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Assessment of the Functional and Nutritive Properties of Thermally Modified Maize Biopolymer

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ABSTRACT

Cereal grains are important because of their abundance and readily available biopolymer made up of mainly digestible starch, proteins and other minor components like lipids and non-starch polysaccharides which is present only in small concentrations but affect the properties of the biopolymer considerably. In its native form cereal starch is neither suitable for direct human consumption nor industrial processes, and must therefore, be modified to develop specific properties such as digestibility, palatability, solubility and texture for food applications. In this research maize grain biopolymer were thermally modified and their functional and nutritive properties were determined. Significant reduction was observed in water absorption capacity (WAC), least gelling concentration (LGC), gelatinisation temperature (GT) and swelling capacity (SC), but the process led to significant increase ($p < 0.05$) the bulk density (BD). Final moisture, ash and fat contents recorded significant reduction as a result of thermal modification, while protein and carbohydrate contents were significantly increased by 5.7% and 2.8%. Essential amino acids (EAA) recorded some increments as a result of the biopolymer modification ranging from 1.5% to 26.7% depending on the amino acid. Histidine, tryptophan and methionine showed highest increments with 26.7%, 17.5% and 13.6% respectively. Leucine, phenylalanine and isoleucine are next in percentage increase with 9.4%, 7.4% and 6.1% respectively. It is noted that nutritional index (Ni), total aromatic essential amino acid (TAEAA) and total sulphur-containing amino acids (TSAA) are statistically significant, while essential amino acids index (EAAI), essential amino acids ratio (TEAA/TAA) and protein efficiency ratio (PER) are not.

Keywords: Pre-gelatinisation, functional properties, amino acid profile, protein quality indices

1.0 INTRODUCTION

Cereal grains are important because of their large abundance of readily available biopolymer made up of mainly digestible starch, proteins and other minor components like lipids and non-starch polysaccharides which are present only in small concentrations but affect the properties of the biopolymer considerably. In its native form cereal starch is neither suitable for direct human consumption nor industrial processes, and must therefore, be modified to develop specific properties such as digestibility, palatability, solubility and texture for food applications or to develop tolerance to the heating temperatures used in industrial processes (Singh *et al.*, 2007; Sweedman *et al.*, 2013). Several modification processes are developed including physical, chemical, enzymatic and hydrothermal methods (Yadav *et al.*, 2013) that alter the starch polymer, making it highly flexible and changing its physicochemical properties and structural attributes to increase its value for food and non-

food industries (López *et al.*, 2010). Physical methods involve the use of heat and moisture to improve water solubility and reduce the size of the starch granules. This can be achieved by pre-gelatinization and by hydrothermal modification processes of annealing (ANN) and hydrothermal treatment (HMT). While annealing (ANN) and hydrothermal modification (HMT) imparts changes in the physical and chemical properties of the starch by partial gelatinisation without destroying the granule structure, pregelatinization, on the other hand, involves complete gelatinization and drying processes (Zavareze and Dias, 2011) that alter the granular structure of the matrix. These processes involve water imbibition by the starch granules at elevated temperatures followed by break-down of the intermolecular association between the amylose and amylopectin molecules at solid state. The major effect of this process is the destruction of the granular structure, resulting in complete granular fragmentation, loss of

