Journal of Applied Biosciences 83:7579– 7594

ISSN 1997–5902

# Physicochemical, nutritive and safety evaluation of local cereal flours sold in areas of the District of Abidjan-Côte d'Ivoire

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Original submitted in on 11th September 2014. Published online at www.m.elewa.org on 30th November 2014.

http://dx.doi.org/10.4314/jab.v83i1.8

## SUMMARY

*Objective:* The aim of this work was to contribute to the food safety of Ivorian consumers by investigating the nutritive value and the microbial quality of local cereal flours offered for retail sale on different markets located on selected areas of the District of Abidjan.

*Methodology and results:* Local cereal flours samples were collected and their physicochemical and microbiological characteristics determined. Mean value intervals were as follow: moisture (22.53 – 35.36 %), pH (4.46 – 7.95), ash (0.38 – 1.93 %), proteins (3.93 – 7.46 %), lipids (1.20 – 3.84 %), carbohydrates (72.13 – 89.19 %). The cereal flours analyzed in this study contained remarkably high amounts of potassium (162.92 – 1363.93 mg/100 g) with highest value (718.08 - 1363.93 mg/100 g) for potash-treated samples. The calculated [Phytates]/ [Fe] and [Phytates]/[Zn] ratios in all the maize flours ranged in the values of 10.27 – 46.28. The total microbial species isolated ranged from 3.65 to 8.33 Log cfu/g with *Enterococcus* (1.27 – 1.86 Log cfu/g) and thermotolerant coliforms (1.06 – 1.60 Log cfu/g). These retailed market flours contained also relatively high amount of yeast and moulds ranged from 2.05 to 3.33 Log cfu/g. Local cereal flours sold in retail markets of Abidjan have a quite heterogeneous physicochemical, nutritive and microbiological quality, which do not display a sanitary guarantee for consumers.

*Conclusion and application of results:* Given the results obtained, awareness campaign on good hygiene practices and good manufacturing processing should be considered. Such initiatives need to be carried amongst local cereal producers to help minimize food safety risk and limit nutritive depletion in flour meals due to practices inherited from traditional processing methods.

**Keywords:** cereal flours, proximate composition, nutritive value, microbial quality.

## INTRODUCTION

Cereals are major staple foods for the world population since the beginning of the modern civilization (Mazoyer & Roudart, 1997). They are produced worldwide and mainly are rice, wheat, maize, sorghum, millet, rye, barley, triticale and oat. Wheat, rice and maize are the dominant crops with regard to consumption and the extent of farmland cultivated (Abecassis & Bergez, 2009).

They are good source of energy providing about 350 kcal per 100 grams of whole grains (Chopra *et al*., 2002) and contribute to about half of the food protein available in the world, mainly in developing countries (Butt *et al*., 1997; Schönfeldt & Gibson, 2012). ). In coastal countries of West Africa such as Côte d'Ivoire, they contribute to 45 percent of dietary proteins (FAO, 2003). However cereals have low quality proteins because of limiting amino acids as lysine and tryptophan (MacCrae *et al*., 1993; Cissé *et al*., 2013). Such essential amino acids deficiency remains an important dietary problem, particularly among the children and the elderly (Krivanek *et al.*, 2007). So, it is advised to compensate limiting amino acids by combining cereals with protein-rich legumes such as cowpea, when meat products are not included in the diet (Afoakwa *et al*., 2004; Oyarekua, 2011; Oyarukua, 2012;). In this context, biofortification which is the development of food crops rich in bio-available nutrients is a promising strategy to address essential amino acids deficiency in maize by conventional breeding (Johns & Eyzaguirre, 2007). Cereals fulfil an important role in the diet as a source of starch and dietary fibre that make up to 70 to 77 % of the whole grain (McKevith, 2004) while proteins account for only 6 to 15 % (Goldberg, 2003). As whole grain, cereals can potentially contribute to B vitamins (Kulp & Ponte, 2000) and minerals (Kowieska *et al*., 2011) intake. As concerns lipids, they are the minor components consisting mainly of unsaturated fatty acids (Souhthgate, 1993). Anti-nutrients in cereals such as phytates and tannins affect the efficient utilization of nutrients (Lorenz, 1998). Phytates are considered as anti-nutritional factors mainly due to their ability to build mineral complexes with multivalent cations such as calcium ($Ca^{2+}$), zinc ($Zn^{2+}$) and iron ($Fe^{2+}$) thus inhibiting their absorption (Hurrell, 2004). This results for example in incidence of iron deficiency anaemia (Lestienne *et al*., 2003). Phytic acid is mainly located in the aleurone layer (rice, millet, sorghum, wheat) and the germ of maize (Cheryan, 1980). Tannins on the other hand adversely affect digestibility of proteins by lowering bioavailability of amino acids. Several traditional food processing and preparation methods can significantly improve the bioavailability of nutrients (Hortz & Gibson, 2007). Indeed, processes like thermal and mechanical treatments (Anon, 1979), soaking (Lestienne *et al*., 2003), fermentation (Adegunwa, 2012; Metzler-Zebeli *et al*., 2014), germination malting (Egli *et al*., 2002; Ocheme & Chinma, 2008) and alkali treatment (Drinah *et al*., 1990; Ochanda *et al*., 2010) has been reported to improve the chemical bioavailability of proteins and minerals. The microflora of cereals and cereal products is variable (Christensen, 1982). Thus, there is potential for contamination and deterioration with moulds, yeasts, bacterial pathogens, coliforms, and Enterococci (Bullerman & Bianchini, 2009). Pests and rodents also are major sources of problems (Jood & Kapoor, 1994). So, several measures are recommended such as the use of typical insecticides, good storage, moisture content of grain, temperature and duration of storage are important to keep the stability of the grain (Chelowski, 1991; Macrae *et al.*, 1993; Richard-Molard, 2003). Grain products can be categorized into two different types, whole grains and refined grains. Whole grains contain the entire grain kernel; in refined cereals however, the pericarp, germ and aleurone layer that are rich in micronutrients are mainly removed thus resulting in loss of important nutrients (MacEvilly, 2003). Diet rich in highly refined cereal meals are more energy dense and less nutrient rich than whole cereals (Wang *et al*., 2007). Such meals could be responsible for deficiency diseases such as "beriberi" caused by lack of thiamine (B1 vitamin) less than 0.3 mg per kcal (Ensminger & Ensminger, 1993). Polished white rice, white flour, degerminated cornmeal can be named among the implicated meals. In Côte d'Ivoire, local cereals are mainly grown in savannah zones (Northern areas) and traditionally consumed, after processing into flour, as staple foods by the native population (Kouakou *et al*., 2010). Local cereal production concerns mainly rice (*Oryza sativa*), maize (*Zea mays*), sorghum (*Sorghum bicolor*), millet (*Pennisetum typhoides*) and fonio (*Digitaria exilis*). Traditionally cereal flour production was arduous because it was made by hand pounding using

