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# Characterization of White and Yellow Maize Cob Ash for Application as a Food Additive in Cornbread Preparation

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## Abstract

Maize cob ash (MCA), a traditional alkaline cooking aid in Zimbabwean households, is commonly used as a substitute for commercial sodium bicarbonate in preparing staple foods such as cornbread. Despite its widespread use, limited scientific information exists on its physicochemical properties, chemical composition, and leavening potential in food systems. This study aimed to characterise white and yellow maize cob ash for potential application as a food additive in cornbread preparation. Maize cobs were collected, incinerated, and sieved to produce fine ash powders, which were then dissolved in both distilled and borehole water at different concentrations (1%, 5%, 10%) to prepare MCA solutions. Borehole water is the standard water source utilised in most rural households to prepare traditional ash solutions. The MCA solutions were analysed for pH, conductivity, total dissolved solids, specific gravity, turbidity, and sodium bicarbonate content. FTIR was used to determine functional groups, while Inductively Coupled Plasma Mass Spectrometry (ICP-MS) was used to assess mineral content. MCA solutions were also tested as leavening agents in indigenous cornbread preparation, followed by sensory evaluation using a nine-point hedonic scale. Results showed that MCA solutions were alkaline (pH 9.9–11.5), with increasing concentration enhancing pH and alkalinity expressed as NaHCO3 equivalent. Mineral analysis indicated the presence of essential and trace elements, including calcium, magnesium, iron, and aluminium. In baking trials, MCA solutions, particularly yellow maize ash in borehole water at 1%, produced cornbread with comparable or better volume and sensory acceptability than the control sample using sodium bicarbonate. The principal component analysis (PCA) revealed a strong association between specific MCA formulations and favourable sensory attributes such as flavour, mouthfeel and overall acceptability. These findings suggest that maize cob ash, especially from yellow maize, holds potential as a locally sourced, sustainable, and culturally accepted food additive for resource-limited settings. Further studies on its safety, optimal dosage, and long-term health effects are recommended.

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## Introduction

Maize *(Zea mays L.),* also known as corn, is a vital staple grain across sub-Saharan Africa, where it plays a central role in food security and household livelihoods (Badu-Aproku and Fakorede, 2017; Grote et al., 2021). In Zimbabwe, maize is cultivated extensively and contributes significantly to both rural and urban diets (Basera et al., 2020). It is also a key input in the livestock feed industry, supplying between 47% and 75% of total energy requirements for animal feed formulations. To meet this growing demand, maize is cultivated by more than 90% of Zimbabwe's 1.3 million farming households, highlighting its critical importance to rural livelihoods and national agricultural systems (AUDA-NEPAD, 2022). However, alongside this substantial production is the generation of large volumes of agricultural waste, including maize leaves, husks, stalks, and cobs (Gramig et al., 2013). These by-products are largely underutilised and often discarded or burned, despite growing recognition of their potential value in food systems and beyond (Zhang et al., 2010). In Southern Africa, maize cobs are typically used as firewood, incorporated into

fields as organic matter, or simply discarded (Adetogun et al., 2014). Valorising maize cob waste aligns with circular economy principles and supports sustainable food systems (Ariyanti et al., 2025; Maqsood et al., 2025). Research has demonstrated a wide range of possible applications, including animal bedding and feed, fertilizer, activated carbon (Aloko and Adebayo, 2007; Lala et al., 2023), and even dietary fibre for human nutrition (Njideka et al., 2020).

One particularly promising but underexplored traditional use of maize cobs in Zimbabwe is the production of maize cob ash. After incineration, the ash is mixed with water to form a solution locally known as Mutyora, Fesha, or Muketa in Shona. Rural communities widely use this solution as a traditional alkaline cooking aid, substituting for commercial sodium bicarbonate when preparing dishes such as pumpkin leaves, okra, dried meat, and cornbread. Cornbread, made wholly or partially with cornmeal, is a culturally significant food in Zimbabwe, especially in low-income rural areas where it constitutes an affordable, filling staple (Ekpa et al., 2019; Swati et al., 2024). In these applications, maize cob ash functions mainly through its alkalinity, which mimics the leavening and textural effects of sodium bicarbonate. However, the chemical characteristics of biomass ash vary widely and depend on the feedstock and combustion conditions. Plant-derived ashes are complex mixtures of inorganic oxides, carbonates, and hydroxides, and their alkalinity arises from multiple species rather than a single compound. This complexity means maize cob ash's leavening potential cannot be assumed to match that of sodium bicarbonate, and its behaviour in food systems requires systematic characterisation.

While sodium bicarbonate is the standard leavening agent in most commercial and home-based baking, it poses several challenges. It is often unaffordable in low-resource settings and is associated with an unpleasant taste in traditional breads. Moreover, studies suggest potential adverse health effects, including gastrointestinal distress, even at low levels of intake (Han et al., 2022). As a result, maize cob ash remains a preferred alternative in some communities, valued not only for its accessibility but also for the taste and texture it imparts to traditional foods. White and yellow maize varieties differ in their kernel composition, including carotenoid content, mineral profiles, and phytochemical constituents, all of which may influence the chemical composition and functional properties of the resulting ash. In addition, the water source used to prepare the ash solution and the ash concentration in the solution are critical variables that may affect pH,alkalinity, and the presence of potentially harmful compounds. Despite this, no systematic comparisons have been made between ash derived from white and yellow maize varieties, nor between different water sources or ash concentrations, limiting opportunities for its optimisation and broader adoption.

A critical concern is that the safety and nutritional implications of using maize cob ash as a food additive remain largely uncharacterised. Biomass ash can contain heavy metals, polycyclic aromatic hydrocarbons, and other potentially toxic compounds depending on the soil, plant uptake, and combustion conditions. Without systematic evaluation of its chemical composition and safety profile, promoting its use as a food additive could pose public health risks, particularly in communities where it is already widely used. Despite this long-standing traditional use, maize cob ash remains largely uncharacterised in terms of its physical properties, chemical safety, nutritional potential, and functional performance in food applications. Specifically, three critical knowledge gaps remain unaddressed: The extent to which white and yellow maize varieties differ in the physicochemical and functional properties of their resulting ash is unknown. No comparative data exist on how maize variety influences ash composition, alkalinity, or leavening performance. The effect of water source on the chemical and functional properties of maize cob ash solutions has not been investigated.