birefringence properties and changes in the functionality depending on the thermal treatment, drying conditions and the source of the starch (Ashogbon and Akintayo, 2014). Masakuni Tako and his co-workers proposed a starch gelatinization mechanism that suggests intermolecular association between the O-6 of amylose and the OH-2 of amylopectin molecules due to hydrogen bonding, where the short amylopectin chains (A and B1) take part in intermolecular associations. They explained that the tetrahedral bonding capacity of water molecules is only partially involved in gelatinized starch solutions due to the higher kinetic energy of the short side chains (A and B1) of amylopectin molecules; hence, the about 4% starch molecules that adopt a hexagonal conformation changed large number of the liquid water molecules into a network of tetrahedrally hydrogen-bonded water molecules which results in gelatinization (Tako *et al.*, 2014). The hemiacetal oxygen and hydroxyl groups of the starch molecules may be responsible for arranging a network of tetrahedrally hydrogen-bonded water molecules. Pregelatinized starch (PGS) is primarily used as thickener in many instantaneous products, such as baby foods, soups and desserts, due to its ability to form pastes and dissolve in cold water, but rarely used in traditional cereal recipes like *tuwo*, *dan-wake* etc. Considering the many benefits of starch modification, its application in the preparation of traditional foods can revolutionise the processes and impart positive changes that can enhance functionality, increase variety and facilitate industrialisation of indigenous cereal-based foods. This necessitates the evaluation of the impact of maize grain biopolymer modification by pregelatinization on the nutritive and functional properties of the modified flour as an integral part of the efforts towards the development of traditional maize-based products and their standardisation (Ndjeunga and Nelson, 2003, Bolade *et al.*, 2009)

2.0 MATERIALS AND METHODS

2.1 Sample Preparation

2.1.1 Raw Flour

Three kilograms (3kg) of maize grains was first tempered with water using a quantity of 3% (v/w) followed by decortication of the grains in commercial dehulling machine (previously cleaned), where the germs and hulls of the grains were removed. The decorticated grains

were aspirated manually to remove adhering hulls and then ground into flour using a Laboratory Hammer mill. The sample flour obtained was sieved using a standard sieve with 300 μ m aperture and then kept in airtight polythene bags until needed as described by Akaffou, *et al.*, 2018 with modifications.

2.1.2 Thermally Modified Flour

The 3kg decorticated and aspirated maize grains were introduced into a basin containing two litres of boiling water. The grains were then gently stirred to achieve even distribution of the grains in the water. The water was first brought to boil before adding the grains to maintain constant temperature for uniform thermal treatment and were allowed to stay in the boiling water for 10 minutes for complete gelatinization of the starch granules. The grains were then decanted and dried in a solar dryer. The dried grains were then milled in a laboratory hammer mill and sieved through a standard sieve with 300 μ m aperture and then kept in airtight polythene bags until required for use.

2.2 Determination of Functional Properties

2.2.1 Determination of Water Absorption Capacity (WAC)

Water absorption capacity was determined using the method of Sathe and Salunkhe (1981) with slight modifications. 10 ml of distilled water was added to 1.0 g of the sample in a beaker. The suspension was stirred using a glass stirrer for 5 min. The suspension obtained was thereafter centrifuged at 3555 rpm for 30 minutes and the supernatant measured in a 10 ml graduated cylinder. The density of water was taken as 1.0 g/cm³. Water absorbed was calculated as the difference between the initial volume of water added to the sample and the volume of the supernatant.

2.2.2 Determination of Least Gelling Concentration (LGC)

The least gelation concentration was determined by the method of Sathe *et al.* (1981). Test tubes containing suspensions of 2, 4, 6, 8 up to 20% (w/v) flour in 5 ml distilled were heated for 1 h in boiling water, followed by cooling in ice and further cooling for 2 h at 4°C. The least gelation concentration was the one at which the sample did not fall down or slip when the test tube was inverted.

2.2.3 Determination of Gelatinization Temperature (GT)

GT was determined according to the method described by Shinde (2001). 1 g of flour sample was weighed accurately in triplicate and transferred to 20 ml screw capped tubes. 10 ml of water was added to each sample. The samples were heated slowly in a water bath until they formed a solid gel. At complete gel formation, the respective temperature was measured and taken as gelatinization temperature.

