicolor) and mixed flour from wheat (Triticum sativum), finger millet (Eleusine coracana), tef (Eragrostis tef) and malt flour. The proportions (w/w) of unmalted ingredients used in all the experiments were, 2 maize: 2 a mixture of wheat, finger millet and tef: 1 sorghum. The heat treatments of unmalted cereal ingredients used and the preparation of malt are described by Abegaz *et al.* (2002). The malt was prepared from barley (Hordeum vulgare) and maize. All the unmalted ingredients were cooked at 90-98°C and cooled to 23-25°C before blending with malt flour and/or the fermenting mash at the appropriate phases of *borde* fermentation. Whenever flour replaced grits, roasting of *enkuro* (granular mass) was substituted by baking of kita (flat

bread) at **Phase II** except experiment **2.3A** below. The malt required in all treatments was calculated against the weight of grits or flour used in Phase I. Then 80% of the total required malt was added at Phase II and the rest at Phase IV. Except where otherwise stated, 3% barley malt (w/w) was used.

Phases of *borde* fermentation

The four phases of *borde* fermentation (Abegaz *et al.*, 2002) are briefly described as follow:

Phase I
Maize grits or flour was mixed with equal amount of water (w/v) and fermented for 24-48 h before apportioning into 2:2:1 (w/w) and using each part in Phase II, III and IV respectively.

Phase II
About 40% of 24 h fermented maize from Phase I was roasted on a hot griddle into *enkuro* (experiment **2.3A**) or baked into *kita* (experiments **2.3B, C** and D). After cooling, the *enkuro* or *kita* was thoroughly blended with water and 80% of the total malt into a thick brown mash called *tinsis*. The *tinsis* was left to ferment for 24 h.

Phase III
A further 40% of the fermented maize from Phase I (48 h) was gently roasted or baked, kneaded with more mixed fresh flour, moulded into dough balls and then steam cooked into *gafuma*. The *gafuma* was broken into pieces, cooled and blended with the fermented *tinsis* into a thick brown mash called *difdif*. The *difdif* was left to ferment for 18 h.

Phase IV
The remaining 20% of fermented maize from Phase I (48 h) was mixed with sorghum and boiled for 90 min with continuous stirring into a thick porridge. After cooling, the gelled porridge was added to the fermented *difdif* along with the remaining 20% malt, thoroughly mixed and sieved. When grits and sorghum grains were used (experiment **2.3A**), residues were repeatedly wet-milled with grinding stones and wet-sieved by slurrying with water.

Experimentation
A. Effect of substituting flour for grits

Equivalent weights of flour were used to replace grits or grains in the MT process. An equal mixture (w/w) of barley and maize malt (18%) as per the brewer's traditional judgment was used. Both the grits (G) and flour (F) used at Phase II were roasted to *enkuro*.

1. **G:** maize grits, sorghum grains and mixed flour + malt flour
2. **F:** all in the form of flour + malt flour.

The production of *borde* was carried out according to the traditional process except that it was unnecessary to wet mill the fermenting mash of F at Phase IV. The fermenting mash of G was wet-sieved and repeatedly wet-milled, while F was wet-sieved only once. It was found that Phase IV took four instead of the normal six hours when F was used (result not shown). The production process was therefore timed so that both G and F *borde* were ready for consumption at the same time. The yield of *borde* and the residue of G and F were compared.

B. Effect of omitting Phase I in borde fermentation
This experiment was to investigate possibilities of producing *borde* without Phase I. All ingredients were used as flour with 3% barley malt (unpublished results).
1.**MT:** fermented flour from Phase I + traditional cooking methods (4 phases)
2.**NF:** non-fermented flour + traditional cooking methods (3 phases)
3.**NFP:** non-fermented flour + all unmalted ingredients cooked as porridge (3 phases)

NF and **NFP** fermentations were initiated together with that of Phase II for the **MT**. The malt flour and cooked ingredients were blended with water at this step of each treatment. All the treatments were sieved once and the filtrate was left for 4 h fermentation at Phase IV.

C. Effect of merging some phases of *borde* fermentation
This experiment was designed to investigate the effects of merging Phase III and IV (**M1**); Phase II, III and IV (**M2** and **M3**); or Phase II and III (**M4**) using 24 and/or 48 h fermented maize

flour and a mixture of fresh flour. These treatments were compared with the **MT** recipe. All ingredients were used as flour with 3% barley malt. The cooking methods and proportion of ingredients used in the merging phases were identical to each representative phase as used in the four-phase **MT** procedure.

1.MT: 24 and 48 h fermented maize from Phase I + fresh mixed flour (4 phases)

2.M1: 24 and 48 h fermented maize from Phase I + fresh mixed flour (3 phases)

3.M2: 48 h fermented maize from Phase I + fresh mixed flour (2 phases)

4.M3: 24 h fermented maize from Phase I + fresh mixed flour (2 phases)

5.M4: 24 h fermented maize from Phase I + fresh mixed flour (3 phases)

Figures 1a, b, c and **d** show the flow diagram of MT, M1, M2/M3 and M4 respectively. Finally, each treatment was wet-sieved and then the filtrate was left for 4 h fermentation.

D. Effect of using different cooking methods in *borde* production

In order to select a cooking method that would ease the traditional technology of *borde* production, baking, steam cooking and boiling were used singly for the whole cooking process and compared with their combined use in the MT procedure. Traditionally, roasting, steam cooking and boiling were used at Phase II, III and IV respectively. However, baking substituted roasting in the MT procedure due to the use of flour. Non-cooked ingredients were used as a control. Otherwise, unmalted flour and 3% barley malt were used in all treatments.

1.MT: modified traditional cooking (baking, steam cooking and boiling),

2.B: all ingredients baked into *kita* (flat bread),

3.S: all ingredients steam cooked to *gafuma* (steamed dough balls),

4.P: all ingredients boiled to a thick porridge,

5.NC: ingredients not cooked.

After cooling, the ingredients were blended with malt and/or fermenting mash at the appropriate phases and finally, the filtrate was fermented for 4 h at Phase IV.