Table 1. MCA solutions identity and composition

| Solution identity | Solution composition |
|---|---|
| YD1 | 1 g Yellow variety in distilled water |
| YD5 | 5 g Yellow variety in distilled water |
| YD10 | 10 g Yellow variety in distilled water |
| YB1 | 1 g Yellow variety in borehole water |
| YB5 | 5 g Yellow variety in borehole water |
| YB10 | 10 g Yellow variety in borehole water |
| WD1 | 1 g White variety in distilled water |
| WD5 | 5 g White variety in distilled water |
| WD10 | 10 g White variety in distilled water |
| WB1 | 1 g White variety in borehole water |
| WB5 | 5 g White variety in borehole water |
| WB10 | 10 g White variety in borehole water |

Rural communities use various water sources such as boreholes, rivers, and rainwater, yet the potential for these sources to introduce contaminants or alter ash solution chemistry is undocumented; lastly, the relationship between ash concentration and both functional performance and safety is not well understood. While higher concentrations may enhance leavening, they may also increase the risk of excessive alkalinity or toxic compounds. These gaps are not merely academic. Without this knowledge, it is impossible to establish safe, effective, and standardised guidelines for using maize cob ash as a food additive. Addressing these gaps is essential not only to optimise traditional culinary practices but also to improve public health

outcomes through safer food additives derived from local, sustainable resources. This study, therefore, aims to characterize white and yellow maize cob ash by evaluating their physical characteristics, chemical composition, and functional properties across different water sources and ash concentrations, with a view to assessing their potential as sustainable, locally appropriate food additives in the preparation of cornmeal bread.

## Materials and Methods

### Sample collection and preparation

White and yellow maize cobs were collected from 4 small- to medium-scale farmers around Gweru city, Midlands province, Zimbabwe. The maize cobs were separately filled into two 50kg polystyrene bags. The maize cobs were sun-dried for 72 hours in open air until they achieved a constant weight of 12%. The cobs were then stored at room temperature (approximately 20- 25 $^{o}$C) awaiting further processing. Samples were milled to 2-3 cm chips for uniform combustion. The chips were placed in a muffle furnace at 550 $^{o}$C for 6 hours to obtain a white-grey ash. The maize cob ash (MCA) was cooled in a desiccator to room temperature then passed through a very fine mesh sieve (75 µm/0.075mm) to produce fine ash powder.

Both yellow and white MCA were analysed for functional and chemical properties. Six MCA solutions were prepared from each maize variety, making a total of 12 solutions. The solutions were prepared by taking 1 g, 5 g, and 10 g of each of the MCA samples and adding to 100ml of borehole water (the most commonly used) and 100 mL of distilled water separately in 250ml beakers, and stirred water separately in 250ml beakers, and stirred using a glass rod until thoroughly mixed, covered with aluminium foil and labelled as indicated in Table 1. The solutions were left for 24 hours at room temperature (a simulation of common household procedure), afterwhich they were filtered using Whatman filter paper No. 1. The filtrate was placed in 100ml Duran bottles, labelled and stored at room temperature awaiting analysis. The samples were analysed for physicochemical properties, then used as raising agents in making indigenous corn bread. In addition, MCA solutions were analysed for raising-agent strength, and sensory evaluation was conducted on the breads using untrained panelists.

MCA samples were analysed for mineral elements using inductively coupled plasma-mass spectrometry (Agilent ICP-MS 7800/7900, Japan). The samples were weighed and digested in hydrochloric acid to near dryness; distilled water was then added to 50 mL in a volumetric flask, filtered, and analysed. Safety assessment was performed for MCA solution as a traditional food additive. Two FAO/WHO Joint Expert Committee on Food Additives (JECFA, 2011) approaches were used: purity specification for the additive and safety of the MCA solution as a food additive. The concentrations of potentially toxic elements were compared with the values provided by FAO/WHO Joint Expert Committee on Food Additives limits for food ingredients/ additives (FAO/WHO JECFA, 2011).

Fourier-transform infrared spectroscopy (FT-IRNicolete 6700, Thermo Scientific) was used to determine the functional groups of the MCA solutions at a range of 400-4000 $cm^{-1}$ (Anukam et al., 2017). The pH of the MCA solution samples was determined using a pH meter (Precision, ORP Meter 920, USA) that was standardized
using buffer solutions of pH 4-9 as described by Ogunjobi & Lajide (2013). The acidity/ alkalinity of the samples was determined by acid-base titration where the concentration of titratable alkalinity as $NaHCO_3$ equivalent was determined using a previously described procedure (Alshatteri, 2019; Pierrre 2019)

Conductivity was determined using a conductivity metre (Bartram and Balance, 1996). Sodium chloride was used to calibrate the conductivity metre. The probe was dipped into the distilled and borehole water samples until a stable reading was observed and recorded. Turbidity was determined by a standardized turbidimeter as explained by Ergenzinger & Schmidit (2008). The MCA solution samples were poured into a measuring bottle and the bottle dipped into silicon oil. The bottle was then put into the turbidimeter to obtain the results. Total dissolved solids were determined by the glass fiber filter method following a procedure by described by Greenberg et al., (1999). Specific gravity was determined using a hydrometer following a previously described procedure (Owolabi et al., 2015).

### Determination of raising agent strength

Wheat flour (500 g) was weighed for each of the twelve MCA solutions, a positive control with bicarbonate of soda and a negative control with no raising agent. One hundred ml of each of the MCA solutions was topped with distilled water to 300 ml and each was added to the weighed flour. Distilled water (300 ml) was added to both controls with 10 g of bicarbonate of soda added to the positive control. All samples were hand-mixed for one minute and left to rest for 5 minutes. The mixed doughs were hand-moulded and placed in small, greased baking tins. The dough was then baked in a preheated oven at 230 $^{o}$C for 20 minutes after which the baked bread was cooled to 30 $^{o}$C core temperature. The weight, volume and specific volume of the final baked products were measured and recorded.