wooden pestle and mortar, or by grinding with stones. Presently, milling by mechanical means commonly using abrasive decorticators and disk mills has become popular for it provides a service to low-income customers (FAO, 1985). In the districts of Abidjan, only millet and maize flours are commercially produced (N'guessan *et al*., 2014). Four types of maize flours were thus identified: pure white and yellow maize in one hand and potash-treated white and yellow maize. The most commonly sold are pure white and potash-treated yellow maize. Unlike millet, grains that undergoes only milling process, maize grains are decorticated then soaked overnight prior to milling. The majority of cereals processors are women, which have no educational background. With no formal training, their professional experience results from years of traditional family education. Thus, cereal flours are produced and handled under poor hygiene conditions. An African regional standards project has been defined for local cereal flours by the Codex Alimentarius (FAO/WHO, 1985) where conditions of hygiene and packing have been fixed. Moisture content, particle size determination and ash content are crucial factors for quality attributes of cereal flours. These standards aim at helping both processor and user to better characterize and position their products. So far, there is no formal report on the influence of the artisanal processing on the nutritional quality and safety of the local cereal flours. This study aims at evaluating the physicochemical, microbiological and nutritive qualities of the commercial local cereals flours sold on the markets of some areas of the District of Abidjan.

## MATERIALS AND METHODS

**Market samples collection:** Cereal flours samples were obtained from producers on regular markets of nine (9) areas of the District of Abidjan including Abobo, Adjamé, Attécoubé, Cocody, Marcory, Koumassi, Port-Bouet, Treichville and Yopougon. Two grand producers (sellers) were identified per district making a total of 18 sellers. Twice a week, two sellers were randomly selected (4 sellers a week) for samples collection for microbiological analysis. Each time, the rest of the samples were fragmented into smaller part and kept under sterile polyethylene bags at 4 °C. Each type of cereal flour was thus sampled 18 times; a representative sample (900 g) of each type of cereal flour was obtained by mixing equal amount (50 g) of all the different samples. These representative samples were split into aliquots (30 g) for physicochemical and biochemical analysis.

**Standard samples processing:** Standards were made out of raw grains (100 g) of millet, yellow and white corn processed in laboratory conditions by applying the commercial transformation steps. Processing used is described by the figure 1. Maize grains were hulled, washed and soaked in two volumes of distilled water with or without potash crystals (50 g/kg of grains). Tempering was done overnight (15 h) then grains were rinsed (cleaned), ground and sieved. For the production of millet flour, milling and sieving were used after wet cleaning of millet grains.

**Physicochemical and nutritive characterization**

**Proximate analysis:** Proximate analysis was performed using the AOAC (1990) standard methods. The moisture content was determined by the difference of weight before and after drying the sample (10 g) in an oven (Memmert, Germany) at 105 °C until constant weight. Ash fraction was determined by the incineration of dried sample (5 g) in a muffle furnace (Pyrolabo, France) at 550 °C for 12 h. The percentage residue weight was expressed as ash content. PH was determined as follow: 10 g of flour sample was homogenized with 100 mL of distilled water and then filtered. The pH value was recorded after the electrode of pH-meter (Hanna, Spain) was immersed into the filtered solution. For crude fibres, 2 g of sample were weighed into separate 500 mL round bottom flasks and 100 mL of 0.25 M sulphuric acid solution was added. The mixture obtained was boiled under reflux for 30 min. Thereafter, 100 mL of 0.3 M sodium hydroxide solution was added and the mixture were boiled again under reflux for 30 min and filtered through a Whatman paper. The insoluble residue was then incinerated, and weighed for the determination of crude fibres content.