Figure 1 a. Flow chart: a modified traditional (MT*) fermentation of *borde* in southern Ethiopia
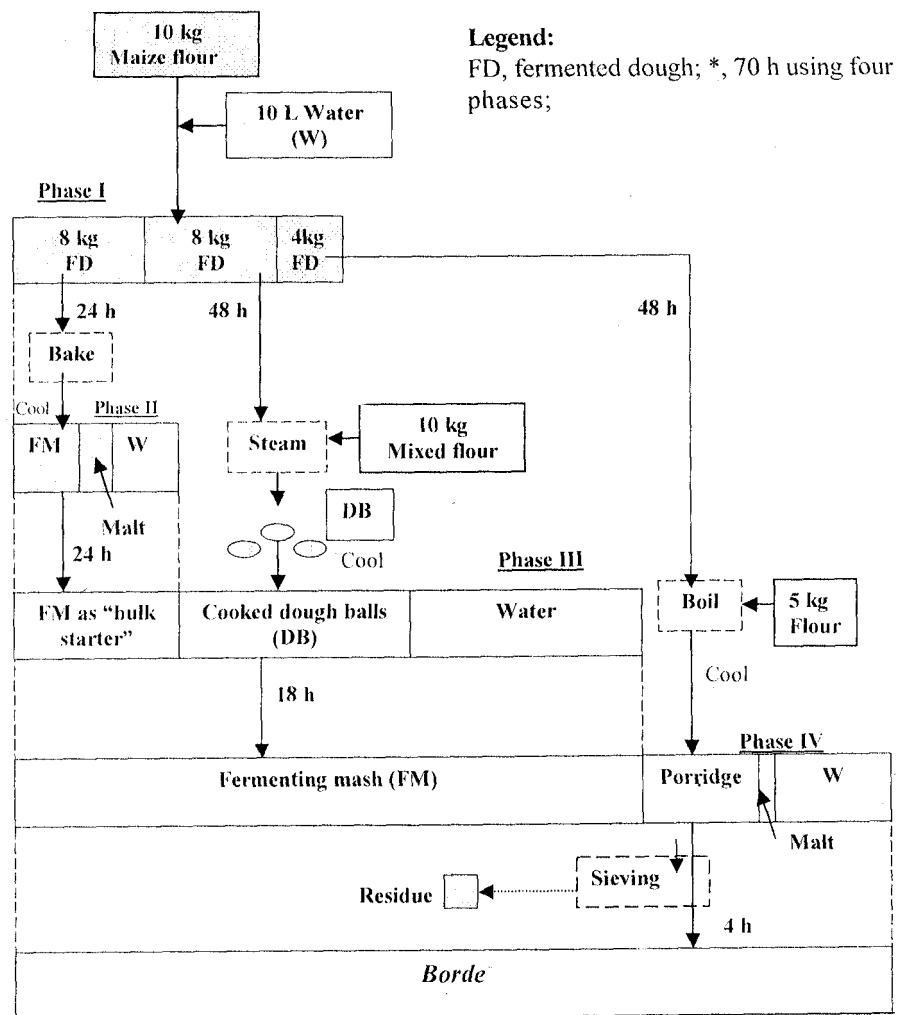

Figure 1b. Flow chart: option 1: modified technique for production of *borde* by merging Phase III and IV (M1)*.
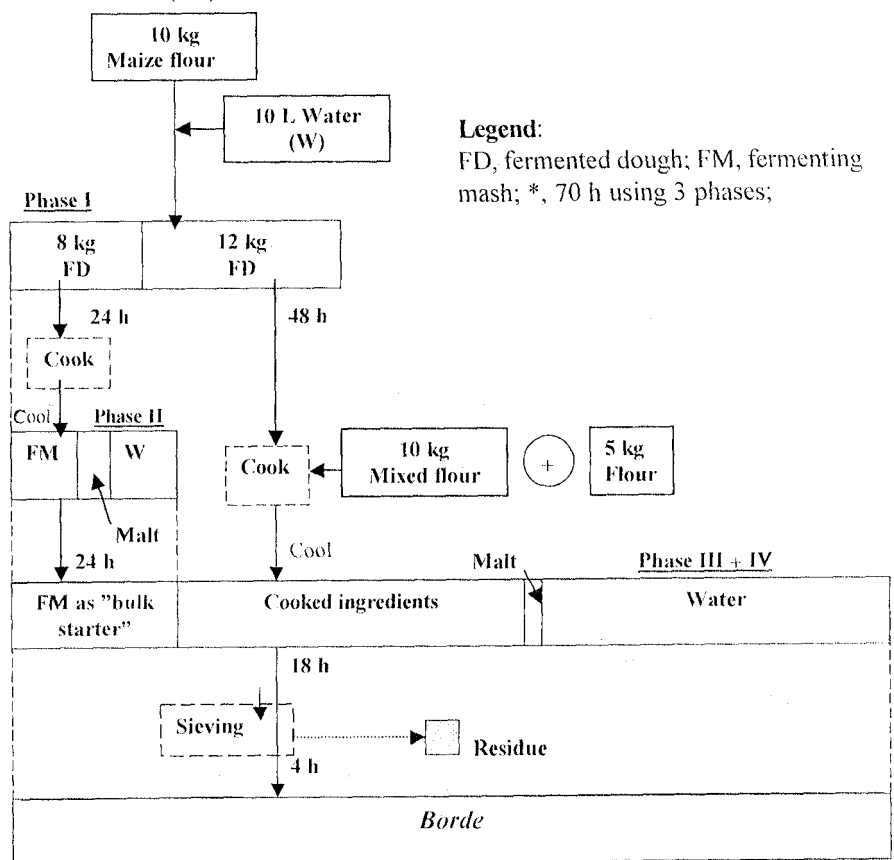
Figure 1c. Flow chart: option 2: modified technique for production of *borde* by merging Phase III and IV (M2**/M3***).
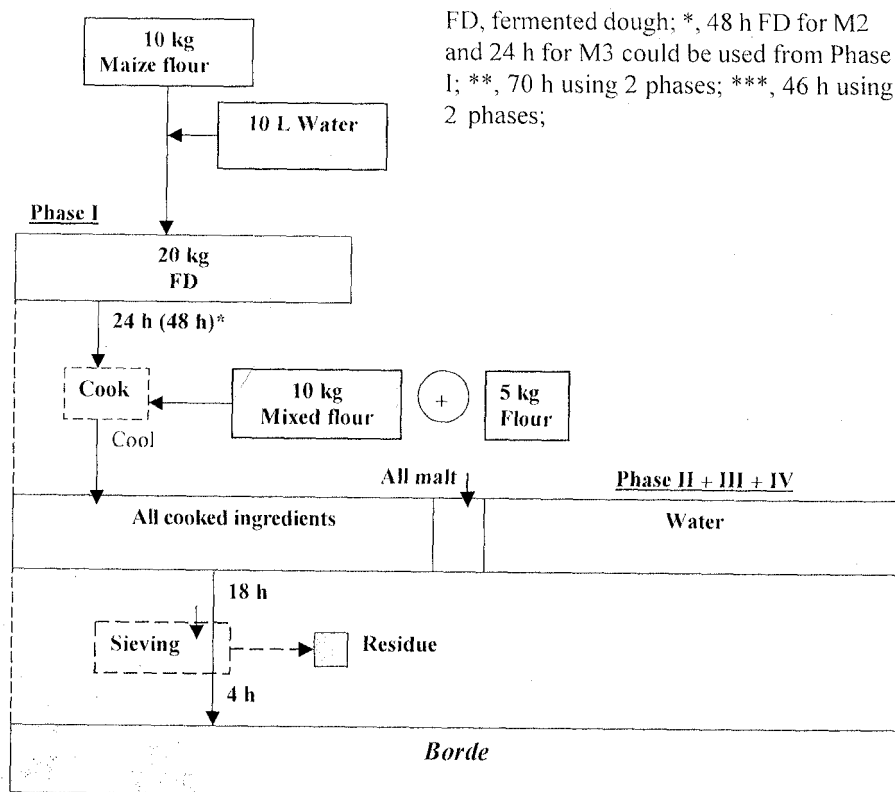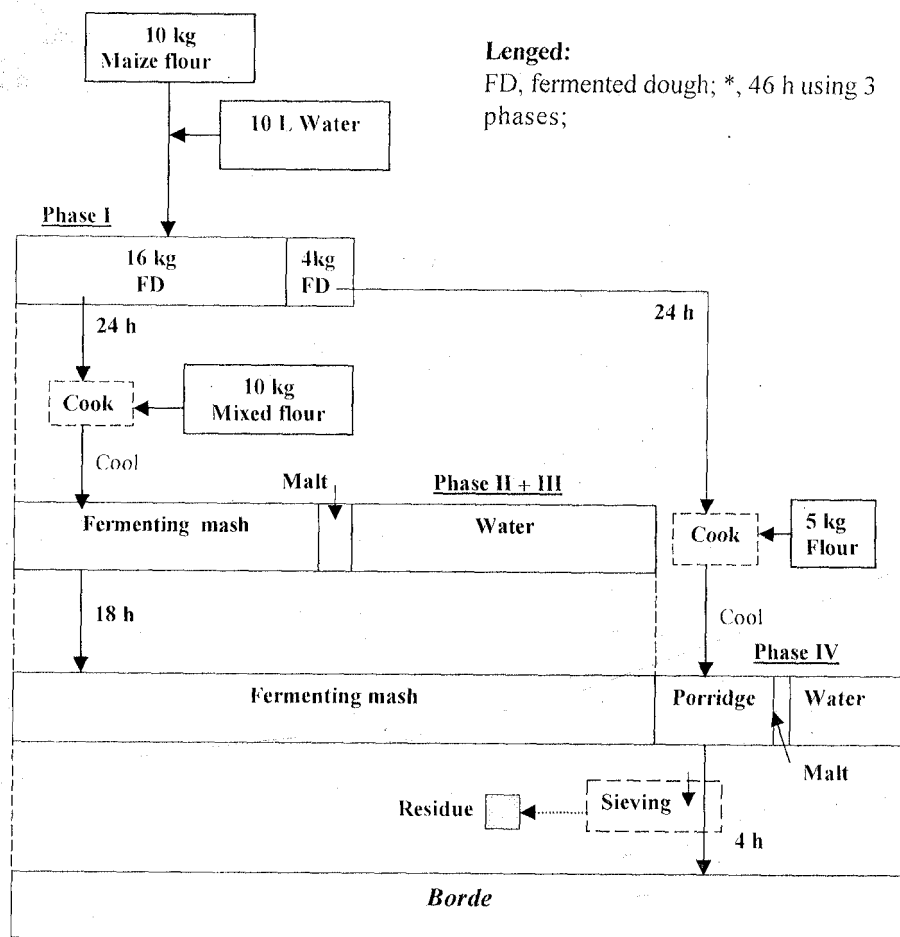
FD, fermented dough; *, 48 h FD for M2 and 24 h for M3 could be used from Phase I; **, 70 h using 2 phases; ***, 46 h using 2 phases;

