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HEAT-MOISTURE TREATMENT IMPROVES NUTRITIONAL QUALITY, STARCH CHARACTERISTICS, ANTIOXIDANT ACTIVITIES OF WHOLE MAIZE FLOUR AND SENSORY ATTRIBUTES OF ITS DOUGH MEAL

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Abstract

Heat moisture treatment (HMT) is a hydrothermal modification technique that can influence the nutritional and functional properties of cereal flours. This study evaluated the impact of varying (HMT) conditions on digestibility, chemical composition of whole maize flour, and sensory attributes of its dough meal. Maize grains were subjected to HMT in a water bath at two temperatures (80 and 100 °C) and two durations (30 and 60 min). Following treatment, the grains were dried, milled, and analyzed for proximate, minerals, starch digestibility, glycemic index, enzyme inhibition, antioxidant activities and sensory properties according to standard procedures. HMT increased dietary fibre (7.11% to 6.73%) and protein (6.93% to 12.93%) contents with longer treatment time, irrespective of the temperature examined. Treated samples had lower total starch (50.95% to 62.51%) than the control (63.32%), which increased with increase in treatment time, but decreased with higher temperature. Amylose and slowly digestible starch followed similar trends. Resistance starch content decreased (20.18% to 24.33%) compared to the control (31.81%), but increased at higher temperatures. HMT for 60 min exhibited higher α-glucosidase inhibition, and glycemic index values ranged from 42.85% to 48.25%. Flavonoids and carotenoids contents increased. Sensory evaluation indicated moderate consumer acceptance of dough meals prepared from HMT-treated flour. HMT for up to 60 min and 100°C enhanced starch and nutritional properties of whole maize flour while maintaining acceptable sensory quality of the dough meal. This modification suggest that HMT has potential for enhancing quality of dough meal products from maize.

Keywords: α-glucosidase, α-amylase, carotenoids, glycemic index, proximate, resistant starch

Introduction

Maize is a cereal grain which ranked next as a staple food to wheat and rice. It is cultivated for human consumption, livestock feed and fuel following several processing techniques. Maize grain is made up of the bran, pericarp, germ and endosperm. The bran is made up of the tip cap and pericarp (fiber-rich outerlayer) which contains B vitamins and minerals. The germ is high in fat and also contain vitamins from B complex and vitamin E (Gwirtz and Garcia-Casal, 2013). The pericarp is a semipermeable membrane surrounding the germ and the endosperm. The endosperm is primarily starch surrounded by a protein matrix (Gwirtz and Garcia-Casal, 2013). The starch as a primary component of cereals, like maize, provides the metabolic energy needed to support daily human activities (Chen *et al*, 2017). Starch granules comprises of two components which are amylose and amylopectin. The starch content of maize contains 20-25% amylose and 70-75% amylopectin (Putri *et al*, 2022). Certain researches indicated that the nutritional and physiological properties of starch-rich food, including its digestion rate and absorption speed, have a major impact on human health and are linked to various health issues, such as diabetes and cardiovascular diseases (Chen *et al*, 2017). Starch is also classified into three, based on the rate of digestion or hydrolysis; rapidly digestible starch (RDS) is the fraction of starch that hydrolyzes or digest rapidly within 20 minutes; slowly digestible starch (SDS) is the fraction of starch that digest at a slow rate in the digestive system particularly small intestine within 20 to 120 minutes after ingestion; and resistant starch (RS) is the fraction of starch which is not digestible by the digestive enzymes, therefore is passed to the colon for microbial fermentation (Cheng *et al*, 2024). RDS leads to increase in blood glucose level while SDS and RS reduce the conversion of starch to glucose. Therefore, consumption of food products that contain more RS leads to lower glycemic and insulin response which provides health benefits to consumers (Cheng *et al*, 2024). Starch digestibility is affected by different factors such as amylose/amylopectin ratio which impacts the rate and extent of digestibility as amylopectin digest rapidly while amylose digest slowly. Also, the digestibility of starch is modified due to the molecular structure of starch with other molecules such as proteins and lipids (Chisbert *et al*, 2024). It may also be influenced by cooking conditions which include water content, temperature and pressure (Chisbert *et al*, 2024).