### Preparation of cornbread with MCA solutions

Twelve standard indigenous corn breads were prepared using the MCA solutions as raising agents. In addition a positive control bread was made with sodium bicarbonate as a raising agent and a negative control that had no raising agent was also prepared. The indigenous corn breads were prepared using the following recipe: 180g maize meal, 170g plain wheat flour, 250ml whole milk (for samples with no MCA) and 150 ml whole milk for samples with MCA solutions, 100g sugar, 90 ml vegetable oil, 1 egg, 1 teaspoon salt and 1 teaspoon sodium bicarbonate or 5 g in100 ml water to make the MCA solution. The oven was preheated, moist ingredients were whisked together then mixed well with sifted dry ingredients. The batter was baked in greased, floured baking tins for 45 minutes till skewer came out clean.

Sensory evaluation of corn bread with MCA solutions

Sensory evaluation was done using a 9-point hedonic with 50 untrained panelists between the ages 19- 25 years. The panelists were requested to assess 12 indigenous cornbread samples prepared using MCA solutions. A 9-point hedonic scale was designed to assess the level of preference of the samples with evaluations based on colour, texture, flavor, mouthfeel and overall acceptability. The narratives on the scale were scored from 1 to 9 with 1 being dislike extremely and 9 being like extremely. The samples were placed in a disposable paper plate coded with randomly generated 3- digit numbers. Serving order across the panelist was randomized using a balanced Latin square. Evaluations were done in individual booths under standard white light. Panelists were provided with distilled water to rinse their mouths during the testing process. Ethical clearance was sought from the Department of Food Science and Nutrition at Midlands State University and the ethical clearance number was FSNutri001/03/2024.

All experiments were done in triplicate and data was subjected to full factorial ANOVA to evaluate main effects (maize variety, water type, concentration) and their interactions at $p \leq 0.05$ followed by Duncan Multiple Range Test (DMRT) for mean separation. Data for all parameters were presented as mean ± standard deviation.

**Results and Discussion**

All samples that were extracted in borehole water had a significantly lower pH ($p \leq 0.05$) as compared to those that were extracted in distilled water (Table 1). Generally, the yellow variety maize cob ash had a higher pH ranging from 11.33 to 11.50, than the white variety maize cob ash which ranged from 10.00 to 11.48. Furthermore, an increase in the concentration of maize cob ash in the solutions resulted in a corresponding increase in pH. pH of a solution measures the degree of acidity or alkalinity of a solution (OECD, 2013; Ahmad et al., 2024). The increase in the pH observed in MCA samples extracted using borehole water (Table 2) could be attributed to the salts already present in the water. Borehole water is usually associated with the presence of carbonates and bicarbonates of alkaline earth metals (Rees, 2006). The increase in pH after addition of a higher concentration of corn cob ash is attributable to more dissolved solutes from the ash. The yellow maize MCAs had a higher pH and this could be due to more minerals which make the pH higher than the white corn cob ash sample. Yellow MCAs have a higher pH than that from white cobs (Ogunjobi and Ladije 2013). The pH differences observed between maize varieties and water types can be explained by the solubility of alkaline species in the ash and the buffering chemistry of the water.

There was no significant ($p > 0.05$) difference in titratable alkalinity, expressed as NaHCO3 equivalent, between white and yellow maize cob ash extracted at 1% using distilled water and borehole water, or at 5% for white maize ash and 10% for yellow maize ash. As compared to white maize cob ash at 5%, the yellow maize cob ash had a significantly ($p \leq 0.05$) higher alkalinity expressed as $NaHCO_3$ equivalent concentration. Furthermore, at the same concentration (5%), borehole water had a higher titratable alkalinity than distilled water for the yellow maize cob ash. At 10% concentration, generally, $NaHCO_3$ was higher compared to 1% and 5% for both varieties. With respect to maize cob ash at 10%, borehole water had a significantly ($p \leq 0.05$) higher $NaHCO_3$ concentration compared to distilled water. However, there was no significant difference ($p > 0.05$) in titratable alkalinity (at 10%) for the yellow maize cob ash for both distilled and borehole water. The more the corncob ash dissolved in solution the more the concentration of sodium hydrogen carbonate in solution. The higher concentration of sodium carbonate is also related to a higher pH value that was found in the yellow maize corn cob ash varieties. A higher pH in cornbread batter promotes the production of carbon dioxide leading to rising of the dough, which is important for bread volume. In addition, high pH weakens gluten network in cornbread batter resulting in a more tender and less chewy texture (Hu et al., 2023). Alkaline conditions also favour maillard reaction, leading to a more intense browning and a richer, more complex flavour cornbread (Hu et al., 2023; Mzoughi et al., 2024).

There was a significant ($p \leq 0.05$) difference in the conductivity of the white and yellow maize cob ash for both borehole and distilled water at 1%. At 1% and 5% concentrations, conductivity differed significantly ($p \leq 0.05$) between white and yellow maize cob ash. Furthermore, maize cob ash extracted in borehole water had a higher conductivity than that in distilled water for both varieties at 1% and 5%. With the exception of white maize cob ash extracted using distilled water at 10%, there was no significant ($p > 0.05$) difference in the conductivity of the white and yellow maize varieties.

Conductivity is the ability of an aqueous solution to carry an electric current, and it is influenced by factors such as the presence of sodium chloride and potassium chloride (Al Dahaan et al., 2016). These chemicals dissociate in water to produce an electric current by producing ions in solution. Conductivity decreased with an increase in the concentration of the MCAs, (Table 2). The relationship between conductivity and TDS is not directly linear but depends on the activity of specific dissolved ions, average activity of all ions in the liquid, and ionic strength (Rusydi, 2018). Distilled water does not conduct electricity as it does not contain any dissolved salts, which also explains the results that show how there was a difference in TDS of varying concentrations of MCAs made with distilled water and MCAs made with borehole water (Agrahari et al., 2021). The difference could be attributed to the combined effect of ions in borehole water, together with those ions that are already present in the maize cob ash. Conductivity is important and has recently gained increasing interest in the food industry as it has an impact on the quality of end products. In bread making, for example, dough expansion depends on temperature, therefore, good electrical conductivity of the dough ingredients, including the leavening agent can facilitate uniform heating, potentially shortening proofing time.