Figure 1d. Flow chart: option 3: modified technique for production of *borde* by merging Phase II and III (M4)*.

Lenged:
FD, fermented dough; *, 46 h using 3 phases;

Sample analysis
pH and titratable acidity (TA)
The pH was measured using a digital pH meter (ORION 420A, Boston, USA) after calibration at 25°C using buffers of pH 4 and 7 (Merck KGaA, 64271 Darmstadt, Germany). TA was determined on 5 ml samples by titration using 0.1 N NaOH and 0.1 ml 0.5% phenolphthalein as indicator. The amount of acid produced was expressed as percent lactic acid.

Microbiological analysis
Ten g sample was transferred aseptically to a Stomacher bag (Lab-Blender 400, Seward Medical, London, England) with 90 mL sterile 0.1% peptone water (Merck) and homogenized for 30 s at 'normal' speed. The homogenate was then serially diluted and aliquots of 0.1 mL from appropriate dilutions were spread-plated in duplicate on pre-dried plates of violet red bile dextrose (VRBD), plate count agar (PCA) and yeast extract glucose chloramphenicol (YGC) agar. The VRBD and PCA were from Merck. The YGC consisted of (gram L^{-1}): yeast extract, 5.0; glucose, 20.0; chloramphenicol, 0.1; bromophenol blue, 0.01; agar, 15; pH, 6.0 to 6.2. Purple-red colonies on VRBD agar plates were counted as Enterobacteriaceae (EB) after incubation at 30°C for 24 h. The total aerobic mesophilic count (AMC) was enumerated on PCA plates after incubation at 30°C for 48 h. Yeast and mould colonies were counted on YGC plates after incubation at 28°C for 3 to 5 days. The numbers of EB, AMC or yeast on duplicate countable plates are reported as log CFU g^{-1} calculated from the mean of three replicates.