2.2.4 Determination of Swelling Capacity (SC %)

This was determined with the method described by Leach *et al.* (1959) with modification for small samples. One gram of the flour sample was mixed with 10 ml distilled water in a centrifuge tube and heated at 80°C for 30 min. This was continually shaken during the heating period. After heating, the suspension was centrifuged at 1000×g for 15 min. The supernatant was decanted and the weight of the paste taken. The swelling power was calculated as:

$$\text{Swelling power} = \text{weight of the paste} / \text{weight of dry flour.}$$

2.2.5 Determination of Bulk Density

This was carried out using the procedure of Narayana and Narasinga (1984). A specified quantity of the flour sample was transferred into an already weighed measuring cylinder (W_1) and

gently tapped to eliminate spaces between the flour. The level was noted to be the volume of the sample and then weighed (W_2). The study was conducted in triplicate and Bulk Density obtained as follows:

$$\text{Bulk density (g/cm}^3\text{)} = W_2 - W_1 / \text{Vol. of Sample}$$

2.3 Proximate Analyses and Energy Value

2.3.1 Moisture Content

moisture content of samples was determined by hot air oven drying method as recommended by AOAC (1990).

2.3.2 Crude Protein

The Kjeldahl Digestion method was used to estimate the nitrogen in the sample which was then multiplied by the nitrogen conversion factor 6.25 to obtain the percentage protein (AOAC, 1990).

2.3.3 Fat Content

This was carried out according to (AOAC, 1990). Diethyl ether at 50°C was used for the extraction under reflux for 5h using a Soxhlet apparatus.

2.3.4 Total Ash

The ash content in the sample was determined by incineration with the furnace at 550°C (AOAC, 1990) after a period of 32hr, ash was removed and placed in a desiccator for 1hr and then weighed.

$$\text{Ash content (\%)} = (\text{Weight of Ash} / \text{Weight of sample}) \times 100\%$$

2.3.5 Carbohydrate

Percentage Carbohydrate was obtained by difference (AOAC, 1990). The sum of Percentage Moisture, Fat, Protein and Ash was subtracted from 100 and the balance was recorded as percentage Carbohydrate.

2.3.6 Energy Value (kcal.)

The sample calorific value was estimated in kcal/g by multiplying the percentages of crude protein, crude fat and carbohydrate with the recommended factors (% Protein x 2.44, % Fat x 8.37 and % CHO x 3.57) as proposed by Martin and Coolidge [1978].

2.4 Determination of Amino Acids

Amino Acids were profiled by the Isocratic HPLC – 2 methods (AOAC, 2000). Samples were solubilized, centrifuged and filtered through a 0.22 µm membrane. The filtrate was then used for the experiment. Standard solutions of the amino acids (both essential and non-essential) were prepared and serially diluted to give 25pmol of each amino acid derivative. Chromatographic separation of samples was carried on a Buck scientific BLC10/11 – model HPLC equipped with UV 338nm detector.

2.5 Calculation of Protein Quality Indices

2.5.1 The Essential Amino Acid Index [EAAI]: was calculated using the method of

Labuda *et al.* (1982) as reported by Steve (2012), according to the following equation:

$$EAAI = \sqrt[9]{\frac{[Lys \times Thr \times Val \times Met \times Ile \times Leu \times Phe \times His \times Trp]_a}{[Lys \times Thr \times Val \times Met \times Ile \times Leu \times Phe \times His \times Trp]_b}}$$

where: [lysine, tryptophan, isoleucine, valine, threonine, leucine, phenylalanine, histidine and methionine]_a is the amino acids contents in test sample and [lysine, tryptophan, isoleucine, valine, threonine, leucine, phenylalanine, histidine and the sum of methionine and cystine]_b is the contents of the same amino acids in standard protein [%] [egg or casein] respectively.