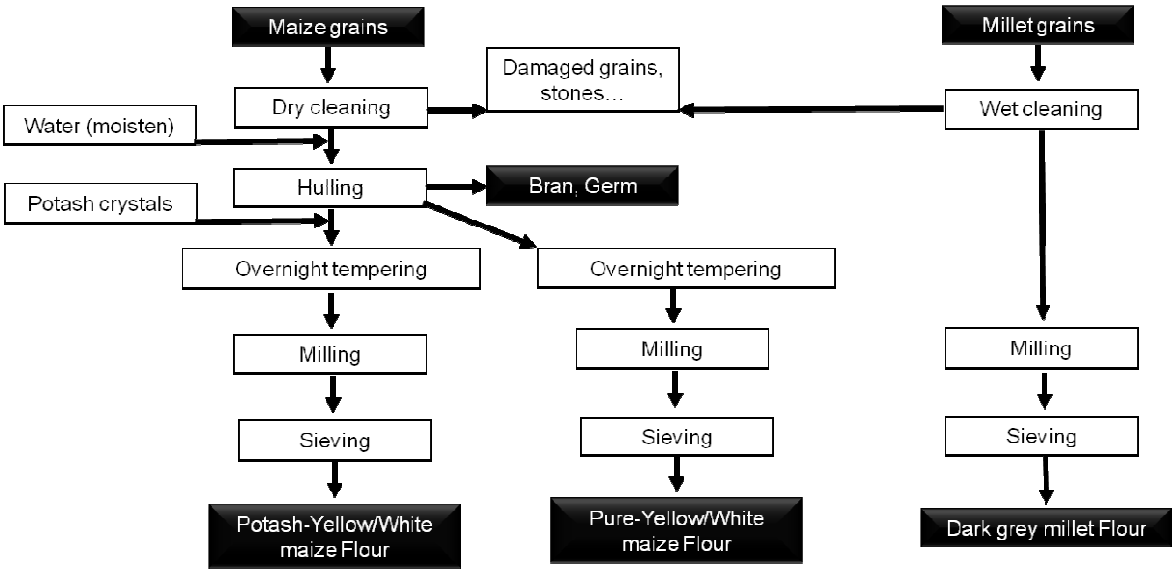


**Figure 1**: Diagram of market and standard (maize and millet) flours processing

Proteins were determined through the Kjeldhal method and the lipid content was determined by Soxhlet extraction using hexane as solvent. Carbohydrates and calorific value were calculated using the following formulas (FAO, 2002):

Carbohydrates: 100 – (% moisture + % proteins + % lipids + % ash + % fibres).

Calorific value: (% proteins × 4) + (% carbohydrates × 4) + (% lipids × 9).

The results of ash, fibres, proteins, lipids and carbohydrates contents were expressed on dry matter basis. Polyphenols were extracted and determined using Folin–Ciocalteu's reagent (Singleton *et al*., 1999). A quantity (1 g) of dried powdered sample was soaked in 10 mL of methanol 70 % (w/v) and centrifuged at 1000 rpm for 10 min. An aliquot (1 mL) of supernatant was oxidized with 1 mL of Folin–Ciocalteu's reagent and neutralized by 1 mL of 20% (w/v) sodium carbonate. The reaction mixture was incubated for 30 min at ambient temperature and absorbance was measured at 745 nm by using a spectrophotometer (PG Instruments, England). The polyphenols content was obtained using a calibration curve of gallic acid (1 mg/mL) as standard. Phytates contents were determined using the Wade's reagent spectrophotometric method (Latta & Eskin, 1980). A quantity (1 g) of dried powdered sample was mixed with 20 mL of hydrochloric acid (0.65 N) and stirred for 12 h. The mixture was centrifuged at 12000 rpm for 40 min. An aliquot (0.5 mL) of supernatant was added with 3 mL of Wade's reagent. The reaction mixture was incubated for 15 min and absorbance was measured at 490 nm by using a spectrophotometer (PG Instruments, England). Phytates content was estimated using a calibration curve of sodium phytate (10 mg/mL) as standard.

**Mineral analysis:** The mineral content was estimated by dry ashing of dried powdered sample (5 g) in a muffle furnace (Pyrolabo, France). The ash obtained was dissolved in 5 mL of $HCl/HNO_3$ and analyzed using emission spectrometer coupled with electronic microscopy (MEB/EDS).

***In vitro* starch digestibility:** Digestive fluid of the giant snails *Achatina achatina* was extracted according to the method given by Colas (1977) and used as enzymatic source. The reactions were carried out at 37 °C with 20 µL of enzyme solution, 100 µL of gelatinized flour (1%; w/v) in 80 µL of sodium acetate buffer (100 mM, pH 5.0) for 24 hours. A blank, made out of 100 µL of substrate and 100 µL of buffer, was simultaneously run. At various intervals, 100 µL of samples were withdrawn to quantify the total reducing sugars (Bernfeld, 1955). A standard curve was prepared using glucose (1 mg/mL). Amylolytic enzymes activities were expressed as the amount of catalysts, which release 1 µmol of reducing sugar from starch per minute under the experimental conditions.

**Microbial analysis:** The culture dependent approach was performed as follow: 225 mL of peptone water (Oxoid, Basingstoke, United Kingdom) was added to 25

g of flour in a sterile Stomacher bag that was vigorously shaken for 5 min in a Stomacher 400 (Seward, Worthington, United Kingdom) to obtain a uniform homogenate. Samples (1 mL) of the homogenate were serially diluted 10-fold in peptone water, from which aliquots (0.1 mL) were spread-plated onto different selective agar media and incubated at different temperatures for 1 to 4 days for isolation and enumeration (by recording the number of CFU) of specific groups of microorganisms: plate count agar (PCA; Oxoid) for the total aerobic bacterial count (30 °C), yeast glucose chloramphenicol (YGC; Oxoid) agar for yeast and moulds (30 °C); Rapid E. coli (BioRad) agar for *E. coli* (44 °C)*;* Baird Parker (BioRad) agar for *S. aureus* (37 °C); Violet Red Bile Lactose (VRBL, AES Laboratoire) agar for coliforms (30 °C for total coliforms and 44 °C for thermotolerant coliforms); Hektoen (BioRad) for *Salmonella*, Trypton Sulfite Neomycin (TSN, BioRad) agar for anaerobes (46 °C) and Bile Esculin Azide (BEA, Oxoid) agar for *Enterococci* (37 °C). Colonies obtained from selective agar mediums were purified through sub-culturing on nutrient agar. Confirmation was done by using morphological and biochemical characteristics with reference to the Bergey's Manual of Determinative Bacteriology (Bergey & Holt, 1994).