Sensory evaluation
A consumer-oriented panel of judges was used to assess the quality of *borde* produced during this study. Five judges who regularly consume *borde* and who are similar to the target population of consumers were selected from 21 volunteers. The judges were selected on the basis of perception of the sensory attributes of *borde* developed from analysis of earlier survey data from six localities (Abegaz *et al.*, 2002). The sensory attributes are: appearance (uniformly turbid), foaming activity, thickness, aroma (degree of freshness),

Figure 2. The mean changes in pH and TA during the four-phase fermentation of *borde* using grits or flour at Phase I

O. flour or △. grits fermentation; (———). pH; (......). TA, titratable acidity as percent lactate;
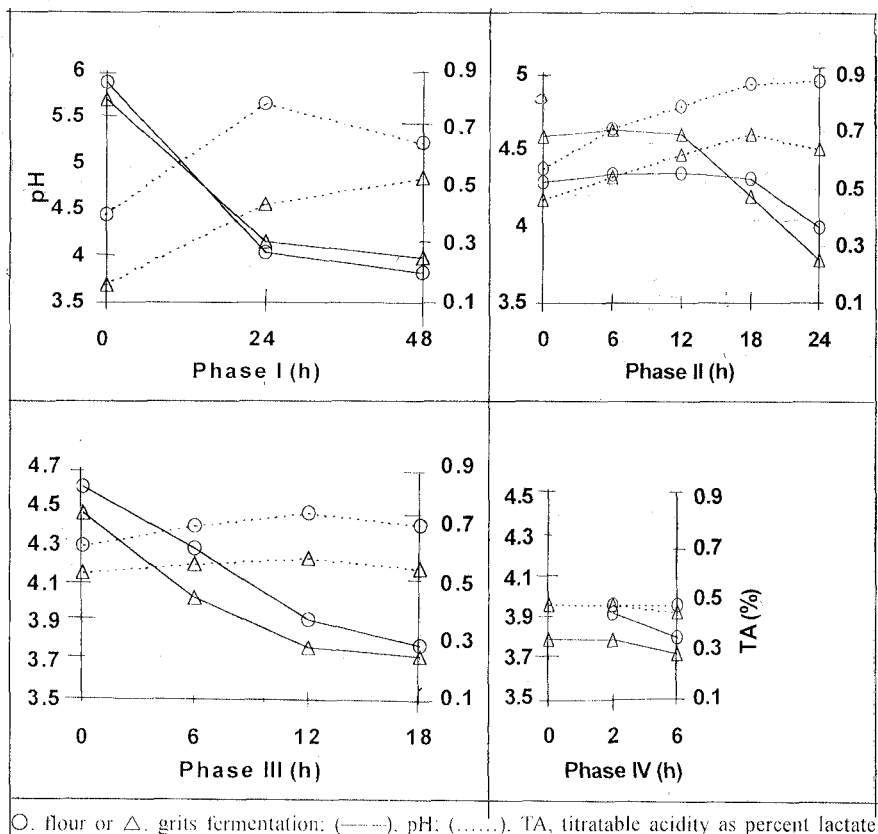
taste (degree of sweet-sourness) and smoothness (mouth feel). Samples (50 mL) of *borde* were coded with random numbers and presented in 100 mL beakers to the judge. The panelists were asked to evaluate their acceptance of each *borde* and to score from 1 (least-) to 5 (most- acceptable).

Statistical analysis

The average values of pH, TA, sensory scores and microbial load of the samples from triplicates of independent experiments were reported after performing ANOVA using Minitab Release 13.1 (Minitab Inc.) statistical Programme at the 5% level of significance. The five-judge sensory scores of each attribute were compared between treatments in each experiment.

Results and Discussion

A. Effect of substituting flour for grits in *borde* production

The TA in Phase I before cooking was found to develop differently according to whether maize G or F was used (Fig. 2). When F was used, the TA was higher but declined after 24 h. The TA was low and still slowly increasing after 24 h in case of G. The pH of F (4.0 ± 0.03)

was significantly lower ($p < 0.05$) than G fermentation (4.2 ± 0.07) after 24 h at Phase I just before cooking at Phase II. This difference could be due to the fact that flour has larger surface area that would provide more available soluble substrate thereby accelerating the fermentation. The rate of hydrolysis of starch is dependent on the accessible surface area (Aggarwal and Dollimore, 1998). In a study on kenkey (Nche *et al.*, 1996), dry-milled maize was reported to have a fast water uptake and high endogenous enzyme activity at 4 and 25°C and then a rapid swelling of the maize starch component on heating to 95°C after 24 h fermentation. In our laboratory, higher amounts of soluble carbohydrates were observed during flour fermentation than grits (data not shown). Higher concentrations of total soluble and fermentable sugars were reported in fine grits than coarse grits (Lasekan *et al.*, 1995).

When cooled *enkuro* was blended with malt flour in Phase II (Fig. 2), the starting pH (4.3 ± 0.1) of F fermentation was thereby lower ($p < 0.05$) than the G (4.6 ± 0.2). During Phase II, the decrease in pH of F fermentation was not as rapid as when G were used. This lower

initial pH and extensive utilization of carbohydrates in Phase I are probably the cause of the retarded pH reduction during F fermentation in Phase II. The lower pH would result in slow malt amylase activity, thus producing less fermentable carbohydrates for the microorganisms. Carbohydrate degrading enzymes in malted and unmalted finger millet have an optimal range of pH 4.6-6 (Nirmala *et al.*, 2000). However, slower hydrolysis of starch occurred at low pH and then production of reducing sugar decreased gradually (Syu and Chen, 1997). The fermentation of G progressed to a lower pH 3.8 compared to pH 4.0 in that of the F at the end of Phase II. Although the grits would be expected to have less soluble carbohydrates in Phase I, more substrate may become available after cooking in Phase II. The fermentation of F showed the highest pH from 18 h at Phase II to the end of Phase IV and the highest TA throughout *borde* fermentation. The reduction of TA after 24 h F fermentation in Phase I and the low TA in G contrary to its low pH after 18 h in Phase II onwards need further study. The high pH at the start of G in Phase II (**Fig. 2**) and M3/M4 in Phase III (**Fig. 4**), owing to less acid production in Phase I, resulted in a faster reduction of pH than that of F and M2 respectively. However, the carried-over effect of acid from preceding to the succeeding phases would be possible to optimise by monitoring the progress of pH and TA in each phase.

The temperature of fermenting mash increased from 23.2 ± 0.2 to $29 \pm 1.2°C$ with no significant difference between F and G fermentation. Both reached maximum at about 12 h in Phase III.