2.5.2 Protein Efficiency Ratio (PER)

Protein Efficiency Ratio of the samples were calculated according to the equations developed

by Alsmeyer *et al.* (1974) as used by Ogunmodimu *et al.* (2015)

$$PER = 0.06320 [X10] - 0.1539$$

Where: $X10 = Thr + Val + Met + Ile + Leu + Phe + Lys + His + Arg + Tyr$

2.5.3 Biological Value (BV)

Biological Values were computed according to the methods of Mune-Mune *et al.* (2011) as a function of EAAI.

$$BV = 1.09 (EAA \text{ Index}) - 11.7.$$

2.5.4 Nutritional Index (NI)

The nutritional index of the food samples was calculated using the formula below as described by Crisan and Sands (1978).

$$\text{Nutritional Index}(\%) = \frac{EAAI \times \% \text{ Protein}}{100}$$

2.5.5 Amino Acid Score

The amino acid score was calculated using the ratio of a gram of the limiting amino acid in the food to the same amount of the corresponding amino acid in the reference diet multiplied by 100. The scoring patterns suggested by the FAO/WHO/UNU6 for children of 1-2 years of age were used for this purpose.

$$\text{Amino Acid Score} (\%) = \frac{\text{Value of EAA in Food Sample (g/100g Protein)}}{\text{Reference Value of Essential Amino Acids}} \times 100$$

2.5.6 TEAA + His + Arg/ TAA

This value expresses the percentage abundance of EAA including histidine and arginine relative to all the amino acids available in the test material.

2.5.7 TEAA/TAA

This is similar to the above value only that histidine and arginine are not included in the sum of the available EAA.

2.5.8 TNEAA/TAA

This is the percentage ratio of dispensable amino acids relative to all the amino acids found in the sample.

2.5.9 TSAA (Meth + Cys g/100g)

This is the sum total of all the sulphur containing amino acids in the sample.

2.5.10 TAEAA (Phe + Tyr g/100g)

This expresses the total sum of the aromatic indispensable amino acids in the test material.

2.5.11 TEAA/TNEAA

This expresses the relative abundance of indispensable amino acids in relation to the non-essential ones in the sample material

3.0 STATISTICAL ANALYSIS

The results were analyzed by 3-way ANOVA and mean separation carried out by the Tukey-Kramer Honestly Significant Difference (HSD) using MATLAB statistical software [MATLAB 7.12.0 (R2011a)]

4.0 RESULTS AND DISCUSSION

4.1 Functional Properties of Flour Samples

Table 1 shows the measured values of the functional properties of the native and modified maize flour samples. Thermal modification has significantly reduced the measured values of the functional properties considered in this work except bulk density which recorded a significant ($P < 0.05$) increase of 31%.

Table 1: Functional Properties of Raw and Pregelatinized Maize Flours

Property	Raw Flour	Thermally Modified Flour	Percent Change
WAC	190.3 ± 2.10 ^{ad}	169.7 ± 2.52 ^{ae}	-10.8
LGC	7.8 ± 1.0 ^{ad}	6.2 ± 0.76 ^{ae}	-20.5
GT	62 ± 1.7 ^{ad}	22.3 ± 1.15 ^{ae}	-64.0
SC	15.8 ± 0.6 ^{ad}	12.7 ± 0.58 ^{ae}	-19.6
BD	0.51 ± 0.08 ^{ad}	0.67 ± 0.02 ^{ae}	31.3

Mean values in the same row with different superscript differ significantly ($p < 0.05$)

From the table above, it was observed that thermal modification has caused a significant decrease in *water absorption capacity* (WAC) of maize flour as it was equally observed by Adebowale *et al.*, (2005). The modification process might have reduced the solubility of the protein matrix due to insolubilisation of kafirins and greater cross-bonding with disulphide bonds (Hamerker *et al.*, 1987; Kirleis, 1990). This insolubilisation and bonding might have resulted in the hardening of the modified starch structure and the resultant low WAC observed in this work. It was also observed that thermal modification has significantly reduced the *least gelling concentration* (LGC) compared to the native flour possibly due to the disintegration of the amorphous regions of the starch granules and consequent weakening of the granule structure, permitting granule fragmentation with little swelling (Alhusaini, 1985). It was equally observed that thermal treatment of the flour have significantly decreased ($p < 0.05$) its *gelatinization temperature* (GT) due to the initial water imbibition at elevated temperature and probably partial loss of birefringence on the part of the thermally modified starch granules. This observation is a direct contrast to an account by Hoover and Vasanthan (1994) which shows that heat-moisture treatments alter the crystallinity of starch granules and makes the starch gelatinization temperature higher. The GT values recorded in this work compared favourably with that of Chandra and Samsher