Heat-Moisture treatment (HMT) is a hydrothermal or physical method used for the modification of starch due to its low cost and nontoxic effect as it doesn't involve the use of chemicals (Schafranski *et al*, 2021). It involves heat-treating starch at a low moisture content of 10-30%, and a high temperature above the glass transition temperature but below the gelatinization temperature, usually between 80-120°C, for a specific period of time 15mins – 16hrs (Fang 2022; Yang *et al.*, 2022). HMT is an effective method which alters the properties of starch through the disruption of crystalline structure, disassociation of double helix structures and reassociation of disrupted crystals. This leads to increasing or strengthening of the interactions between amylose and amylopectin structure (Fonseca *et al*, 2021). The impact of HMT on the components of starch-rich food is complex and depends on various factors such as moisture content, starch composition especially the amylose levels, heating time and temperature range. Increasing HMT temperature and time can lead to both increase and decrease in amylose content, depending on the moisture content and initial amylose level (Yang *et al.*, 2020). High temperatures typically 120-130°C, can lead to increased resistance starch content, due to enhanced molecular interactions within starch granules (Faridah *et al.*, 2021) while low temperature is reported to increase amylose content in rice endosperm (Ahmed *et al.*, 2008). Extended treatment time has been reported to lead to increased crystallinity and gelatinization temperatures while reducing the swelling power and solubility (Pepe *et al.*, 2015). Prolonged heating at high moisture levels (>30%) can decrease the amylose content due to gelatinization and structural changes in the starch (Yang *et al.*, 2020). HMT can reduce digestibility of starch which may be beneficial for developing low glycemic index food products suitable for individual with diabetes (Chakraborty *et al.*, 2021). HMT process increased pasting temperature, and reduced swelling power and gelatinization enthalpy of starch. In millet starch, HMT was reported to decrease crystallinity significantly and change pasting profiles and molecular weight indicating alterations in the structural and molecular properties of the starch (Zheng *et al.*, 2020). HMT affected granule surface, increased moisture and heat levels, and altered amylose content of potato starch (Bartz *et al.*, 2017). Generally, HMT modifies physical, chemical, structural and functional properties of starch. This modification may be tailored toward developing certain food products for specific purposes for health and food industry applications. Due to complex interaction between HMT conditions and composition of starch containing food, study on the influence of HMT on properties of whole maize is essential. Understanding this interaction is crucial to develop maize flour or meal with low glycemic index and modifying the functionality of the maize product for various purposes, thereby impacting better health benefit on its consumer. This study aimed to evaluate the effects of varying heat-moisture treatment (HMT) conditions on the nutritional composition, starch digestibility, antioxidant properties, and sensory attributes of whole maize flour and its dough meal, with the goal of improving its functional quality and consumer acceptability.

Materials and Methods

Materials

Healthy dried maize was purchased from Okitipupa market, Okitipupa, Ondo state, Nigeria. The maize was sorted to remove inedible portions and foreign materials, then maize flour was prepared using a milling equipment.

Heat moisture treatment (HMT) of whole maize grains

The HMT of whole maize grains for each sample was conducted by adjusting the moisture level of 500g of maize grains with 25% of moisture (125 ml of water) and equilibrating it for 24 h. Thereafter, the grains were heat treated using water bath at two different temperatures (80°C and 100°C) for two different duration (30 and 60 minutes) to obtain four HMT samples. After HMT, the maize grains were dried in a dehydrator at 50°C for 6 h. After cooling, the grains were milled with a milling machine to obtain HMT-modified whole maize flour and was labelled appropriately. Whole maize grains milled into flour after sorting and cleaning was used as control. All analyses were conducted in triplicate, ensuring sufficient statistical reliability based on previous studies.