Both F and G resulted in actively fermenting acceptable *borde*. However, *borde* made from the F was preferred and had a significantly better ($p < 0.05$) aroma and taste (**Table 1A**). It was also observed that the keeping quality of *borde* from F was at least 4 h longer than borde from G, which soon developed a vinegary aroma (results not shown). The repeated wet milling and wet sieving of intact grits at Phase IV could create additional surface area of the substrate and also allow microbial contamination. This may cause secondary fermentation

Table 1. The mean scores of sensory attributes of *borde* produced by using different treatment of ingredients and merging some phases of the fermentation

Types of *borde***	The mean scores* of sensory attributes of *borde*					
	Appearance	Foaming	Consistency	Aroma	Taste	Texture
A. Effect of substituting flour for grits						
Grits	4.63 ± 0.43^a	4.68 ± 0.34^a	4.61 ± 0.42^a	4.22 ± 0.47^b	4.12 ± 0.36^b	4.72 ± 0.34^a
Flour	4.82 ± 0.33^a	4.74 ± 0.38^a	4.83 ± 0.28^a	4.81 ± 0.28^a	4.72 ± 0.41^a	4.67 ± 0.34^a
B. Effect of omitting Phase I fermentation						
MT	4.83 ± 0.36^a	4.80 ± 0.25^a	4.93 ± 0.18^a	4.80 ± 0.25^a	4.83 ± 0.24^a	5 ± 0.00^a
NF	4.40 ± 0.47^b	3.90 ± 0.34^b	4.03 ± 0.35^b	3.97 ± 0.35^b	3.93 ± 0.37^b	4.20 ± 0.32^b
NFP	4.23 ± 0.46^b	3.60 ± 0.43^c	3.67 ± 0.49^c	3.87 ± 0.35^b	3.73 ± 0.49^b	4.17 ± 0.24^b
C. Effect of merging some phases of *borde* fermentation						
MT	$4,83\pm0.31^a$	4.95 ± 0.14^a	4.80 ± 0.37^a	4.80 ± 0.37^a	4.89 ± 0.28^a	5.00 ± 0.00^a
M1	$4,83\pm0.31^a$	4.23 ± 0.26^b	4.67 ± 0.52^a	4.90 ± 0.28^a	4.72 ± 0.41^a	5.00 ± 0.00^a
M2	3.93 ± 0.56^b	3.32 ± 28^c	3.97 ± 0.48^{bc}	3.22 ± 0.34^b	3.37 ± 0.64^b	4.02 ± 0.24^b
M3	$3,89\pm0.37^b$	3.55 ± 0.36^c	3.84 ± 0.63^b	3.49 ± 0.46^b	3.49 ± 0.48^b	4.15 ± 0.26^{bc}
M4	3.76 ± 0.43^b	3.09 ± 0.38^d	3.51 ± 0.49^{bd}	3.35 ± 0.57^b	3.20 ± 0.53^b	3.95 ± 0.14^{bd}
D. Effect of different cooking methods						
MT	4.60 ± 0.39^a	4.37 ± 0.30^a	4.60 ± 0.43^a	4.47 ± 0.48^a	4.37 ± 0.48^a	4.73 ± 0.26^a
B	4.60 ± 0.47^a	3.80 ± 0.25^b	4.20 ± 0.46^b	4.10 ± 0.60^a	4.33 ± 0.59^a	4.43 ± 0.32^b
S	4.23 ± 0.37^b	3.90 ± 0.28^b	4.27 ± 0.46^{ab}	4.3 ± 0.53^a	4.22 ± 0.58^a	4.57 ± 0.26^{ab}
P	4.53 ± 0.52^{ab}	3.80 ± 0.25^b	4.23 ± 0.42^b	4.37 ± 0.48^a	4.42 ± 0.58^a	4.57 ± 0.37^{ab}
NC	1.80 ± 0.80^c	1.03 ± 0.13^c	1.06 ± 0.26^c	1.00 ± 0.00^b	1.00 ± 0.00^b	1.00 ± 0.00^c

*, highest score = 5 = the best; lowest score = 1 = the least quality of *borde*; means with different letters within a column of A, B, C or D are significantly different ($p < 0.05$); **, legends at section **B**, **C** and **D** of column one are similar to **Figs. 2, 3** and **4**, respectively;

and result in production of acetic and butyric acids that are detrimental to flavour (van der Merwe *et al.*, 1964/65). Acetic acid bacteria commonly occurred with the most visible characteristics of vinegary flavour and off-odour in deteriorating traditional fermented cereal beverages (Sanni *et al.*, 1999). However, the mean counts (log CFU mL^{-1}) of AMC and yeast in *borde* from F (10.6 ± 0.3 and 8.5 ± 0.5) were not significantly different (**NSD**) from that of in G *borde* (10.3 ± 0.5 and 7.9 ± 0.6). EB were not detected in both cases, which would be due to the acidic fermentation. The new ingredients added at different phases may reduce the acidic stress and also replenish substrates for microbial growth in the fermenting mash of borde.

The substitution of grits with flour considerably improved the efficiency of *borde* production since the problems of unhygienic and tedious wet-milling, large loss of residue and low profit were

resolved. The spent residue from G was $3.7\pm0.0.16$ kg compared to 0.3 ± 0.05 kg in F fermentation. Thus, the net yield (recovery) of *borde* increased from 70% to 97%. Improvements in aroma, taste and keeping quality were observed in *borde* made from flour.

B. Effect of omitting Phase I in *borde* fermentation

The development of pH and TA during Phase I fermentation of MT is shown in **Fig. 3**. The fermentation of NF and NFP were started together with Phase II of the MT. Regardless of the different cooking methods used, the fermentation of NF and NFP showed the same development in pH. When non-fermented flour was used at the start of NF and NFP fermentation, the initial pH was higher ($p < 0.05$), but was significantly lower than MT at the end of Phase II. The same pattern was observed for Phase III, but the difference was much less pronounced. This may be due to greater amylase

activity at higher pH and thereby a greater concentration of available substrate for fermenting organisms in NF and NFP than in the MT. The lower initial pH and retarded fermentation of the MT can be considered as the carried over effects of acidic maize from Phase I. Conversely, NF and NFP would possibly benefited from unexploited substrate (non-fermented maize) within the range of optimal pH 4.6-6 for carbohydrate degrading enzymes (Nirmala *et al*, 2000) and pH 5.5 for most of bacterial a-amylases (Aguilar *et al*, 2000). Syu and Chen (1997) reported that the rate of starch hydrolysis is governed by initial substrate concentration and enzymatic activity and also showed that low pH slows down the hydrolysis of starch and accumulation of reducing sugars for microbial growth. The amount of fermented maize was small as compared to the amount of fresh flour added in the MT at Phase IV and then the pH of *borde* was identical for the three