**3.5 Statistical analysis:** All the analyses were performed in triplicate and data were analyzed using EXCELL and STATISTICA 7.1 (StatSoft). Differences between means were evaluated by Fisher's Least Difference test. Statistical significant difference was stated at $p < 0.05$.

## RESULTS AND DISCUSSION

**Proximate composition:** The proximate composition of the selected local cereal flours is depicted in Table 1. The values of the physicochemical parameters varied with the types of flours and showed significant difference ($p < 0.05$). The moisture content of the flours ranged from 29 to 35% thus they are hardly kept beyond 24 hours. These flours are meant to be consumed within 12 hour to ensure freshness. The moisture values obtained are in accordance with those obtained from traditional wet processing flours, which have 22 to 46 % moisture content (FAO, 1994). These values are well above the Codex standard specifications that limit flour moisture to a maximum range of 13% and 15% for millet (Codex-Stan 170, 1989) and maize (Codex-Stan 154, 1985) flours, respectively. Moisture is a specific criterion of food quality that has a direct influence on the stability during storage. Organism naturally occurring in the flour would readily thrive at high moisture all of which cause deterioration during storage (Ntuli *et al.,* 2013). Ash content gives information on the efficiency of the hulling process. Hulling is not favourable to millets due to their small grains sizes thus the common practice is to produce whole meal flours in order to maximize yield. The ash content, of the maize flours, with the exception of the potash treated ones, was lower than the level expected for decorticated cornmeal meaning 0.7 % (FAO, 1985). Ash content of the samples ranged from 0.38 to 1.93 %. The highest values (1.46 and 1.93 %) were found in potash-treated yellow maize. The ash content in millet flour (0.89 - 1.26 %) almost met the standard specification (FAO, 1985; Codex- Stan 170, 1989) whereas the ash content (0.38 – 0.66 %) in pure yellow and white cornmeal was below the standard level (0.7 %) expected for decorticated grains (FAO, 1985).

**Table 1:** Proximate composition of market and standard flours from maize and millet

| | Flours | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Yellow maize** | | **Yellow maize + potash** | | **White maize** | | **White maize + potash** | | **Millet** | |
| | **Market** | **Standard** | **Market** | **Standard** | **Market** | **Standard** | **Market** | **Standard** | **Market** | **Standard** |
| Moisture (%) | $35.36^{a}\pm0.1$ | $22.93^{b}\pm0.1$ | $33.33^{a}\pm1.72$ | $23.43^{b}\pm0.15$ | $33.86^{a}\pm0.15$ | $22.92^{b}\pm0.60$ | $34.89^{a}\pm0.11$ | $22.53^{b}\pm0.50$ | $34.30^{a}\pm0.17$ | $23.63^{b}\pm0.50$ |
| Ash (%) | $0.53^{d}\pm0.01$ | $0.38^{e}\pm0.01$ | $1.93^{a}\pm0.11$ | $1.38^{b}\pm0.01$ | $0.66^{d}\pm0.11$ | $0.58^{d}\pm0.01$ | $1.46^{b}\pm0.30$ | $1.38^{b}\pm0.01$ | $1.26^{b}\pm0.11$ | $0.89^{c}\pm0.10$ |
| pH | $4.46^{e}\pm0.01$ | $4.49^{e}\pm0.01$ | $7.50^{b}\pm0.01$ | $7.91^{a}\pm0.01$ | $4.53^{e}\pm0.02$ | $4.50^{e}\pm0.01$ | $7.86^{a}\pm0.05$ | $7.95^{a}\pm0.11$ | $4.98^{d}\pm0.02$ | $5.56^{c}\pm0.01$ |
| Fibres (%) | $0.20^{c}\pm0.05$ | $0.70^{b}\pm0.10$ | $0.15^{d}\pm0.01$ | $0.85^{b}\pm0.05$ | $0.25^{c}\pm0.01$ | $0.73^{b}\pm0.03$ | $0.15^{d}\pm0.01$ | $0.78^{b}\pm0.13$ | $0.27^{c}\pm0.02$ | $2.70^{a}\pm0.03$ |
| Lipids (%) | $1.44^{d}\pm0.03$ | $1.84^{c}\pm0.04$ | $1.20^{e}\pm0.01$ | $1.26^{e}\pm0.07$ | $1.79^{c}\pm0.00$ | $1.91^{c}\pm0.03$ | $1.19^{e}\pm0.00$ | $1.51^{d}\pm0.02$ | $2.12^{b}\pm0.05$ | $3.84^{a}\pm0.16$ |
| Proteins (%) | $4.99^{d}\pm0.15$ | $5.26^{c}\pm0.14$ | $3.94^{e}\pm0.17$ | $4.24^{d}\pm0.62$ | $5.56^{c}\pm0.43$ | $6.06^{b}\pm0.06$ | $3.93^{e}\pm0.10$ | $3.87^{e}\pm0.43$ | $6.44^{b}\pm0.41$ | $7.46^{a}\pm0.26$ |
| Carbohyd.(%) | $76.03^{b}\pm0.2$ | $72.13^{c}\pm0.2$ | $73.64^{c}\pm0.23$ | $73.56^{b}\pm1.89$ | $74.16^{b}\pm0.19$ | $85.64^{a}\pm0.66$ | $74.06^{b}\pm0.45$ | $71.87^{c}\pm0.55$ | $89.19^{a}\pm0.47$ | $77.89^{b}\pm0.49$ |
| Polyphenols (mg/100g) | $69.10^{d}\pm1.1$ | $86.30^{c}\pm0.0$ | $62.49^{e}\pm3.57$ | $23.79^{h}\pm0.00$ | $63.14^{e}\pm4.01$ | $70.39^{d}\pm0.00$ | $55.70^{f}\pm0.28$ | $44.36^{g}\pm0.05$ | $95.81^{b}\pm5.67$ | $195.43^{a}\pm0.0$ |
| Phytates (mg/100g) | $17.90^{c}\pm0.2$ | $23.20^{a}\pm0.2$ | $14.87^{d}\pm0.5$ | $21.90^{b}\pm0.5$ | $11.51^{f}\pm0.5$ | $17.97^{c}\pm0.2$ | $20.57^{b}\pm0.1$ | $29.62^{a}\pm0.5$ | $13.68^{e}\pm0.64$ | $20.54^{b}\pm0.27$ |
| Energy (kcal/100g) | $337^{d}\pm1.00$ | $326.1^{e}\pm1.1$ | $321.43^{e}\pm1.1$ | $322.61^{e}\pm8.9$ | $335.07^{d}\pm0.1$ | $384.07^{a}\pm2.9$ | $322.76^{e}\pm0.0$ | $316.60^{f}\pm3.9$ | $365.67^{c}\pm3.6$ | $375.99^{b}\pm4.5$ |

