The Effect of Feed Moisture and Barrel Temperature on the Essential Amino Acids Profile of Sorghum Malt and Bambara Groundnut Based Extrudates

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Abstract

Malnutrition is prevalent and serious problem in Africa especially where most people are ravaged and displaced by war especially in northern Nigeria by the activities of the terrorists Boko Haram. Sorghum malt and bambara groundnut flour were processed to produce an extruded product using a twin screw co-rotating intermeshed extruder. The formulations were extruded at 100°C, 120°C and 130°C and feed moisture contents of 20%, 25% and 30% respectively. This work has therefore attempted to investigate the effect of feed moisture and barrel temperature on the retention of essential amino acids in the extrudates. Extrusion was used to obtain best extrusion conditions to develop a protein-enriched extruded product with desirable physio-chemical and sensory properties. The results showed different physical and chemical properties of the extrudates compared to those of the raw materials used. The extrusion of Sorghum malt and Bambara groundnut blend gave a good complement in terms of the essential amino acids but was faced with the challenge of depletion of the amino acids resulting from maillard reaction probably. Extrusion of foods in the presence of reducing sugars has been found to have negative effect on the quality and quantity of the essential amino acids due to maillard reaction. The results showed that the mean observed values for lysine ranged from 3.62 g/100 g to 4.51 g/100 g, while methionine has the values from 1.47 g/100 g to 2.68 g/100 g. The values for reducing sugars ranged from 222.16 mg/100 g to 453.51 mg/100 g in glucose to 680.70 mg/100 g to 835.70 mg/100 g in maltose. ANOVA was adapted for the statistical analyses. The values showed significant difference at p ≥ 0.01. The values decreased with increased barrel temperature, while increase in feed moisture increased the reducing sugar and essential amino acid contents. The essential amino acid content of the extrudates met the FAO/WHO (1973) recommended pattern for supplementary foods. This is the first attempt to produce protein enriched sorghum malt and bambara groundnut extruded product with millet and beans that can be included in a child’s meal as a breakfast cereal or a snack to fight protein malnutrition.

Keywords: Essential amino acid; Feed moisture; Barrel temperature; Bambara groundnut; Sorghum malt

Practical Application

The research was based on scientific procedures which can be interpreted for applications with respect to its originality and strategically for an industry-driven programme with the focus of yielding results that can be translated directly into real products for mitigating food security problems in Sub Saharan Africa.

Introduction

Sorghum is the most common and widely utilized among all the cereal grains. This is due to its cultivation by mostly subsistence farmers, moderate resistance to drought and weed as well as adaptability to poor soils and weather conditions when compared to other cereals. Carbohydrates are the main dietary contribution in cereals, although they also provide proteins and small amounts of lipids, fibre and vitamins. However, a well-identified and important problem relating to the nutritional value of sorghum is their low protein content and the limited biological quality of their proteins (the protein is limited in lysine) when compared with proteins found in legumes and animals flesh [1].

Bambara groundnut (Vigna subterranea) is a legume commonly grown in the northern part of Nigeria along with cereals and other legumes. It is resistant to drought and grows well on poor soil conditions [2]. The protein of Bambara groundnut is of good quality and has surplus lysine and which complements cereals in the diet. The composition of the seeds, from the point of view for human nutrition is very well balanced [3]. Bambara ground nut has been reported as a complete food [4]. It is high in protein but unlike ordinary groundnuts, it contains very little oil, which reduces the risk of spoilage from rancidity on storage and products produced from Bambara groundnut [5].

The low protein values of cereals have limited their sole utilization for food. The co-consumption of cereals with other food products such as animal foods, vegetable and legumes become one of the best alternatives for cereal complementation in terms of the protein requirements. The quality of a protein depends upon the relative amount of each of the essential amino acids it contains. Animal proteins usually have a better balance of the amino acids than plants proteins. However, the use of animal protein as a complement of this plant protein is limited by the high cost of animal products and the level of poverty in Africa. Therefore the combination of plant proteins can provide a similar balance, in other words, a relative deficiency of amino acid from one plant protein can be made up by the amino acids from another plant protein. Cereals which are low in Lysine but rich in Methionine and Cystine can be adequately complemented by legumes which are rich in Lysine but poor in Methionine and Cystine so that the

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cereal-legume combination provides high quality protein comparable to or higher than reference proteins [6]. The protein of the cooked sorghum is significantly less digestible than that of other cereals. This also affects the digestion of starches since starch granules in sorghum grains are usually entrapped in the protein matrix [7].