Determination of proximate composition of whole maize flour obtained by HMT of grains

Moisture content, total ash, crude protein, crude fat, crude fibre and carbohydrate were determined using the procedure of AOAC (2005). The moisture content was determined by using the oven drying method. The ash content was determined by dry ashing at 550^0C in a muffle furnace. The crude protein content was determined by using the Kjeldahl method with a nitrogen conversion factor of 6.25. The crude fat content was determined via the solvent extraction method with n-hexane, and the carbohydrate content was calculated based on the difference.

Determination of mineral composition of whole maize flour obtained by HMT of grains

The mineral composition of Heat-moisture treated maize flour was determined by subjecting the flour to dry ashing at 550^0C. The ash was dissolved in 25 mL of 10% hydrochloric acid (HCL) and 2 mL of 5%

lanthanum chloride. The volume was increased to 50 mL with distilled water. Mn, Cu, Zn, Fe, Mg and Ca were determined with an atomic absorption spectrophotometer. Na and K were measured with a flame photometer. Phosphorus was determined by using the phosphovanadomolybdate method.

Amylose content Determination

The amylose content of the samples was determined based on the iodine colorimetric method of described by Addy *et al.* (2014). Absorbance of standard amylose with known amylose concentration was used to estimate the amylose content.

$$\%Amylose = \frac{\%amylose\ of\ standard \times Absorbance\ of\ sample}{Absorbance\ of\ standard}$$

In vitro starch digestibility Determination

In vitro starch digestibility was analyzed following the method described by Englyst *et al.* (1996) with slight modifications by Sandhu and Lim (2008). The values of total starch (TS), Rapidly Digestible Starch (RDS), Slowly Digestible Starch (SDS), and Resistant Starch (RS) were calculated using the values of glucose released after 20 min (G20), 120 min (G120), free glucose (FG) and total glucose (TG) as reported by Englyst *et al.* (1996).

$$Glucose = \frac{Absorbance\ of\ sample}{Absorbance\ of\ glucose\ standard} \times 100$$

$$TS = (TG - FG) \times 0.9 \quad 1$$

$$RDS = (G20 - FG) \times 0.9 \quad 2$$

$$SDS = (G120 - G20) \times 0.9 \quad 3$$

$$RS = (TG - G120) \times 0.9 \quad 4$$

Determination of cooking properties and sensory evaluation of maize meal dough

Approximately 50 g of whole maze flour obtained by HMT of maize grains was weighed and gradually added to 100 ml boiling water while stirring continuously to avoid lumps. Thereafter, 50 ml of hot water was added and allowed to cook until firm elastic consistency was achieved. Stop watch was used to monitor the time required for each sample to cook to a firm elastic consistency. The cooked dough was then wrapped in small quantity with food grade polythene film for sensory panel evaluation. The cooked dough was served to the panel members to evaluate for colour, taste, aroma, and overall acceptability using a 9-point hedonic scale. The dough samples were quantified on the scale with nine for like extremely and one for dislike extremely. The sensory assessment was performed in accordance with the established protocols of the committee on sensory evaluation and consumer protection of the Department of Food Science and Technology, Olusegun Agagu University of Science and Technology, Okitipupa, Nigeria (Ref: OAUSTECH/FST/2024-009)

Statistical Analysis

The data (triplicate) was entered into Statistical Package for Social Sciences (SPSS) version 20 (SPSS Inc., Chicago, IL, USA). Significance of difference was determined at probability $p < 0.05$, while post hoc Duncan multiple range test was used to analyze the differences between means.