Data are represented as means ± SD (n=3). Mean with different letters in the same line are statistically different ($p < 0.05$) according to Fisher's test.

These results clearly indicate depletion of minerals, which can be attributable to the unnecessary prolonged tempering of hulled grain during processing (Ndjouenkeu *et al.*, 1989). This observation can also be applied to the protein content (3.93 - 5.56 %) of market cornmeal instead of the 7 % expected in decorticated maize flour (FAO, 1985). Long-time tempering of decorticated grain is impoverishing because of draining of nutriments such minerals, vitamins and proteins (Favier, 1989). This traditional practice tends to be counterproductive and problematic when addressing issues like protein deficiency by introduction of quality protein maize (QPM) in the diet (Krivanek *et al.*, 2007). The main traditional meal made of yellow and white maize flours is a thick porridge called *tô* (Nguessan *et al*., 2014); therefore the consumption of *tô* can be implicated in malnutrition because of its extremely low protein content. Whole millet flour displayed higher protein content (6.44 – 7.46%) as well as higher fat content (2.12 – 3.84%). It should be recalled that fat content along with moisture is a decisive factor in appreciating the shelf life of flours (Sauer, 1992); thus, high fat content could lead to rancidity during storage (Kaced *et al*., 1984). The fat content was significantly ($p < 0.05$) lower in the potash-treated maize flour presumably due to defatting caused by alkalinity (Matz, 1991). In addition, there was significant difference ($p < 0.05$) in pH values of the samples. The pH of the potash-treated maize flour increased from 4.46 to 7.95 due to the potash added. Plant phenolics include condensed tannins, which reduce proteins bioavailability (Naczk & Shahidi, 2004). Recent studies (Lestienne *et al*., 2003) have revealed that soaking of whole seeds for 24 h led to a significant reduction of phytates content of maize (21%) and millet (28%). Phytates are the principal storage form of phosphorus and are particularly abundant in cereals (Champ, 2002). These anti-nutrients chelate divalent cations such as calcium, magnesium, zinc and iron, thereby reducing their bioavailability (Sandberg, 2002). Therefore, whole seed soaking or limiting soaking times (N'djouenkeu *et al*., 1989) of hulled grains prior to milling could be considered as detoxification method in commercial flour processing (Ekop & Eddy, 2005). In the same context, the tempering process used for maize flours manufacturing also reduce the levels of anti-nutritional factors such as polyphenols and phytates (Afify *et al*., 2012).

**Mineral composition:** Mean values for mineral content of the selected cereal flours are presented in Table 2. The samples analyzed in this study contained remarkably high amounts ($p < 0.05$) of potassium (162.92 – 1363.93 mg/100 g) with the highest value (718.08 - 1363.93 mg/100 g) observed for potash-treated samples. Although the increased potassium intake might have salutary effects on blood pressure (He *et al*. 2010), some concern may be raised for consumers with diabetes, heart or kidney failure. Indeed, the relatively higher level of potassium in potash-treated flours could lead to hyperkalaemia that cause excess potassium in the bloodstream (Soetan *et al*., 2010). A campaign to raise awareness of local flour processors on the possibility of standardizing the level of potash in yellow maize to ensure consumers safety might be needed. It was also observed that potash-treated flours showed higher content (4.31 – 101.71 mg/100g) of sulfur than the (1.56 – 34.05 mg/100g) non potash-treated ones. This molecule could be considered as impurity of potash crystals.