(2013) with slight disparities probably brought about by the agronomic history of the different samples and even by the measurement precision of the various methods adopted by different researchers. Thermal modification was observed to have significantly lowered the *Swelling capacity* (SC) of the flour compared to control samples probably due to initial water absorption and losses of soluble components during the thermal treatment (Narayana and Narasinga, 1982). However, the process led to a significant increase ($p < 0.05$) in *bulk density* (BD) of the flour by more than 30% probably due to the structural reorganisation brought about by granular fragmentation, amylose solubilisation, insolubilisation of kafirins and greater cross-bonding with disulphide bonds (Hamerker *et al.*, 1987; Kirleis, 1990) which might have reduced the inter-granular spaces leading to a more densely packed molecules with consequent increase in the BD.

4.2 Proximate Composition and Energy Value

Table 2 below shows the results of the proximate composition analysis including energy value for the raw and modified maize polymer. It was observed that final moisture, ash and fat contents recorded significant reduction as a result of pregelatinization, while protein and carbohydrate contents were significantly increased. Energy value, on the other hand is not significantly affected by the process.

Table 2: Proximate Composition of Raw and Pregelatinized Maize Flours

Property	Raw Flour	Thermally Modified Flour	Percent Change
Moisture (%)	10.5 ± 0.5 ^{adg}	9.8 ± 0.7 ^{aeg}	-6.7
Ash (%)	1.6 ± 0.4 ^{abdg}	0.9 ± 0.6 ^{abeg}	-43.8
Fat (%)	2.0 ± 0.2 ^{adg}	0.8 ± 0.3 ^{aeg}	-60
Protein (%)	7.0 ± 1.0 ^{adfg}	7.4 ± 1.0 ^{aedg}	5.7
Carbohydrate (%)	78.9 ± 1.7 ^{adg}	81.1 ± 1.2 ^{aeg}	2.8
Energy Value (Kcal)	315.6 ± 4.3 ^{abdg}	314.3 ± 2.8 ^{abdg}	-0.4

Mean values in the same row with different superscript differ significantly ($p < 0.05$)

The observed decrease in the final *moisture content* of the raw and modified flours may be due the reorganised nature of the starch amyloplast and the protein matrix which might have facilitated more moisture transfer during drying leading to a higher reduction in moisture content relative to the unmodified biopolymer. Higher moisture values of 10.82%, 10.53% were reported in literature (Adeoti *et al.*, 2013, Adenike *et al.*, 2014) which may be due to difference in drying conditions. The thermal modification process was observed to have significantly reduced the *ash content* of the modified maize flour by -43.8% compared to the control samples may be due to loss of soluble matter since the process involves contact with water at elevated temperature. It was equally observed that *fat content* of the modified sample is significantly lower ($p < 0.05$) than that of control samples. The thermal treatment might have resulted in the solubilization of the oil in the aqueous solution at high temperature which was discarded along with the thermal treatment medium leading to a decrease in the fat content of the final product. The modification process was also noted to have significantly increased (p

> 0.05) the protein content by 5.7% probably due to the reduction in ash and fat contents which was translated into percentage increase in protein, and not because new peptide molecules were added by the process. The 2.8% increase observed in *carbohydrate content* after thermal modification may be attributed to the increase and decrease in other components since carbohydrate is obtained by difference. As for the energy value obtained from the values of the proximate composition and recommended factors, variations in the energy values of the samples follow logically from the variations in the proximate values as they are affected by the thermal modification process. Hoover and Vasanthan, (1994) equally reported that the energy value is increased (as determined by DSC) after the treatment.

4.3 Amino Acids Profile

The results of amino acids profiling were presented in table 3. It was observed that all the *essential amino acids (EAA)* recorded some increments as a result of thermal modification ranging from 1.5% to 26.7% depending on the amino acid.