Table 2. Physical and chemical characteristics of different concentrations of white and yellow maize cob ash dissolved in distilled and borehole water.

| Maize cob ash sample | Ph | $NaHCO_3$ conc./100 $cm^3$ | Conductivity (µs/cm) | Total Dissolve Solids (ppm) | Specific Gravity $g/cm^3$ | Turbidity (ntu) |
|---|---|---|---|---|---|---|
| WD 1% | 11.20± 0.00$^{f}$ | 0.20 ± 0.28$^{a}$ | 7286.00± 0.00$^{e}$ | 3564.30± 2.31$^{a}$ | 1.080± 0.50$^{j}$ | 8.49± 0.13$^{cd}$ |
| WB 1% | 9.90 ± 0.20$^{a}$ | 0.65 ± 0.07$^{ab}$ | 7502.00± 0.00$^{g}$ | 3642.00± 1.73$^{b}$ | 0.967± 1.00$^{a}$ | 9.30± 0.10$^{d}$ |
| YD 1% | 11.33± 0.05$^{g}$ | 0.50 ± 0.14$^{ab}$ | 7550.67± 1.15$^{h}$ | 3771.67± 5.77$^{d}$ | 1.037± 0.15$^{i}$ | 8.34± 0.05$^{bc}$ |
| YB 1% | 10.43± 0.05$^{b}$ | 0.70 ± 0.14$^{ab}$ | 7344.00± 0.00$^{f}$ | 3669.30± 4.62$^{c}$ | 0.983± 1.09$^{b}$ | 3.69 ± 0.63$^{a}$ |
| WD 5% | 11.30± 0.08$^{g}$ | 1.50± 0.14$^{abc}$ | 4410.00± 0.00$^{c}$ | 7204.30± 1.15$^{g}$ | 0.992± 1.11$^{c}$ | 14.23± 0.69$^{fg}$ |
| WB 5% | 10.66± 0.25$^{c}$ | 1.00± 0.28$^{abc}$ | 4702.00± 0.00$^{d}$ | 7351.00± 0.00$^{h}$ | 1.016± 0.72$^{e}$ | 13.70± 0.17$^{f}$ |
| YD 5% | 11.40± 0.00$^{g}$ | 2.05± 0.35$^{abcd}$ | 4185.30± 4.62$^{b}$ | 7094.00± 0.00$^{f}$ | 1.002± 1.00$^{d}$ | 7.50± 0.05$^{b}$ |
| YB 5% | 11.05± 0.10$^{d}$ | 2.70± 0.14$^{abcd}$ | 4702.67± 1.15$^{d}$ | 7067.00± 0.00$^{e}$ | 0.982± 2.08$^{b}$ | 8.07± 1.09$^{bc}$ |
| WD 10% | 11.48± 0.05$^{h}$ | 3.15± 0.07$^{abcde}$ | 3960.00± 0.00$^{a}$ | 7094.30± 0.57$^{f}$ | 1.037± 0.54$^{i}$ | 12.40± 0.90$^{e}$ |
| WB 10% | 11.10± 0.00$^{e}$ | 3.35± 0.21$^{bcd}$ | 4410.00± 0.00$^{c}$ | 7205.00± 0.00$^{g}$ | 1.029± 1.06$^{h}$ | 15.30± 0.36$^{h}$ |
| YD 10% | 11.50± 0.00$^{h}$ | 4.60 ± 0.28$^{d}$ | 4410.67± 1.15$^{c}$ | 7205.00± 0.00$^{g}$ | 1.022± 0.65$^{f}$ | 13.76± 0.32$^{f}$ |
| YB 10% | 11.23± 0.05$^{f}$ | 4.85 ± 0.35$^{d}$ | 4410.00± 0.00$^{c}$ | 7205.00± 0.00$^{g}$ | 1.027± 0.41$^{g}$ | 4.26± 0.18$^{fg}$ |

1. Data presented as mean ± standard deviation (n = 3). The different superscript letters in the same column indicate values that are significantly different ($p \leq 0.05$).
2. WD-White variety Distilled water; WB- White variety Borehole; YD- Yellow variety Distilled water; YB- Yellow variety Borehole water

There was a significant ($p \leq 0.05$) difference in total dissolved solids (TDS) of the white and yellow maize cob ash solutions at both 1% and 5%. However, TDS for 5% solutions were higher as compared to that at 1% for both varieties. Generally, there were no significant ($p > 0.05$) differences in TDS of both varieties at 10% with the exception of white maize cob ash extracted in distilled water. Generally, specific gravity was lower for solutions in borehole water as compared to distilled water for both varieties with the exception of white maize ash at 5% and yellow maize ash at 10%. Turbidity was generally higher in the solutions in borehole water, with the exception of yellow maize cob ash at 1% as well as white maize cob ash at 5%. Total dissolved solids (TDS) is a measure of inorganic and organic solutes present in a solution (Oyem et al., 2014). It is a combination of cations and anions present in water, such as bicarbonate, carbonate, sulphate, phosphate, magnesium, nitrate, calcium, organic ions and other ions. Suspended solids may have been present in the solution and may have led to higher TDS values of MCAs. This explains the results of this study where it is evident that conductivity decreased with an increase in the concentration of the MCAs. TDS contributes to conductivity, which is also influenced by a number of other factors such as the temperature and pH of the solution, valence of the dissolved ions, carbonate compounds and the degree of ionization (Rebello et al., 2020). Suspended solids may be present in the solution and may lead to higher TDS values and do not affect conductivity. TDS, particularly from salts and minerals, can influence water absorbed by dry ingredients during backing and higher TDS can lead to a drier dough, while lower TDS can result in a wetter, stickier dough (Abera et al., 2017; Prameswari et al., 2018). In wheat flour-based doughs, TDS can affect the gluten network, while in cornbread, which often uses cornmeal, the impact of TDS on the gluten network is less significant, although it can still influence the way the starch granules hydrate and swell. Further, TDS determines water absorption and consequently bread texture and crumb structure (Abera et al., 2017; Prameswari et al., 2018). . Specific gravity from the study ranged from 1.000 to 2.100, which is a lower value than other values from literature. Olufusi et al., (2018) reported that the specific gravity of MCA in their study was 3.49. The difference could be due to the state of the samples during analysis. Specific gravity is a dimensionless ratio of the density of a reference substance typically water. For a solution, the specific gravity is influenced by the concentration of dissolved solids and the density of the solvent. For a dry powder, the specific gravity is typically determined using a pycnometer and reflects the true density of solid particles, including ant internal porosity.