**Table 2:** Mineral composition (mg/100g) of market and standard flours from maize and millet

| | Flours | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Yellow maize** | | **Yellow maize + potash** | | **White maize** | | **White maize + potash** | | **Millet** | |
| | **Market** | **Standard** | **Market** | **Standard** | **Market** | **Standard** | **Market** | **Standard** | **Market** | **Standard** |
| Na | $0.00^{f}$±0.00 | $1.42^{c}$± 0.02 | $0.00^{f}$±0.00 | $0.20^{e}$±0.05 | $0.00^{f}$±0.00 | $1.16^{d}$±0.04 | $0.00^{f}$±0.00 | $1.68^{b}$±0.11 | $0.00^{f}$ ± 0.00 | $4.23^{a}$ ± 0.09 |
| Mg | $65.67^{d}$±0.18 | $69.21^{d}$±1.90 | $37.63^{g}$±9.11 | $68.94^{d}$±1.11 | $41.14^{f}$±0.70 | $56.44^{e}$±2.00 | $70.19^{d}$±1.95 | $97.85^{c}$±3.30 | $101.37^{b}$± 1.78 | $162.05^{a}$±4.10 |
| P | $284.14^{e}$±2.74 | $390.81^{a}$±7.0 | $237.69^{f}$±7.73 | $357.50^{c}$±5.11 | $205.03^{g}$±1.6 | $281.39^{e}$±1.0 | $338.90^{d}$±3.26 | $380.00^{b}$±9.3 | $252.13^{f}$± 4.14 | $394.63^{a}$± 5.70 |
| S | $14.94^{e}$±1.94 | $2.18^{h}$± 0.13 | $53.36^{b}$±3.08 | $4.31^{g}$±0.72 | $34.05^{c}$±0.75 | $1.56^{h}$±0.20 | $101.71^{a}$±24.12 | $54.40^{b}$±4.73 | $17.78^{d}$±2.15 | $9.26^{f}$± 0.76 |
| K | $247.76^{g}$±6.00 | $171.10^{h}$±1.4 | $1092.30^{b}$±23.6 | $718.08^{d}$±10.9 | $162.92^{h}$±9.6 | $119.49^{i}$±0.8 | $1363.93^{a}$±9.50 | $766.45^{c}$±4.0 | $471.55^{e}$±2.30 | $298.60^{f}$± 3.74 |
| Ca | $2.58^{d}$±0.07 | $2.89^{d}$±1.00 | $2.18^{e}$±1.10 | $1.15^{f}$±0.57 | $4.63^{c}$±0.22 | $4.46^{c}$±0.20 | $7.23^{b}$±1.21 | $5.00^{c}$±1.81 | $8.48^{a}$ ± 2.55 | $7.53^{a}$± 0.20 |
| Mn | $0.00^{d}$±0.00 | $0.12^{c}$±0.01 | $1.70^{a}$±0.07 | $0.00^{d}$±0.00 | $1.70^{a}$±0.07 | $0.00^{d}$±0.00 | $0.00^{d}$±0.00 | $0.00^{d}$±0.00 | $0.00^{d}$ ± 0.00 | $1.51^{b}$± 0.10 |
| Fe | $0.77^{c}$±0.06 | $0.74^{c}$±0.08 | $0.26^{f}$±0.09 | $0.48^{e}$±0.04 | $0.26^{f}$±0.09 | $0.45^{e}$±0.04 | $0.56^{d}$±0.07 | $0.64^{d}$±0.09 | $2.17^{b}$± 0.09 | $13.0^{a}$ ± 0.06 |
| Zn | $0.00^{e}$±0.00 | $1.43^{b}$±0.02 | $0.00^{e}$±0.00 | $1.64^{a}$±0.01 | $1.12^{c}$±0.08 | $1.33^{b}$±0.09 | $0.00^{e}$±0.00 | $1.55^{b}$±0.05 | $1.14^{d}$±0.01 | $10.62^{a}$±0.38 |
| Cu | $0.00^{e}$±0.00 | $0.00^{e}$±0.00 | $0.00^{e}$±0.00 | $1.28^{d}$±0.09 | $2.22^{c}$±0.29 | $1.01^{d}$±0.03 | $0.00^{e}$±0.00 | $4.44^{b}$±0.89 | $2.58^{c}$±0.07 | $8.09^{a}$±0.42 |
| Phy/Fe | 23.25 | 31.35 | 57.19 | 45.62 | 44.27 | 39.93 | 36.73 | 46.28 | 6.30 | 1.57 |
| Phy/Zn | - | 16.22 | - | 13.35 | 10.27 | 13.51 | - | 19.10 | 12.00 | 1.93 |

Data are represented as means ± SD (n=3). Mean with different letters in the same line are statistically different ($p < 0.05$) according to Fisher's test.

Therefore, the consumption in high amount of potash-treated flours may have adverse effect on human health. The iron and zinc contents (13.08 ± 0.66 and 10.62 ± 0.68 mg/100g) detected in standard millet flour were noticeable, higher than values (8 and 6 mg/day, respectively) recommended for human dietary allowance (FAO/WHO, 1988). To predict the bioavailability of iron and zinc, anti-nutrients to nutrients ratios were calculated. The calculated [phytates]/ [Fe] and [phytates]/ [Zn] ratios in all studied flours were above the critical level of 10 known to impair iron and zinc bioavailability (Davies & Olpin, 1979; Saha *et al*., 1994). This implies that the phytates content of these processed flours may hinder iron and zinc bioavailability. Therefore, treatment such as soaking the flours prior to cooking without discarding the steeping water will be necessary to significantly improve the bioavailability of iron and zinc in infant meals (Lestienne *et al*., 2003).