Table 3: Essential Amino Acids of Raw and Pregelatinized Maize Flours (g/100g Protein)

Property	Raw Flour	Thermally Modified Flour	Percent Change
Histidine	0.3 ± 0.000 ^{adg}	0.38 ± 0.014 ^{adg}	26.7
Isoleucine	0.825 ± 0.007 ^{adg}	0.875 ± 0.007 ^{adg}	6.1
Leucine	1.17 ± 0.014 ^{adg}	1.28 ± 0.014 ^{adg}	9.4
Lysine	0.87 ± 0.000 ^{adg}	0.9 ± 0.014 ^{adg}	3.5
Methionine	0.405 ± 0.007 ^{adg}	0.46 ± 0.014 ^{adg}	13.6
Phenylalanine	0.81 ± 0.014 ^{adg}	0.87 ± 0.014 ^{adg}	7.4
Threonine	0.675 ± 0.007 ^{adg}	0.685 ± 0.007 ^{adg}	1.5
Tryptophan	0.20 ± 0.014 ^{adg}	0.235 ± 0.007 ^{adg}	17.5
Valine	0.95 ± 0.014 ^{adg}	0.965 ± 0.007 ^{adg}	1.6
TEAA	6.21	6.65	7.1

Mean values in the same row with different superscript differ significantly ($p < 0.05$)

It was observed that histidine, tryptophan and methionine showed the highest increases with 26.7%, 17.5% and 13.6% respectively. Leucine, phenylalanine and isoleucine are next in

percentage increase with 9.4%, 7.4% and 6.1% respectively. The rest of the EAA including lysine, valine and threonine are the least increased with 3.5%, 1.6% and 1.5%

respectively. The overall increase in *total essential amino acids (TEAA)* is 7.1%. The percentage increase observed in TEAA as a result of the thermal process may be attributed to the solubilisation of the amylose and amylopectin globules thereby increasing the relative availability of the protein constituents leading to increased exposure of the constituent amino acids for determination.

4.4 Amino Acid Score

The result of the amino acids scores of the raw and pregelatinized maize flour is as shown in table 4. Following the pattern of the amino acids, all the amino acid scores recorded increases to various percentages ranging from 1.5% to 26.6% after thermal modification.

Table 4: Amino Acid Score (AAS %) & Limiting Amino Acids (LAA) of Maize Flours

Property	Raw Flour	Thermally Modified Flour	Percent Change
Histidine	13.64 ^{adg}	17.27 ^{adg}	26.6
Isoleucine	15.28 ^{adg}	16.2 ^{adg}	6.0
Leucine	13.6 ^{adg}	14.88 ^{adg}	9.4
Lysine	12.43 ^{adg}	12.86 ^{adg}	3.5
Methionine	4.35 ^{adg}	4.95 ^{adg}	13.8
Phenylalanine	17.23 ^{adg}	18.51 ^{adg}	7.4
Threonine	14.36 ^{adg}	14.57 ^{adg}	1.5
Tryptophan	4.26 ^{adg}	5.0 ^{adg}	17.4
Valine	14.39 ^{adg}	14.62 ^{adg}	1.6

Mean values in the same row with different superscript differ significantly ($p < 0.05$)

It was observed that the amino acid score of histidine, tryptophan and methionine showed the highest increments with 26.7%, 17.5% and 13.6% respectively after pregelatinization. Leucine, phenylalanine and isoleucine are next in percentage increase with 9.4%, 7.4% and 6.1% respectively. The rest of the EAA including lysine, valine and threonine are the least increased with 3.5%, 1.6% and 1.5% respectively. The overall increase in *total essential amino acids (TEAA)* is 7.1%.

4.5 Calculated Protein Quality Indices

The values of calculated Protein quality of the samples are shown in Table 5 below. It was observed that all the quality indices increased to different percentages as a result of polymer modification. However, at <0.05 level of significance, it is noted that *nutritional index (Ni)*, *total aromatic essential amino acid (TAEAA)* and *total sulphur-containing amino acids (TSAA)* are statistically significant, while *essential amino acids index (EAAI)*, *essential amino acids ratio (TEAA/TAA)* and *protein efficiency ratio (PER)* are not.