Result and Discussion

Proximate Composition of Whole Maize Flour obtained by HMT of Grains

Proximate composition of heat moisture treated whole maize flour is presented in Table 1. Crude fat, ash and crude fibre range are 3.05-3.85%, 4.40-4.74%, and 6.84-7.11% respectively. All HMT samples showed a reduction in crude fat (2.96-3.54%) contents compared to CT (3.85%), the untreated whole maize flour which served as the control sample, and also and a decrease with increasing treatment time irrespective of the temperature. An increase in treatment time resulted in a reduction in total ash content with an increase in fibre content, indicating that shorter HMT time supports higher ash content while longer HMT enhance the fiber content. The crude protein content of all samples significantly (P≤0.05) varied, with the control sample showing the least value (6.93%). The protein content ranged from 6.93 to 12.93% with percent increase observed in all the HMT samples as compared with the control ranging from 36.59-46.40%. This is an indication that HMT within the conditions examined (80-100 °C; 30-60 min) has capacity to enhance the protein content of whole maize grains. The decrease in fat content of this study is consistent to the report of Hosseini *et al* (2024) for modified corn starch with corn germ. The increase in protein content correlates with the result of Mathobo *et al.* (2021). The results of ash and protein were higher than the values reported by Yang *et al.* (2022) for wheat flour-black soybean flour. The variation in values may be due to slight modification in HMT conditions.

Table 1: Proximate composition (%) of heat moisture treated whole maize flour

	CT	CA30	CA60	CB30	CB60
Moisture	10.38±0.02^{e}	11.53±0.03^{c}	11.90±0.05^{b}	11.06±0.03^{d}	12.62±0.03^{a}
Crude Fat	3.85±0.03^{a}	3.20±0.02^{c}	3.05±0.03^{d}	3.54±0.03^{b}	2.96±0.03^{e}
Total Ash	4.40±0.03^{d}	4.16±0.03^{b}	4.08±0.03^{c}	4.74±0.02^{a}	4.05±0.03^{c}
Crude Fibre	6.84±0.02^{c}	6.89±0.02^{b}	7.11±0.01^{a}	6.73±0.02^{d}	6.79±0.03^{c}
Crude Protein	6.93±0.03^{e}	12.66±0.03^{b}	12.93±0.02^{a}	10.93±0.03^{d}	12.47±0.02^{c}
Carbohydrate	70.61±0.04^{a}	61.38±0.13^{d}	61.14±0.04^{e}	61.51±0.05^{c}	62.66±0.03^{b}

Mean ± SD with different superscripts on the same row are significantly different at P ≤ 0.05. CT- Control Sample; CA30- Water bath HMT 80°C, 30 min; CA60- Water bath HMT 80°C, 60 min; CB30- Water bath HMT 100°C, 30 minutes; CB60- Water bath HMT 100°C, 60 min.

Minerals Composition of Whole Maize Flour obtained by HMT of Grains

Table 2 revealed the mineral composition of heat moisture treated whole maize flour. The mineral composition examined include Na, K Ca, Mg, Fe, Zn and Mn and the values in mg/100g 5.13-6.84, 311.63-406.12, 7.69-54.83, 92.86-132.91, 2.32-4.57, 0.45-2.81, 1.02-1.72 respectively. The control sample, CT, had the lowest mineral value for K, Ca, Mg, Fe, and Zn while sample treated at 100°C for 30 min had the highest value for Ca, Mg, Fe, Zn, and Mn. Higher temperature of approximately 100°C but short heating time favours value increase of Ca, Mg, Fe and Zn which are essential mineral. This result indicates that HMT was efficient, irrespective of the time and temperature, in increasing the calcium, magnesium, potassium, iron and zinc of the treated samples when compared with the control. However, as the heat treatment time increases from 30 to 60 min, the mineral element decreased in value. The increase in calcium, magnesium, potassium and iron correlates with the reports of Bello *et al.* (2018) for fermented yellow maize flour. Minerals such as calcium, Fe and Zn are essential for bones development, blood formation and building body cells.