The FTIR spectra for the white maize cob ash and the yellow maize cob ash appeared similar but differed in respect of the band intensities and the precise frequencies at which the highest absorption was generated (Figure 1 and 2). For the maize cob ash, the main functional groups and respective regions of absorption identified were axial deformation of the O-H group in white maize cob ash (3450 $cm^{1}$) and yellow maize cob ash (3440 $cm^{1}$) which are associated with the functional groups of phenols, alcohols and carboxylic acids. Also, there was C=C stretching of aromatic groups in white maize cob ash (1660.64 $cm^{1}$) and yellow maize cob ash (1659.58 $cm^{1}$).

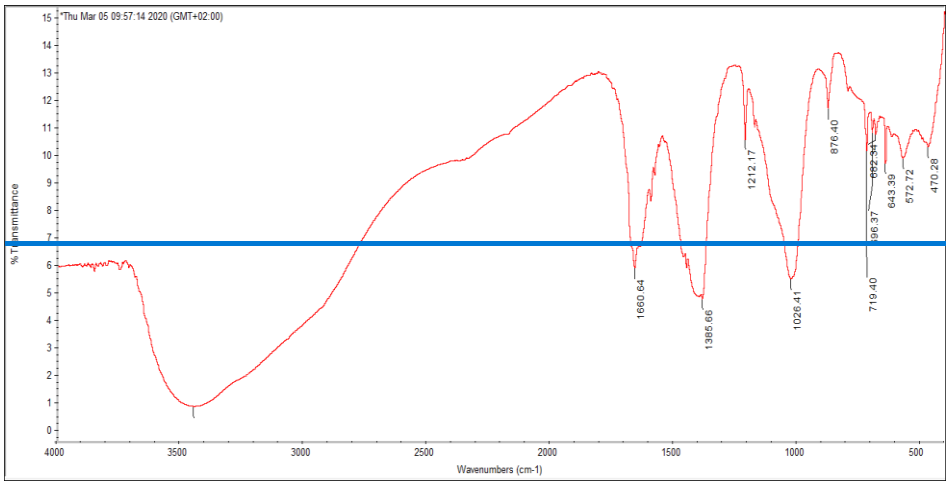



Figure 1. FTIR absorption spectrum of the white variety maize cob ash

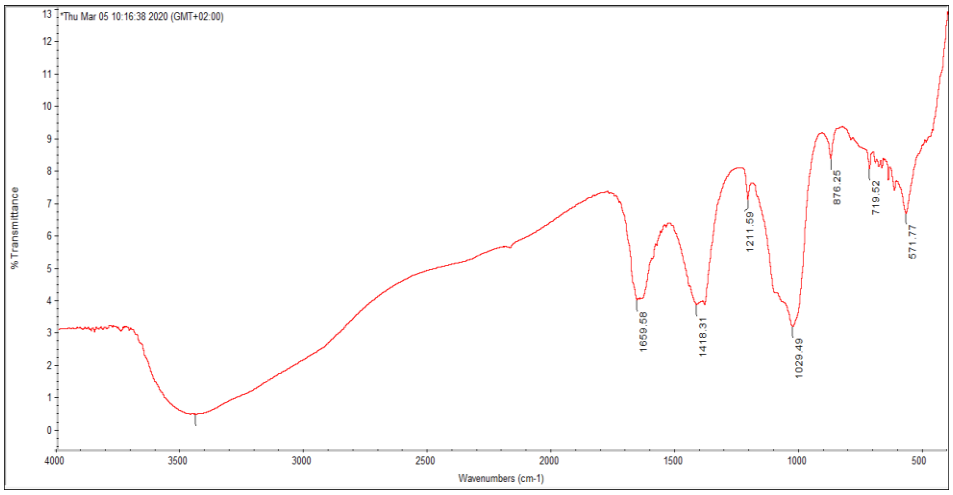



Figure 2. FTIR absorption spectrum of the yellow variety maize cob ash.

The results from the FTIR indicated the presence of –OH (hydroxyl), -C=O (carbonyl), -CH (aromatic compound, alkanes) and –CO (carboxyl) in both the white and yellow varieties MCA ( Fig 1 and fig 2). These results are similar to those obtained by Maepa et al., (2015) in their study on FTIR characterisation of maize tassels and those obtained by Anukam et al., (2017) in their analysis of the corn cob structure. The functional groups noted can also be found within the molecular structure of bicarbonate of soda except for the –CH group.

Table 3. Mineral concentration of maize cob ash (MCA) from white and yellow maize varieties.

| Sample | Minerals (ppm) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mg | Al | Mn | Cr | Co | Ni | Cu | As | Hg | Fe | Zn | Pb |
| White MCA | 127.80 ±2.80$^{a}$ | 6876.83 ±3.05$^{b}$ | 62.50 ±0.50$^{a}$ | 9.67 ±2.52$^{a}$ | 3.33 ±0.29$^{b}$ | 12.50 ±0.20$^{b}$ | 110.70 ±3.40$^{b}$ | 4.10 ±0.10$^{b}$ | 0.10 ±0.00$^{a}$ | 16448.10 ±3.11$^{b}$ | 0.63 ±0.06$^{a}$ | 1.20 ±0.10$^{b}$ |
| Yellow MCA | 9289.03 ±9.86$^{b}$ | 930.23 ±0.25$^{a}$ | 179.63 ±0.31$^{b}$ | 7.43 ±0.45$^{a}$ | 0.70 ±0.00$^{a}$ | 2.00 ±0.00$^{a}$ | 44.93 ±0.12$^{a}$ | 0.30 ±0.00$^{a}$ | 0.67 ±0.31$^{a}$ | 1427.53 ±0.46$^{a}$ | 935.00 ±0.95$^{b}$ | 0.97 ±0.15$^{b}$ |

Data presented as mean ± standard deviation (n = 3). The different superscript letters in the same column indicate values that are significantly different ($p \leq 0.05$).