**Flour (starch) digestibility:** The result of *in vitro* starch digestibility (IVSD) of the local cereal flours is presented in Figure 2 and the calculated hydrolysis rate shown in Table 3. The maize flours all type combined were more susceptible to *in vitro* enzymatic digestibility than millet flours ($p < 0.05$). Possible reasons could be given such as differences in grain characteristics due to botanical origin and treatments prior to milling. Refining processes such as decortications leads to an important loss in nutrients and anti-nutrients (Bach Knudsen *et al*., 1988). Since millet was milled in their whole form, it meant that they were rich in lipids, phenolic compounds and insoluble dietary fibres (Table 1). This may cause restriction in accessibility of starch by amylolytic enzymes (Holm *et al*., 1983; Waniska *et al*., 1990; Cui & Oates, 1999). Recent studies have shown that removing proteins and lipids significantly increased enzymatic starch hydrolysis rate and therefore glycaemic index of millet starches (Annor *et al.,* 2013). Other works reported a possible interaction between starch and polyphenol molecules or between amylase and polyphenols in cereal foods thereby reducing the starch digestibility (Thondre & Henry, 2011). It was thus asserted that polyphenol content could have potential effect on glycaemic response to cereal meals. IVSD for most of market flours were significantly different to their standard counterparts ($p < 0.05$). The commercial processing of the local flours needs generally 2 or 3 passes though the mill in order to minimize losses. This practice results in an important heat built up in the flours, which is known to affect starch granules. During milling and grinding of cereals a mechanical gelatinization of starch occurs, resulting in what is termed "damaged starch" (Hasjim *et al*., 2009) which are more susceptible to amylases. The main difference reported between yellow and white maize was the presence of carotenoids, fat soluble pigments (Morin-Savy, 2005) responsible for the yellow color of the grain (FAO, 1997). Therefore, the slow hydrolysis of pure yellow maize starch compared to pure white maize starch observed in this study might be ascribed to the presence of these pigments (Adejumo *et al*., 2013). The study also showed that potash causes significant increase in the *in vitro* starch digestibility of white maize flours ($p < 0.05$). Indeed, alkalinity is reported to loosen the hulls of maize grains, to modify endosperm cell walls and protein matrix thus exposing starch granules to enzyme action (Altieri *et al*, 2005). Therefore, the structural changes induced by the chemical treatment may partly explain increasing of digestibility (Ørskov & Greenhalgh, 1977). The presence of carotenoids in yellow corn may lead to formation of lipid complex with starch and hence limit *in vitro* digestibility of the potash treated yellow cornmeal (Cui & Oates, 1999; Holm *et al*., 1983). In addition, it is reported that no salivary or gastric enzymes are known to hydrolyze carotenoids (Fardet *et al*., 2013); however, disruption of the cell walls containing the carotenoids during digestion would allow their recovery (Weisse, 2002). Therefore, the popular belief that *tô*, thick porridge, made with potash treated yellow maize is easily digestible may not be fully asserted but it provides undoubtedly the dough with lightness and suppleness. However, studies have shown that maize thick porridges, all types taken together, can be useful in the prevention or treatment of diabetes because of reduced in vitro starch digestibility and predicted glycaemic index ranging from 39 to 50 glucose reference (Van der Merve *et al*., 2001; SABC, 2005).

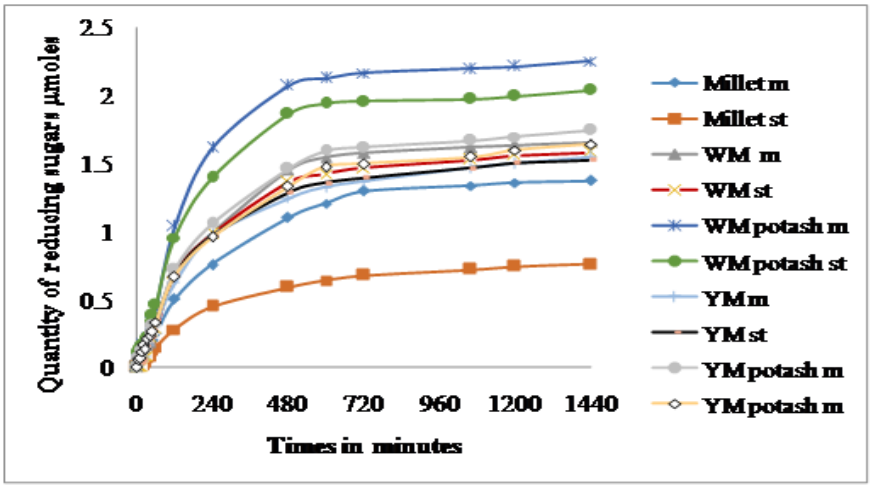


**Figure 2:** *In vitro* digestibility of gelatinized market and standard flours by the digestive fluid of *Achatina achatina*
Legend**: m**-market sample; **st**-standard sample; WM-white maize; YM-yellow maize

**Table 3:** Hydrolysis rates of maize and millet flours (µmoles/min)

| Cereal flours | Standard ($10^{-5}$µmole/min) | Market ($10^{-5}$µmole/min) |
|---|---|---|
| **Yellow maize** | $556^{d} \pm 24$ | $485^{c} \pm 9$ |
| **Yellow maize with potash** | $551^{d} \pm 59$ | $536^{d} \pm 35$ |
| **White maize** | $573^{e} \pm 23$ | $586^{f} \pm 5$ |
| **White maize with potash** | $715^{g} \pm 15$ | $774^{h} \pm 6$ |
| **Millet** | $245^{a} \pm 12$ | $441^{b} \pm 3$ |

Mean with different letters are statistically different ($p < 0.05$) according to Fisher's test.

**Microbial quality:** The microbial load found in the flours samples is shown in Table 4. The presence of high level (6.76 – 8.33 Log cfu/g) of total mesophilic aerobic bacteria count in market cereal flours give them an unsatisfactory microbiological quality according to the health standardized criteria of 5 Log cfu/g (Guiraud, 1998). These bacteria groups include mesophilic, pathogens and non-pathogens microorganisms. The market samples were also contaminated with *Enterococcus* and thermotolerant coliforms (1.27 – 1.86 Log cfu/g and 1.06 – 1.60 Log cfu/g, respectively). These bacteria are widely distributed in the environment (soil, surface waters, plants and vegetables), principally inhabiting the human and warm-blooded animal gastro-intestinal tract (Mundt, 1986). Furthermore, it has been shown that enterococci and coliforms are considered as hygiene indicators in the manufacturing process of foods (Birollo *et al.*, 2001). Therefore, to avoid food borne illnesses due to enterococci and coliforms, cereal market flours must be prepared with good manufacturing practices and good conditions of storage. The high microbial count detected for yeast and moulds might be due to improper postharvest and storage handling of the cereal grains. The residue built up in milling machines as well as the wet process used can be relevant as additional sources of microbial contamination of commercial samples (Berghofer *et al.*, 2003; Shoba *et al.*, 2011). Yeast and moulds growth on processed foods may lead to the formation of mycotoxins, which are secondary fungal toxic metabolites to humans and animals, causing disorders like cancer, immune suppression or endocrine disruption (Filtenborg *et al.*, 1996). Therefore, storage conditions as relative humidity of atmosphere must be a critical control points during processing of cereal flours. It is also important to note that all the analyzed samples were free of toxin producing moulds and pathogenic bacteria such as *Salmonella*, *Staphylococcus*, *Clostridium* and *Escherichia coli* that are usually involved in food poisoning (Bourgeois *et al.*, 1996). Processing techniques such as heat treatment significantly reduce microbial contamination. Therefore, precaution needs to be taken in order to avoid cross contamination of the prepared meals.