Starch Composition and Digestibility of Whole Maize Flour obtained by HMT of Grains

Total starch and glucose contents of HMT whole maize flour as presented in Table 3 are in the range 50.95-62.51% and 56.61-69.45% respectively while the control sample, CT, contain 63.32% total starch and 70.35% total glucose. The values of amylose content of the heat-moisture treated samples (24.30-28.76%) were higher than that of the control sample, (38.79%) which was not treated. However, the amylose content of HMT samples increased with increasing treatment time (from 30 to 60 min) but reduced with increasing treatment temperature (80°C to 100°C). Yang *et al.* (2020) reported that at low moisture levels below 30%, heat treatment increase amylose content as duration increase. Increase in amylose content may be partly due to reorganization of the starch molecules and partial degradation of amylopectin as the treatment time increases. The reduction at higher temperature may be due to low activity of granule-bond starch synthase. High temperature is reported to reduce the activity of granule-bond starch synthase, which is crucial for amylose synthesis, (Ahmed *et al.*, 2008) thereby leading to reduction in amylose value. Fang *et al* (2023) reported increase in amylose content of HMT potato starch while Ahmed *et al.* (2008) reported that high temperatures during grain filling can decrease amylose content. Variation in results may be due to the treatment conditions such as the initial moisture level, amylose level and specific temperature range and time.

As shown in Table 3, compare with the control, the Rapidly Digestible Starch (RDS) and Slowly Digestible Starch (SDS) content of the HMT samples increased with increasing treatment time whereas the resistant starch (RS) content decreased. At 80°C, SDS and RS values obtained for samples heat treated for 30min were not significantly (p=0.05) greater than those heat treated for 60 min. This implied that variation in heat treatment time within an hour does not have significant influence on SDS and RS. Compared to heat moisture treatment at 100°C, the lower temperature treatment (80°C) resulted in a higher SDS and RS content, indicating that increasing temperature reduces SDS and RS content. An increase was observed in SDS and RS content of HMT highland barley flour and mung bean, SDS of modified pearl millet, whole quinoa flour and purple rice flour (Lv *et al.*, 2022; Zhao *et al.*, 2023; Sandhu *et al.*, 2020; Dong *et al.*, 2021; Chuwech *et al.*, 2023). Some studies also reported decrease in RS of HMT treated samples (Kumar *et al.*, 2023; Zhang *et al.*, 2023). This variation may be attribute to differences in the starch source and HMT conditions. Relative to the control, reduction in RS with increasing treatment temperature reported in this study may be attributed to disruption of starch granules and changes in crystalline structure, which may increase interactions between chains thereby cause RS to transform into SDS as temperature increase with time (Fonseca *et al.*, 2021; Zhao *et al.*, 2020).

Table 2: Mineral Composition (mg/100g) of heat moisture treated maize flour

	CT	CA30	CA60	CB30	CB60
Na	5.33±0.01^{d}	5.48±0.01^{c}	5.13±0.00^{e}	6.84±0.00^{a}	6.32±0.01^{b}
K	311.63±0.01^{e}	376.46±0.01^{d}	381.12±0.00^{c}	403.81±0.01^{b}	406.12±0.01^{a}
Ca	7.69±0.01^{e}	50.81±0.01^{c}	50.10±0.01^{d}	54.83±0.01^{a}	54.18±0.01^{b}
Mg	92.86±0.01^{e}	128.11±0.00^{c}	126.74±0.01^{d}	132.91±0.00^{a}	132.49±0.01^{b}
Fe	2.32±0.01^{e}	3.43±0.01^{c}	3.16±0.01^{d}	4.57±0.01^{a}	4.14±0.01^{b}
Zn	0.45±0.01^{e}	2.16±0.01^{c}	2.07±0.01^{d}	2.81±0.01^{a}	2.56±0.01^{b}
Mn	1.69±0.01^{b}	1.06±0.00^{d}	1.02±0.01^{e}	1.73±0.01^{a}	1.37±0.01^{c}

Mean ± SD with different superscripts on the same row are significantly different at P ≤ 0.05. CT- Control Sample; CA30- Water bath HMT 80°C, 30 min; CA60- Water bath HMT 80°C, 60 min; CB30- Water bath HMT 100°C, 30 minutes; CB60- Water bath HMT 100°C, 60 min.