The white variety maize cob ash had higher concentrations of minerals than the yellow maize cob ash with respect to aluminium (6877.5 ppm), iron (18448.8 ppm), copper (110.7 ppm), nickel (12.5 ppm) as indicated in Table 3. The yellow maize cob ash was higher in magnesium (9289.4 ppm), manganese (179.7 ppm), zinc (935.1 ppm). There was however, no significant ($p > 0.05$) difference in chromium, mercury and nickel. This current study obtained similar results in both varieties of the MCA, i.e, Ca, Mg, Fe, Mn and Al. Additionally, Ni, Cu, Pb, Co, Hg, As, Zn and Cr were also determined. Previous studies on MCA found the presence of Si, Al, Na, Mg, Fe, Mn, Ca, Cl as well as K and further determined the potential use of MCA as a supplementary pozzolanic material (Kamau et al., 2016; Yao et al; 2019; Olafusi et al., 2018). White MCA powder contains measurable levels of trace elements such as aluminium and lead, the actual dietary exposure is determined by the solubility of these elements in filtered ash solution and the quantity incorporated into the recipe. Insoluble heavy metals are usually retained on the filter paper during filtration at household level. In this

study, MCA was used as a traditional food additive that is as an alkaline reagent and an acid regulator. The FAO/WHO JECFA (2011) specifies that the permissible limit for lead limit is less than 2 mg/kg and for arsenic, a limit less than 3 mg/kg. The health based guidelines for contaminants established by the JECFA for the dietary exposure assessment from consumption of final food containing the additive shows that the levels of lead are safe and those of arsenic are above the specified limit. While a 4 µg/kg body weight/week for mercury refer to general contaminant limits, they also apply for food additives. Estimated daily intake of such elements is below the WHO/ FAO JECFA provisional tolerable weekly intake. However, higher concentration extracts such as 10% solution of MCA requires caution due to cumulative trace elements exposure. The users may need to ensure routine filtration and decanting of the solutions to minimize particulate intake. It should be noted that for various elements if they are used as active ingredients in the dough they should be 96% to 99% pure. The daily limit for lead has been set at 1 mg/kg and arsenic at 3 mg/kg, these should be kept at minimum since bread is consumed on a daily basis in most households.

Table 4 shows that the weight of the cornbread samples ranged from 338.33 g (BY 10%) to 368.67 g (negative control) Table 4. The volume of the cornbread ranged from 487.33 $cm^3$ (negative control) to 649.66 $cm^3$ (BY 1%). Cornbread produced using yellow maize cob ash at 1% as a leavening agent had the highest volume among the samples. Despite having the same weight of flour for all the samples, the volume of the dough differed owing to the amount of air incorporated in each sample, which was done mechanically, hence could not be controlled. The specific gravity of the MCAs consequently affects the specific gravity of the batter and as a result, it influences the viscosity of the batter and this influence the quality of the end product. If the specific gravity is too high, it results in inadequate volume of air cells as well as low batter viscosity, which leads to a reduction in volume the product (Alahmed et al., 2025). This is like the samples for the sensory which were observed to have poor volume and a dense texture, as was reported in the results. If the specific gravity is too low, the end products will be fragile, exhibiting some tunneling and a crumbly crust due to too much air and a high batter viscosity (Zhou et al., 2011).

There was no significant ($p > 0.05$) difference in bread volume with leavening agent of white maize ash in borehole water at 1% and that produce with the positive control (sodium bicarbonate soda). The similarity in bread volume may be attributable to the solution providing sufficient titratable alkalinity to support carbon dioxide production at a level comparable to the control. However because the present study measured titratable alkalinity expressed as NaHCO3 equivalent rather than actual concentration, a direct equivalence between the two was not established. The comparable leavening performance therefore suggests functional similarity but the underlying alkaline species and their concentrations may differ. Specific volume of the cornbread ranged from 1.32 $cm^3$ to 1.83 $cm^3$. Bread with yellow maize cob ash in borehole water at 1% had a significantly ($p \leq 0.05$) higher specific volume compared to the other samples. In contrast, as expected, the negative control had the lowest specific volume amongst the samples. White maize cob ash in borehole water at 1% (1.65 $cm^3$) had a similar bread volume with the positive control (1.65 $cm^3$). There was no significant difference ($p > 0.05$) in bread volume between the leavening agent of white maize ash in borehole water at 1% and the positive control (sodium bicarbonate soda). This may be because the sodium hydrogen carbonate concentration in the 1% sample was similar to that in the positive control. Specific volume of the cornbread ranged from 1.32 $cm^3$ to 1.83 $cm^3$. Bread with yellow maize cob ash in borehole water at 1% had a significantly ($p \leq 0.05$) higher specific volume compared to the other samples. This may be due to sodium hydrogen carbonate reaching its maximum effective concentration. The observed performance of the MCAs is attributable to the quantity of the base present as it is directly related to the amount of $CO_2$ that will be released during the baking process. However, in order for $NaHCO_3$ to be fully effective in the release of $CO_2$, an acid should be present but since no acid was added to any of the samples the cornbread was not well risen (Babincakova 2020). The produced CO2 is responsible for leavening dough so as to achieve desirable volume (Neeharika et al., 2020; Srivastava et al., 2023). Other factors, such as the balance of alkaline species, ash particle size, or interactions with batter components, may also have contributed to the higher specific volume.