Table 5: Calculated Protein Quality of Raw and Pregelatinized Maize Flours

Property	Raw Flour	Thermally Modified Flour	Percent Change
EAAI (%)	10.98 ^{adg}	12.02 ^{adg}	9.5
TSAA: (Meth+Cys) (g/100g)	0.71 ^{adg}	0.79 ^{aeg}	11.3
TAEAA:(Phe+Tyr) (g/100g)	1.45 ^{adg}	1.56 ^{aeg}	7.6
(TEAA + His + Arg/TAA)%	52.09 ^{adg}	53.93 ^{adg}	3.5
(TEAA/TAA)%	48.9 ^{adg}	50.76 ^{adg}	3.8
PER (g/100g)	0.29 ^{adg}	0.32 ^{adg}	10.3
Nutritional Index	0.77 ^{adg}	0.89 ^{aeg}	15.6

Mean values in the same row with different superscript differ significantly ($p < 0.05$)

It was observed that *Total Sulphur Containing Amino Acids (TSAA)* was significantly increased as a result of thermal modification 11.3%, while *Total Aromatic Essential Amino Acids (TAEAA)* was increased 7.6%. *Protein Efficiency Ratio (PER)* was increased by 10.3%,

Essential Amino Acids Index (EAAI) was increased by 9.5% and *Nutritional Index (NI)* by 15.6%. This is probably due to the structural reorganisation brought about by granular fragmentation, amylose solubilisation, insolubilisation of kafirins and greater cross-

bonding with disulphide bonds (Hamerker *et al.*, 1987; Kirleis, 1990) leading to increased availability of the protein constituents,

5.0 CONCLUSION

Thermal modification process caused significant changes in the functional properties of maize flour. Significant reduction was observed in *water absorption capacity* (WAC), *least gelling concentration* (LGC), *gelatinisation temperature* (GT) and *swelling capacity* (SC), but the process led to significant increase ($p < 0.05$) the BD. The nutritive value of the flour including proximate composition, amino acid profile and protein quality were all variously affected. In proximate composition, it was observed that final moisture, ash and fat contents recorded significant reduction as a result of thermal modification, while protein and carbohydrate contents were significantly increased by 5.7% and 2.8%. It was observed that all the *essential amino acids* (EAA) recorded some increments as a result of the biopolymer modification ranging from 1.5% to 26.7% depending on the amino acid. Histidine, tryptophan and methionine showed highest increments with 26.7%, 17.5% and 13.6% respectively. Leucine, phenylalanine and isoleucine are next in percentage increase with 9.4%, 7.4% and 6.1% respectively. The rest of the EAA including lysine, valine and threonine are the least increased with 3.5%, 1.6% and 1.5% respectively. The overall increase in *total essential amino acids* (TEAA) is 7.1%. Following the pattern of the amino acids, all the amino acid scores recorded increases to various percentages ranging from 1.5% to 26.6% after pregelatinization. Histidine, tryptophan and methionine showed the highest increments with 26.7%, 17.5% and 13.6% respectively. Leucine, phenylalanine and isoleucine are next in percentage increase with 9.4%, 7.4% and 6.1% respectively. The rest of the EAA including lysine, valine and threonine are the least increased with 3.5%, 1.6% and 1.5% respectively. The overall increase in *total essential amino acids* (TEAA) is 7.1%. It was observed that all the quality indices increased to different percentages as a result of polymer modification. However, at <0.05 level of significance, it is noted that *nutritional index* (Ni), *total aromatic essential amino acid* (TAEAA) and *total sulphur-containing amino acids* (TSAA) are statistically significant, while *essential amino acids index* (EAAI), *essential*

amino acids ratio (TEAA/TAA) and *protein efficiency ratio* (PER) are not.

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