**Table 4:** Microbial characteristics ($log_{10}$ cfu/g) of market and standard flours from maize and millet

| | Criteria $log_{10}$ (cfu/g) | Flours | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Yellow maize** | | **Yellow maize + potash** | | **White maize** | | **White maize + potash** | | **Millet** | |
| | | **Market** | **Standard** | **Market** | **Standard** | **Market** | **Standard** | **Market** | **Standard** | **Market** | **Standard** |
| Total microflora | **5** | $7.75^{b}$±0.12 | $3.65^{g}$±0.32 | $7.03^{c}$±0.02 | $5.13^{e}$±0.17 | $6.99^{c}$±0.01 | $4.19^{f}$±0.19 | $8.33^{a}$±0.17 | $5.09^{e}$±0.41 | $6.76^{c}$±0.03 | $4.07^{d}$±0.36 |
| Enterococci | **1** | $1.55^{b}$±0.82 | $0.00^{d}$±0.00 | $1.86^{a}$±0.65 | $0.00^{d}$±0.00 | $1.27^{c}$±1.18 | $0.00^{d}$±0.00 | $1.39^{b}$±0.27 | $0.00^{d}$±0.00 | $1.41^{b}$±0.89 | $0.00^{d}$±0.00 |
| Total coliforms | **3** | $1.40^{c}$±0.17 | $00.0^{e}$±0.00 | $1.48^{c}$±0.12 | $0.00^{e}$±0.00 | $1.64^{b}$±0.07 | $0.00^{e}$±0.00 | $1.90^{a}$±0.34 | $0.00^{e}$±0.00 | $1.48^{c}$±0.20 | $0.33^{d}$±0.00 |
| Thermo. coliforms | **1** | $1.10^{c}$±0.05 | $0.00^{d}$±0.00 | $1.06^{c}$±0.00 | $0.00^{d}$±0.00 | $1.48^{b}$±0.10 | $0.00^{d}$±0.00 | $1.60^{a}$±0.50 | $0.00^{d}$±0.00 | $1.40^{b}$±0.32 | $0.00^{d}$±0.00 |
| *E. coli* | **0** | $0.00^{a}$±0.00 | $0.00^{a}$±0.00 | $0.00^{a}$±0.00 | $0.00^{a}$±0.00 | $0.00^{a}$±0.00 | $0.00^{a}$±0.00 | $0.00^{a}$±0.00 | $0.00^{a}$±0.00 | $0.00^{a}$±0.00 | $0.00^{a}$±0.00 |
| Anaerobes | **2** | $0.00^{a}$±0.00 | $0.00^{a}$±0.00 | $0.00^{a}$±0.00 | $0.00^{a}$±0.00 | $0.00^{a}$±0.00 | $0.00^{a}$±0.00 | $0.00^{a}$±0.00 | $0.00^{a}$±0.00 | $0.00^{a}$±0.00 | $0.00^{a}$±0.00 |
| *S. aureus* | **1** | $0.00^{a}$±0.00 | $0.00^{a}$±0.00 | $0.00^{a}$±0.00 | $0.00^{a}$±0.00 | $0.00^{a}$±0.00 | $0.00^{a}$±0.00 | $0.00^{a}$±0.00 | $0.00^{a}$±0.00 | $0.00^{a}$±0.00 | $0.00^{a}$±0.00 |
| *Salmonella* | **Abs** | Abs | Abs | Abs | Abs | Abs | Abs | Abs | Abs | Abs | Abs |
| Yeast and moulds | **3** | $2.67^{b}$±0.72 | $1.85^{d}$±1.11 | $3.33^{a}$±0.24 | $1.30^{e}$±0.03 | $2.05^{c}$±0.014 | $1.20^{e}$±0.05 | $2.93^{b}$±0.77 | $1.02^{f}$±0.67 | $2.13^{c}$±0.17 | $1.20^{e}$±0.04 |

Data are represented as means ± SD (n=3). Mean with different letters in the same line are statistically different ($p < 0.05$) according to Fisher's test.

## CONCLUSION

Local cereals namely maize and millet flours are in great demand among the Ivorian consumers and show a great introduction on the markets of the District of Abidjan. Up to this point, local cereal flours are mainly manufactured in artisanal way following empirical traditional procedures. The unsuited storage facilities of grains, as well as the wet transformation process (including the unnecessary prolonged tempering) and the poor hygienic handling of the flours affect the final product. The current study thus reveals that the local flours have a quite heterogeneous physicochemical, nutritive and non-satisfactory microbiological quality. Maize and millets have high carbohydrate energy content that make them useful components of dietary foods hence, deserve particular attention. Management quality of these cereal flours is necessary to develop competitive products to conquer a wider urban market. More stringent measure with regard to microbial contamination need to be implemented for consumers' safety. Manufacturing which implies standardizing tempering times and potash addition, drying facilities and conditioning practices of cereal products with novel technology that would offer full sanitary guarantees to the consumers have to be imperatively considered.

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