Figure 3 presents the sensory evaluation of cornbread produced using maize cob ash as a leavening agent, as well as the positive and negative controls. The results are based on a 9-point hedonic scale to measure sensory attributes of the corn bread like colour, taste, texture, aroma, appearance, and overall acceptability of product. The ratings for the crust colour ranged from 4.66 to 6.34, with the negative control having the lowest ranking whilst the cornbread made using BY 5% had the highest rating. Although YB 5% had the highest rating for colour, they were no significant ($p > 0.05$) difference with the positive control, YB 10%, WB 10%, YD 10%, WB 5%, YB 5%, WB 1%, YD 1% and YD 1%. There was no significant ($p > 0.05$) difference in the texture of the cornbread with the exception of the negative control, positive control, WD 10%, WB 5%, YB and YD 5%. YB 5% had the highest preference in texture with the negative control having the least. With respect to flavour, YB 10% had the highest preference with the negative control having the least preference. All the samples containing maize cob ash had a higher preference than the positive and negative controls. The mouth-feel of the samples ranged from 4.07 to 6.79. YB 10% had the highest preference amongst the sensory panellists. Both the negative and the positive controls were rated the lower than the samples containing maize cob ash. With regards to overall acceptability, there was no significant ($p > 0.05$) difference in YB 10%, YD 5% and WB 5% samples. Overall acceptability for the controls was rated much lower than the maize cob ash samples with scores of 4.41 and 4.31, respectively. There was no significant ($p > 0.05$) difference in cornbread samples made using maize cob ash at 1%.

Table 4. Weight, volume and specific volume of cornbread prepared using different concentrations of maize cob ash dissolved in distilled and borehole water as a leavening agent, including the positive and negative controls.

| Sample | Sample Description | Weight (g) | Volume ($cm^3$) | Specific Volume ($cm^3$) |
|---|---|---|---|---|
| 1 | WD 1% | 350.00±2.00$^{c}$ | 521.67±2.89$^{de}$ | 1.49±0.01$^{cd}$ |
| 2 | WB 1% | 357.00±2.08$^{de}$ | 591.33±3.21$^{h}$ | 1.65±0.02$^{f}$ |
| 3 | YD 1% | 365.33±1.73$^{hi}$ | 531.33±1.53$^{f}$ | 1.45±0.04$^{bc}$ |
| 4 | YB 1% | 354.67±1.53$^{d}$ | 649.66±2.51$^{j}$ | 1.83±0.01$^{h}$ |
| 5 | WD 5% | 344.00±1.00$^{b}$ | 511.67±2.89$^{bc}$ | 1.49±0.02$^{cd}$ |
| 6 | WB 5% | 367.66±0.58$^{ij}$ | 489.33±3.06$^{a}$ | 1.33±0.02$^{a}$ |
| 7 | YD 5% | 365.00±1.00$^{hi}$ | 635.00±5.00$^{i}$ | 1.74±0.02$^{g}$ |
| 8 | YB 5% | 351.67±2.52$^{c}$ | 510.33±1.53$^{bc}$ | 1.45±0.02$^{bc}$ |
| 9 | WD 10% | 360.67±2.08$^{fg}$ | 510.00±1.00$^{bc}$ | 1.41±0.02$^{b}$ |
| 10 | WB 10% | 362.33±2.08$^{gh}$ | 516.67±5.77$^{cd}$ | 1.43±0.02$^{b}$ |
| 11 | YD 10% | 350.00±1.00$^{c}$ | 543.33±2.89$^{g}$ | 1.55±0.02$^{e}$ |
| 12 | YB 10% | 338.33±1.54$^{a}$ | 526.67±5.77$^{ef}$ | 1.56±0.02$^{e}$ |
| 13 | Positive | 358.00±1.00$^{ef}$ | 590.00±5.00$^{h}$ | 1.65±0.02$^{f}$ |
| 14 | Negative | 368.67±0.58$^{j}$ | 487.33±3.78$^{a}$ | 1.32±0.08$^{a}$ |

1. Data presented as mean ± standard deviation (n = 3) The different superscript letters in the same column indicate values that are significantly different ($p \leq 0.05$).
2. WD-White variety Distilled water; WB- White variety Borehole; YD- Yellow variety Distilled water; YB- Yellow variety Borehole water

In PCA, the first 2 PCs were extracted which explained over 95% (PC1 = 84.7%, PC2 = 10.4%) of the total variance in the sensory parameters assessed. Figure 4 shows the scores biplot for PC1 versus PC2. The samples without maize cob ash were extended to the left side of the biplot with positive control on upper left and negative control on the lower left. With the exception of YD 10%, WD 10% and WB 1%, the maize cob ash samples were on the right side of the biplot. The samples with maize cob ash were nearer to the sensory parameters (colour, texture, mouthfeel and overall acceptability) evaluated in the study. Maize cob ash samples YB 5%, YD 5%, WD 1%, YD 1% were located on the upper right side nearer to sensory parameters colour and texture. The other maize cob ash samples YB 1%, WD 5%, WD 5%, WB 1% and YB 10% were located in the lower right side of the biplot nearer to flavour, mouthfeel and overall acceptability. Of note, is the YB 10% which was nearest to flavour and mouthfeel. Overall, the biplot indicates that the samples which were leavened with maize cob ash were flavourful and had a good mouthfeel which influenced overall acceptability rating by the panellist. Sodium carbonate, which is produced in the breakdown of bicarbonate of soda, often produces an unpleasant soapy taste and also affects the texture and color of the crumb (Neeharika et al., 2020). This phenomenon was observed in the sample made with the positive control, which was rated very low in the taste attribute. The rest of the samples did not have the unpleasant soapy taste.