Figure 3. The mean changes in pH and/or TA during fermentation of *borde* using non-fermented and/or fermented flour in Phase I.
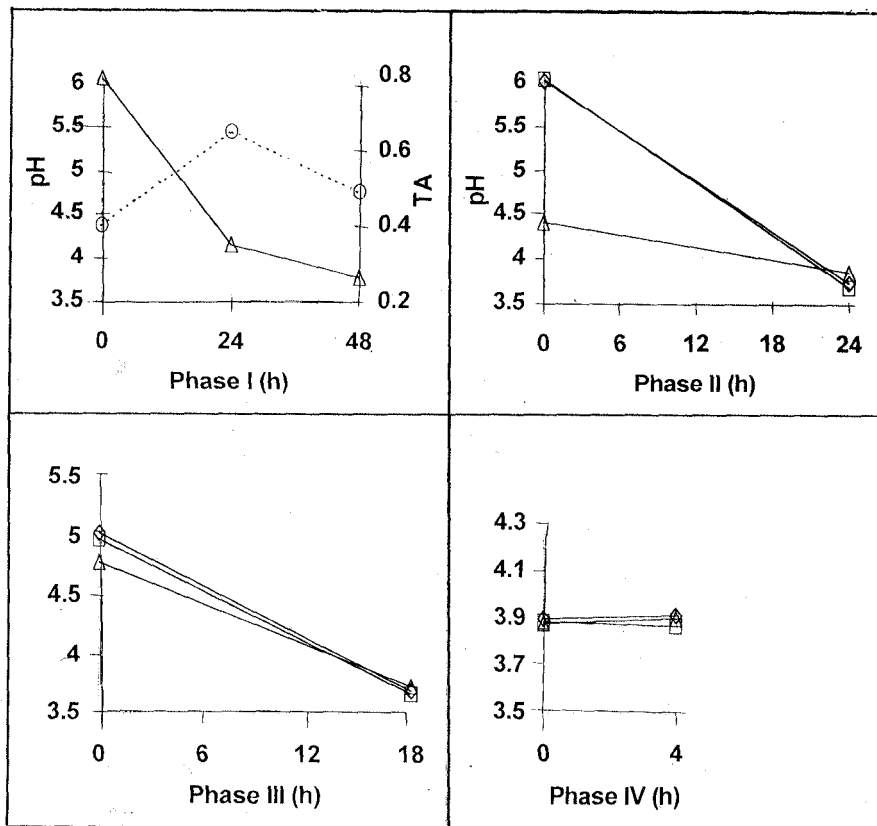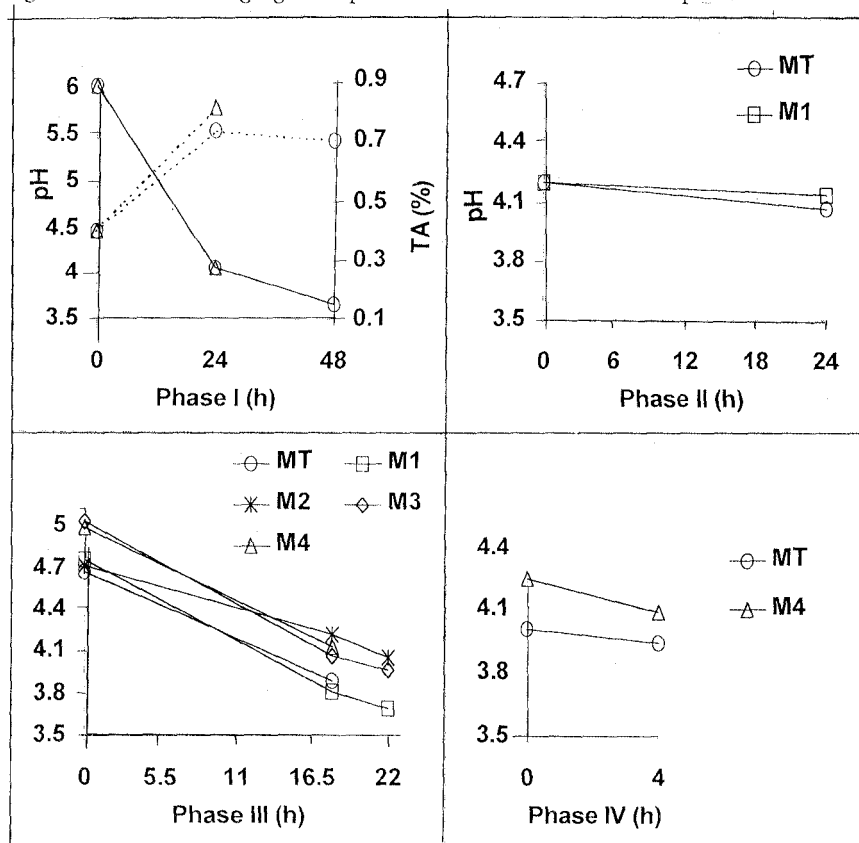

(———). pH; (......). TA. titratable acidity as percent lactic acid; △ **MT**, fermented maize and mixed fresh flour with modified traditional cooking; ◇ **NF**, all non-fermented flour with modified traditional cooking; □ **NFP**, all non-fermented flour cooked into porridge;

Figure 4. Effect of merging some phases of *borde* fermentation on pH and/or TA.

(———). pH: (......). TA. titratable acidity as percent lactic acid; △, 24 h; O. 24-48 h fermentation at Phase I; **MT**, modified traditional fermentation; **M1**, merging of Phase III and IV; **M2** and **M3**, merging of Phase II, III and IV; **M4**, merging of Phase II and III; 48 h fermented flour from Phase I for MT. M1. M2 and 24 h for M3 and M4 were used;

treatments.

No significant differences (p < 0.05) were found in microbial load, pH and TA of *borde* regardless of the methods of cooking and whether fermented or non-fermented flour was used. The AMC was 10-10.5, while yeast increased to 8.2-8.5 (log CFU mL^{-1}) in all treatments. All sensory attributes achieved significantly lower scores when maize was not fermented in Phase I before cooking (**Table 1B**). When *borde* produced using the two methods of ingredient cooking were compared (NF and NFP), NFP *borde* achieved significantly lower scores (p < 0.05) for foaming and consistency. This could be a compounded effect of using non-fermented flour and cooking into porridge. The results show that the fermentation at Phase I is important for the sensory quality of *borde*. In the traditional fermentation, Phase II and IV are initiated by the addition of malt, fermented and non-fermented ingredients to the pot. The results show the magnitude of the effect of adding fermented ingredients on the initial pH. This is particularly marked at the start of Phase II, where the initial pH differed by 1.6 units between treatments. It may be expected that this difference in pH would have a far-reaching effect on the development of the microbial flora at this stage. At the starting pH 4.4, as observed for the MT, only aciduric organisms such as lactic acid bacteria and yeasts would be able to grow. In Phase III and IV, the drop in pH is very small since the initial pH is already so low that few microorganisms would be able to produce additional acid. The effect of omitting Phase I was much greater than using different cooking methods on the fermentation and quality of *borde*. However, *borde* produced by all the three treatments was acceptable.