Table 2: Mineral Composition (mg/ 100g) of Heat moisture treated maize flour

	CT	CA30	CA60	CB30	CB60
Total Glucose	70.35±0.23[a]	68.54±0.10[c]	69.45±0.35[b]	65.82±0.14[d]	56.61±0.13[e]
Total Starch	63.32±0.21[a]	61.69±0.09[c]	62.51±0.31[b]	50.95±0.11[e]	59.24±0.13[d]
RDS	11.88±0.06[f]	12.85±0.05[d]	13.75±0.11[b]	13.54±0.04[c]	18.48±0.09[a]
SDS	25.34±0.09[c]	32.19±0.08[a]	32.32±1.24[a]	26.44±0.63[bc]	27.01±0.07[b]
RS	31.81±0.24[a]	22.07±0.16[c]	21.86±1.06[c]	24.33±0.58[b]	20.18±0.09[d]
Amylose	38.79±0.03[a]	27.84±0.03[c]	28.76±0.03[b]	24.30±0.02[e]	24.98±0.02[d]

Mean ± SD with different superscripts on the same row are significantly different at P ≤ 0.05. CT- Control Sample; CA30- Water bath HMT 80°C, 30 min; CA60- Water bath HMT 80°C, 60 min; CB30- Water bath HMT 100°C, 30 minutes; CB60- Water bath HMT 100°C, 60 min.

Invitro Glycemic Index, and Enzyme Inhibitory Activities of Whole Maize Flour obtained by HMT of Grain

As indicated in Figure 1, the glycemic index, α-amylase inhibition and α-glucosidase inhibition are in the range of 42.85-48.25%, 18.77-32.58% and 9.15-23.01% respectively. Glycemic index value for all the samples was less than 55% reported for low glycemic foods, classifying the whole maize flour as low glycemic food. The α-glucosidase inhibition of HMT samples was significantly higher than that of control except for sample treated at 80°C for 30 min. When compared with the control, both HMT temperature and time lead to a decrease in α-amylase inhibition activity, however increasing treatment temperature to 100°C resulted in higher α-amylase inhibition activity than at 80°C. HMT is reported to cause structural change in starch molecules thereby leading to increase in resistance of digestive enzymes to enzymatic hydrolysis (He *et al.*, 2007) the result obtained in this study is consistent with the report of Vieira and Sarmento, (2008). The researchers reported that HMT can both increase and decrease enzymatic susceptibility, depending on the moisture content, HMT conditions and starch type (Zavareze *et al.*, 2009). The glycemic index obtained in this study decreased when compare with the control which is in line with the report of other researchers that HMT generally leads to reduction in glycemic index (Kunyanee and Luangsakul, 2021; Dong *et al.*, 2021). The results showed that HMT will be effective in developing food products with low diabetes risk factors such as glycemic index and increased enzyme resistance (low enzyme inhibition), beneficial for managing blood glucose level values of the control while phenolic was lower. Sample CB30 treated at 100℃ for not more than 30 minutes possessed highest carotenoids (505 μg/100g), flavonoids (97.31 mg/100g) and phenolic content (58.68 mg/100g). This indicates that HMT at temperature not more than 100°C for a short duration of 30 min preserves the carotenoids, flavonoids and the phenolic contents of the maize flour. Increase in carotenoids content observed in this study may be denaturation of carotenoids-protein complexes during heat treatment (cooking), giving room for a more effective extraction of the carotenoids (Beta and Hwang 2017). The antioxidant activities of HMT samples were lower than those of the control except for ABTS activity which was greater in HMT sample than control. The reduction observed in most of the antioxidant activities as compare with the control may be due to the low content lower quantity of phenolic content of the HMT samples. Phenolic is reported to be responsible for major antioxidant capacity of maize (Beta and Hwang 2017; Lopez-Martinez *et al.*, 2009). The total antioxidant capacity (TAC) of the HMT samples is not significantly different from each other, likewise DPPH except that of the sample CA30 which was treated for 30 minutes at temperature 80°C. This is an indication that HMT temperature up to 100°C within 60 min does not necessarily influence the total antioxidant capacity and DPPH scavenging ability of the flour. The values obtained for DPPH in this study (37.72-38.45%) were within the range reported for sorghum grains (31.72-51.07%) and maize flour. The trend observed for the bioactive compounds and antioxidants activities observed in this study was contrary to the trend reported by some other researchers. Lavanya *et al.* (2021) reported reduction in total phenolic and total flavonoids contents with increased DPPH radical scavenging activity of sorghum grains upon HMT for 4 h in an oven. Beta and Hwang (2017) also reported decrease in carotenoids, phenolic contents, and ABTS during 60 minutes of HMT of orange maize flour in an oven. The variation observed in the bioactive components and the antioxidant activities observed in this study compare to those of other researchers may be due to longer duration of HMT (2-4 h) and method employed (oven).