MCA samples which had a high TDS concentration, did not brown favorably as compared to the positive control. Samples that had a high TDS did not give favourable sensory results. The Maillard reaction, which is promoted by a basic environment resulting from a high pH, contributes to the development of color and flavor compounds of baked products (Qi et al., 2025). TDS has a direct relation to the hardness of water which affects the function of gluten in the flour as a result there is a hindrance to the Maillard reactions (Qi et al., 2025). The results of the sensory analysis showed that the flavor and crumb color of the cornbread made with MCAs, which had pH higher than bicarbonate of soda, was rated higher than that of the controls. The functional aspects that are affected by the pH of the dough include physical state of gluten where pH has an effect on viscosity build up as well as gluten degree of dissolution. pH of the dough also has an effect on the overall keeping quality and safety of the final product. When bicarbonate of soda in the MCA solution is heated, it releases the carbon dioxide gas which is needed for the dough development. In acidic conditions, it can release twice as much gas as under alkaline conditions. At times, it may be necessary to add natural acid ingredients to the dough to improve the hydrogen ions, which helps in creating acid conditions. Some ingredients that may be added to the dough to lower the pH include honey, molasses, cocoa and ginger (Nachay and Malochleb, 2019). An excess amount of bicarbonate of soda usually leads to a white crumb structure in the bread. It also causes a yellowish- brown color and a strong undesirable smell in the baked product. If a batter or dough is made too alkaline, with the addition of excess sodium hydrogen carbonate, it forms soapy flavor, a spot brown color and yellowing of flavonoid pigments in the dough as explained by Neeharika et al., (2020). A dough that is too acidic will lead to whitening of the structure of the baked product. It is important in baking using MCA to ensure that the amount added does not lead to undesirable characteristics.

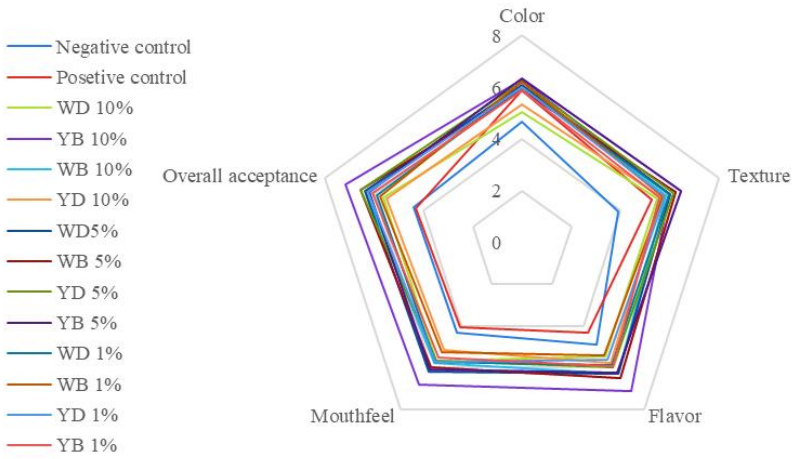



Figure 3. Sensory evaluation for cornbread prepared using different concentration of white and yellow maize cob ash dissolved in distilled water and borehole water as a leavening agent, including the negative and positive controls. (WD-White variety Distilled water; WB- White variety Borehole; YD- Yellow variety Distilled water; YB- Yellow variety Borehole water).

Appearance is one of the sensory attributes that gives first impression regarding the consumer and color plays a crucial role in determining the overall quality of a baked product (Olakanmi et al., 2023). Acidic conditions are important in baking because the Maillard reaction, which is the reaction that leads to browning of baked products requires sugars that are produced from the hydrolysis of starch in the flour under acidic conditions. Starch breaks down under acidic conditions to give simple sugars, which react with proteins in the dough to give the golden color of the baked product. Some of the samples that had an undesirable characteristic off flavor could have been caused by too alkaline conditions.

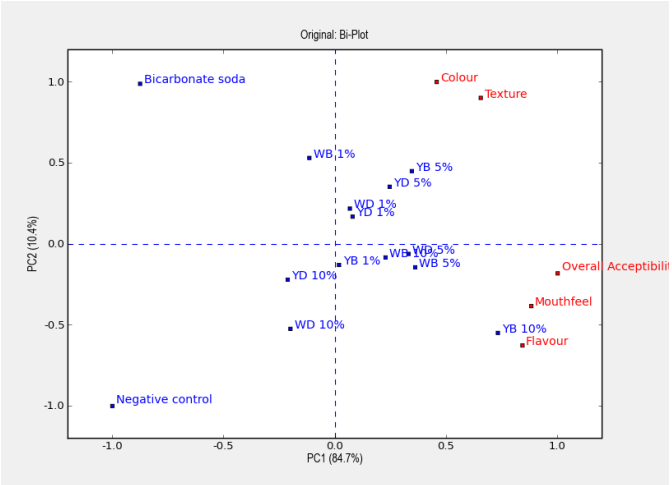



Figure 4: PCA Biplot for first two principal component scores for sensory evaluation of cornbread prepared using white and yellow maize cob ash dissolved in distilled water and borehole water as a leavening agent, including the negative and positive (bicarbonate soda) controls. WD-White variety Distilled water; WB- White variety Borehole; YD- Yellow variety Distilled water; YB-Yellow variety Borehole water.

## Conclusions

This study demonstrated that both white and yellow maize cob ashes possess alkaline properties and functional characteristics that make them suitable for application as leavening agents in cornbread preparation. The chemical and physicochemical analyses showed that MCA solutions, particularly those made with yellow maize ash in borehole water at 1%, achieved pH values and sodium bicarbonate concentrations comparable to commercial baking soda. Although the concentrations used in this study may be too low for full leavening potential on their own, they produced breads with acceptable specific volume and favourable sensory properties, especially in flavour and mouthfeel. Furthermore, the presence of beneficial minerals and functional groups confirms the potential of maize cob ash as a multi-functional food additive. While most minerals were below the expected FAO/WHO JCEFA level, consumers should be cautious with higher MCA as it expose them to higher intake levels of heavy metals. Importantly, MCA-based cornbread was preferred over sodium bicarbonate-leavened bread in several sensory attributes, highlighting its promise as a culturally appropriate and sustainable alternative. Given the wide availability of maize cobs and the traditional knowledge surrounding their use, this study supports the valorisation of maize cob ash as a low-cost, locally relevant innovation in food systems. Future research should focus on refining dosage levels, assessing food safety, and exploring the fortification potential of MCA in traditional and commercial food products.

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