C. Effect of merging some phases in *borde* fermentation
C.1 Merging of Phase III and IV
After 24-48 h fermentation of maize in Phase I, a significant decrease in pH and increase in TA are shown in **Fig. 4**. The TA of 24 and 48 h fermented maize (**FM**) was NSD (p < 0.05) one from another in contrast to their pH. After cooking the FM (pH 4.07 ± 0.06) from Phase I and blending it with malt, the MT and M1 treatments showed low

initial pH 4.2 ± 0.13 and slow development of pH in Phase II. The addition of 48 h FM (pH 3.66 ± 0.04) from Phase I to MT and M1 resulted in a significantly lower (p < 0.05) initial pH 4.7 as compare to pH 5.0 in treatments of M3 and M4 where 24 h FM (pH 4.07 ± 0.06) was added at Phase III. The low pH achieved in FM from Phase I affected further production of acid in the subsequent phases of *borde* fermentation. The acid and high number of acid tolerant microorganisms from Phase II (tinsis) (unpublished results) could be responsible for the low pH at Phase III and IV fermentation of MT and M1 compared to other treatments.

C.2 Merging of Phase II, III and IV or II and III

The fermentation of maize for 24 h in Phase I showed a significant decrease in pH and increase in TA (**Fig. 4**). This FM (pH 4.07 ± 0.06) was used with mixed fresh flour in treatments of M3 and M4 (**Figs. 1c and d**). Conversely, 48 h FM (pH 3.66 ± 0.04) was used for M2. After cooking the unmalted ingredients and blending with malt, M3 and M4 showed higher (p < 0.05) initial pH 5 than M2 (pH 4.7). However, the main fermentation of M2, M3 and M4 (Phase II) was started concurrently with Phase III of MT and M1. M2 had the slowest development of pH among all treatments under investigation. After 18 h fermentation, M2 showed higher pH (p < 0.05) than MT and M1. This is not surprising since M2 is started with high quantities of acidic FM (48 h) from Phase I and unmalted new ingredients added together in the absence of Phase II for starter building up (tinsis). Thus, too small amount of malt inoculum comparing to the cooked ingredients with low initial pH may explain the slowest fermentation of M2. The same amount of malt and absence of Phase II also occurred in M3 and M4. However, the M3 and M4 started with higher pH due to less acidic FM from Phase I. Thus, M3 and M4 could be benefited from positive effects of higher initial pH on amylase activity that would produce greater amount of sugars for the growth of fermenting organisms. Increasing the amount of malt (inoculum) may also accelerate the fermentation of borde in M2, M3 and M4.

The effect of high inoculum from Phase II on the main fermentation in the consecutive phases was pronounced. This may explain the leading progress of MT and M1 in comparison to that of M2, M3 and M4 fermentation. The malt and porridge added to MT and M4 at the final phase resulted in higher pH as compared to M1 and M3 respectively. After sieving and then fermenting the filtrate for 4 h, the pH in M3 (3.97 ± 0.02) *borde* was NSD (p < 0.05) from MT (3.94 ± 0.08) in contrast to M1 (3.77 ± 0.1) and M4 (4.09 ± 0.04). The pH of M2 was 4.06 ± 0.06. The TA of MT (0.44 ± 0.1), M1 (0.44 ± 0.14), M2 (0.6 ± 0.16), M3 (0.59 ± 0.29) and M4 (0.57 ± 0.15) *borde* were NSD (p < 0.05). In all the treatments, AMC and yeasts were in the ranges of 9.9-10.5 and 7.4-8.4 (log CFU mL^{-1}), respectively. Despite the low pH (3.97-4.09) in "young" *borde*, the incidence of EB (< 1-2.7 log CFU mL^{-1}) in 66% of M3 and M4 samples may raise the issue of safety. It is possible that a slightly longer fermentation would improve the microbial safety and ripening of borde.

The results of the sensory assessment showed that the MT and M1 treatments resulted in *borde* that were NSD except from a reduced foaming in M1 (**Table 1C**). This indicates that the addition of a small amount of malt and more ingredients (porridge) at Phase IV is responsible for the short active fermentation that revitalized the basic sensory attributes of *borde*. The MT *borde* was also judged as sweet-sour compared to sourer taste of M1. The other treatments produced a significantly inferior *borde*, although all products were acceptable (score > 3). The foaming, aroma and taste of M2, M3 and M4 *borde* were judged to be markedly inferior to MT and M1. However, these products were described by the judges to be having an acceptable taste but were "too young". After extra 3-4 h fermentation, it was observed that M3 and M4 achieved all the sensory attributes of *borde* in contrast to M2. The low pH of 48 h FM from Phase I negatively affected the quality of M2 borde. The M3 was significantly better (p < 0.05) than M4 in foaming and texture. It may be possible to improve the quality M3 and M4 *borde* by slightly

extending the final fermentation stage and/or increasing the amount of malt inoculum. M3 and M4 had a total fermentation time of 46 h compared to 70 h for other three treatments (**Figs. 1a-d**). Among all these options, M3 could be suggested as a simplified technology for production of acceptable *borde* that may help for modernization. Further work should be done to improve these methods. Optimisation of the pH in Phase I, amount of inoculum and duration of the main fermentation in subsequent phases appeared to be vital for production of quality *borde* using these methods.

These results show that it is possible to shorten and simplify the traditional production technology of *borde* by merging some of the phases, and produce an acceptable *borde*. The 96 ± 2 h (4 phases) traditional fermentation (unpublished results) could be reduced to 46 and 70 h (2-4 phases) as shown in **Figs. 1 a-d**. Scientific improvements of traditional product processing have often led to changes in quality characteristics especially organoleptic (Demuyakor and Ohta, 1993). However, a possible method to overcome changes in product quality is to understand the process and formulation required to improve the traditional product using participatory approach as was tried in this work.

D. Effect of using different cooking methods in *borde* production

As shown in **Fig. 5**, the pH was consistently lower in NC (non-cooked) than the treatments of MT, B, S or P with cooked ingredients. After 24 h in Phase II, NC showed significantly lower pH than all other treatments. The NC was NSD from other treatments at Phase III, but it was significantly lower than MT at the end of Phase IV. The TA in all cooked treatments was about 0.5 ± 0.04, which was lower than 0.84 ± 0.07 in the NC. The number (log CFU mL^{-1}) of yeasts (8.3 ± 0.15 to 8.6 ± 0.22) and AMC (9.8 ± 0.19 to 10.2 ± 0.4) were lower in treatments with cooked ingredients than the yeasts (9.2 ± 0.31) and AMC (10.6 ± 0.03) in the NC. All treatments with cooked ingredients rely mainly on the malt enzymes and micro flora. The occurrence of low pH and high microbial load in NC could be the effects