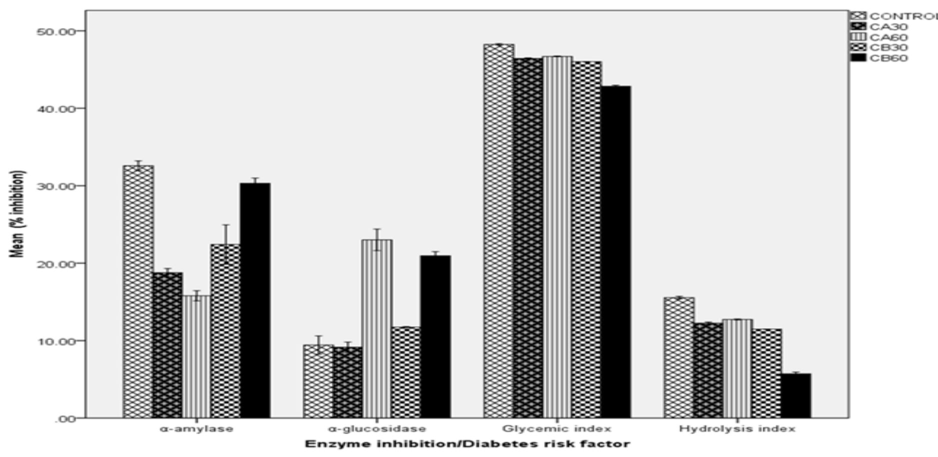

Figure 1: Effect of heat moisture treatment on Enzyme inhibition and glycemic index of whole maize

CT- Control Sample; CA30- Water bath HMT 80°C, 30 min; CA60- Water bath HMT 80°C, 60 min; CB30- Water bath HMT 100°C, 30 minutes; CB60- Water bath HMT 100°C, 60 min.

Table 4: Bioactive compounds and antioxidants activities of whole maize flour obtained by HMT

	CT	CA30	CA60	CB30	CB60
Carotenoids (μg/100g)	161.77±0.00^{e}	203.48±0.00^{b}	192.74±0.00^{c}	205.13±0.01^{a}	168.11±0.01^{d}
Flavonoids (mg/100g)	36.65±2.99^{c}	92.85±1.99^{a}	76.14±4.91^{b}	97.31±5.23^{a}	91.65±0.32^{a}
Phenolic (mg/100g)	75.96±0.90^{a}	46.15±3.19^{c}	43.48±2.89^{c}	58.68±0.43^{b}	37.35±0.96^{d}
TAC....	32.98±1.94^{a}	27.02±1.46^{b}	28.26±0.89^{b}	27.81±2.47^{b}	26.70±0.68^{b}
DPPH (%)	42.39±0.95^{a}	32.98±1.20^{c}	38.15±0.59^{b}	37.72±1.62^{b}	38.45±1.66^{b}
FRAP	99.46±0.29^{a}	98.78±0.38^{ab}	99.34±0.07^{a}	97.94±0.41^{b}	96.58±0.92^{c}
ABTS.....	72.46±0.77^{c}	75.44±0.65^{ab}	77.27±0.59^{a}	76.66±1.42^{ab}	74.76±1.29^{b}

Mean ± SD with different superscripts on the same row are significantly different at P ≤ 0.05. CT- Control Sample; CA30- Water bath HMT 80°C, 30 min; CA60- Water bath HMT 80°C, 60 min; CB30- Water bath HMT 100°C, 30 minutes; CB60- Water bath HMT 100°C, 60 min.

Cooking and Sensory Properties of Dough Meal prepared from Whole Maize flour obtained by HMT

The whole maize flour did not turn instant during preparation, this may have occurred likely because the whole maize kernel remained intact, and the heat treatment applied to the whole maize grain was insufficient to support instant dough formation. However, there was reduction in cooking time to about 2 minutes while the control sample required approximately 7 min 40 sec to cook. According to the comments from the sensory evaluation, panelists suggested improvement in the texture of all HMT samples, while colour (6.10-6.27), was moderately liked. There was no significance difference observed in the texture and colour of all the samples while overall acceptability indicated moderate likeness of the maize dough meal. Textural issue observed in this study is similar to that of "maize tuwo" reported by Summonu *et al.* (2021). Textural inadequacies are reported for dough meal prepared for maize due to inability of the product to form highly elastic, long-bodied gel and its ability to be easily brittle when moulded with the hand on consuming, particularly after cooling and overnight storage (Sunmonu *et al.*, 2021). This effect may be attributed to maize lacking compounds that contribute to gelling or binding structures, unlike cassava and wheat flours, containing pectin and gluten, respectively (Awoyale *et al.*, 2023). These components contribute to the firm structural attributes of their respective doughs.

SAMPLES	Color	Taste	Texture	Flavor	Overall acceptability
CT	6.10±0.10a	5.50±0.78b	5.50±1.28a	5.63±0.89ab	5.93±0.94a
CA30	6.33±0.71a	5.43±1.14b	5.77±0.97a	5.87±0.94ab	6.03±0.89a
CA60	6.23±0.90a	5.13±1.25c	5.73±1.08a	5.47±1.01b	5.83±1.29a
CB30	6.13±0.82a	5.87±0.94a	5.77±0.86a	5.93±0.79ab	6.03±0.72a
CB60	6.27±0.79a	6.07±0.69a	5.63±1.03a	6.01±0.98a	6.17±0.83a

Mean ± SD with different superscripts on the same row are significantly different at P ≤ 0.05. CT- Control Sample; CA30- Water bath HMT 80°C, 30 min; CA60- Water bath HMT 80°C, 60 min; CB30- Water bath HMT 100°C, 30 minutes; CB60- Water bath HMT 100°C, 60 min.

Conclusion

HMT improved the protein and fibre content while longer HMT time resulted in reduced ash and fat content. Variation in HMT time within an hour does not have significant effect on SDS and RS at low temperature while increasing treatment time at temperature below 100°C enhanced the amylose content. HMT temperature and time lead to a decrease in glycemic index and α-amylase inhibitory activity with increased inhibition as temperature increased. The study showed that HMT has potentials in developing low glycemic index food with low starch digestibility and high enzyme resistance to starch hydrolysis, beneficial for managing blood glucose level and for enhancing quality of dough meal products from maize. Therefore, the HMT conditions may require to be carefully optimized to achieve desired functional food products.

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