Figure 5. The mean changes in pH and/or TA during fermentation of *borde* from ingredients cooked using different methods of heating.
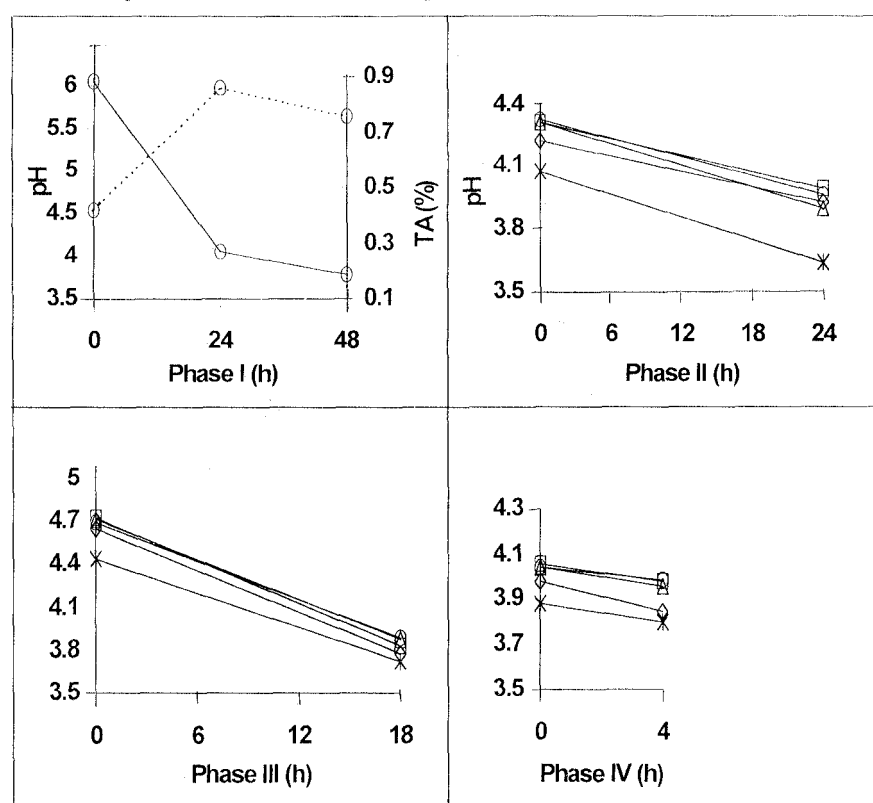
(......), TA, titratable acidity as percent lactic acid; (———), pH; ○ **MT**, modified traditional cooking; △ **B**, baking; ◇ **S**, steam-cooking; ◇ **P**, porridge; ✳ **NC**, non-cooked ingredients;

of aciduric organisms in non-cooked maize from Phase I, diversity of endogenous enzymes and micro flora from mixed fresh flour in addition to the malt.

The NC ingredients resulted in totally unacceptable product (**Table 1D**). However, regardless of using only one form of cooking or their combination, the aroma and taste of *borde* were similar to MT. The aroma, taste and also foaming are the major quality attributes of *borde*. The *borde* made using only baking, steaming or boiling of ingredients was highly acceptable since all products attained a score > 4, except for foaming, which was inferior to MT. The results illustrate that although it is important for the quality of *borde* that the ingredients are cooked, using only one form of heat treatment could be applied for a simplification of the process. Thus, boiling of the ingredients is the simplest technological process to be suggested for *borde* production. It has the advantage of: (1) less charring effect and smaller loss, (2) less tedious post-cooking operations, (3) being easier to blend and sieve and (4) less or no addition

of water and this also reduces post-cooking microbial contamination.

When all the products were heated for 30 min at 80°C water bath, the NC was baked into stiff paste, while others were remained liquid (data not shown). This could indicate that cooking is a critical parameter in the production of acceptable *borde* due to the fact that gelatinisation of the starch improves its degradation by endogenous enzymes mainly from the malt. All the methods of cooking used in this work (90-98°C) would gelatinise cereal starch and inactivate enzymes and vegetative cells. However, the addition of malt at Phase II serves as sources of amylases and fermenting microbes for production of acceptable *borde* (unpublished results).

From this study and other basic works described by Abegaz *et al.* (2002; unpublished results), the traditional technology of *borde* production from gelatinised main ingredients and malt inoculum appeared to be developed consciously in an attempt to control the safety of *borde* using an acidic fermentation. The rationale of this

technology reveals that: (1) the acid produced in Phase I creates acidic environment to the main fermentation that inactivates unwanted micro flora and selects for aciduric organisms. (2) The cooking of unmalted ingredients gelatinises the starch and eases its saccharification with malt amylases. (3) The use of only 16% of the total unmalted ingredients and 80% of the total amount of malt required indicates the attempt to select and attain high number of fermenting microorganisms mainly from the malt in Phase II. (4) Blending the "bulk starters" from Phase II (*tinsis*) and 56% of the total unmalted ingredients without malt at Phase III (*difdif*) indicates the major acidic fermentation of *borde*. (5) Addition of the remaining malt and 28% of the total unmalted ingredients in the form of porridge into the sourer *difdif* at the start of Phase IV eases the homogenisation and sieving processes. Thus, the malt liquefies the thick mash, reduces the bulk density and sweetens the end product (*borde*). It seems that the complexity of traditional technology of *borde* production is aimed at a step-by-step controlling of the bio-physico-chemical process parameters so as to get benefit from the merits of fermentation on safety and quality of the product.

Conclusion

In conclusion, the traditional method for production of *borde* is technologically complex, which does not readily lend itself to larger production volumes or to the introduction of production equipment. From the results of the experiments reported in this study, the opportunity for the simplification of the process has been observed: (1) Flour may be substituted for grits and whole grains. This modification resulted in a well-accepted *borde*, a less laborious process without wet milling and a reduction in residues from the final sieving that increased the net yield of *borde*. In addition, the fermentation proceeded faster than when grits were used and this may necessitate a slight adjustment of the times of the various phases. (2) Merging of the phases of *borde* process resulted in products that were acceptable, although organoleptically slightly inferior, which

may require optimisation of the pH in Phase I, amount of inoculum and time of the main fermentation. A simplification of the process entailing a reduction of the number of fermentation phases would be advantageous. However, since products with a shortened total fermentation time showed the presence of EB, it may be possible to produce microbiologically safe *borde* by a shortened process only if all the ingredients are heat-treated and starter cultures are added. (3) Cooking of unmalted ingredients is a limiting step than omitting Phase I fermentation in the production of *borde*. Acceptable *borde* could be prepared by boiling the un-malted ingredients added after Phase I. This method could be readily adapted to small-scale production units.

Acknowledgements

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