Extrusion cooking technology is a high temperature, short time, versatile and modern food operation that converts agricultural commodities from usually granular or powdered form into fully cooked shelf stable product with enhanced textural and flavour attributes [8]. Extrusion cooking has some unique features compared to other heat processes. It’s capable of breaking covalent bonds in biopolymers and facilitates the reactions otherwise limited by diffusion of reactants and products [9]. Similarly Iwe MO [10], corroborated that extruded food materials are subjected to intense mechanical shear, structural disruption and mixing which facilitate the modification of functional properties of food ingredients and or texturizing them. Extrusion is a powerful food processing operation, which utilizes high temperature and high shear force to produce a product with unique physical and chemical characteristics; extrusion process denatures undesirable enzymes; inactivates some anti-nutritional factors (trypsin inhibitors, haemagglutinins, tannins and phytales) stabilizes the finished product; and retains natural colours and flavours of foods [11]. Extruded fura produced from cereal legume blends by extrusion was reported to have potential of providing consumers with a fast, easy way to prepare nutritious fura which is similar to the traditional fura [12,13]. Extrusion enhanced the water uptake of the product, with reduction in viscosity which is an indication of concomitant increase in nutrient density, but the process method was not optimized.

Malting has been identified as a traditional processing technology that could possibly be used to improve the nutritional quality of the protein [14]. The process of malting comprises three unit operations viz, steeping, germinating and drying. The process requires the activation of the intracellular enzymes (hydrolases) which initiates the hydrolysis of stored nutrients. This result in the reduction in starch content, anti nutritional factors, improves digestibility of protein, increase in vitamin and bioavailability of minerals [15-17]. A reduction in dietary bulk of malted sorghum was also reported [18]. Extrusion of foods in the presence of sugars (particularly reducing sugars) has been found to have negative effect on the Essential Amino acid content as a result of maillard reaction. This reduces both the quality and quantity of the amino acids which are already deficient in most foods. The combination of Sorghum malt and Bambara groundnut blend gives a good complement in terms of the essential amino acids but is faced with the challenge of essential amino acid depletion from maillard reaction on extrusion. This work has therefore attempted to investigate the effect of feed moisture and barrel temperature on the retention of the essential amino acid profile of the extrudates.

**Materials and Methods**

**Research materials**

Sorghum bicolour and bambara groundnut (Vigna subterreana) were used in this study which were obtained from Ganye Main Market Adamawa State Nigeria. The varieties were identified as local white variety of sorghum called Chakalari and an improved cream coloured (AS 17) bambara groundnut by the Adamawa Agricultural Development Program (AADP) Yola Adamawa State Nigeria.

**Malting of sorghum**

The malting process was carried out as described by Svanberg [19]. The sorghum grain was locally aspired and sorted to remove all foreign materials, broken and poorly developed seeds. The grains were then washed several times in potable water to remove dirt and adhering dust particles. The grains were soaked in potable water for 24 hours. With the soaked water changed every 8 hours. The soaked grains were then drained and spread on a cleaned jut sack and allowed to germinate for three days. Cleaned water was intermittently sprinkled on the germinating grains at 12 hours interval throughout the germination period. After the three days period, the germination was arrested by drying in the sun for about 6 hours and the rootlets were removed by brushing followed by local Aspiration.

**Determination of germinating capacity of sorghum**

The modified method of Moshafa et al. [20] was used. About 200 sorghum kernels were steeped for 24 hrs in 200 ml fresh water at room temperature. The steep liquor was strained off and the grains were spread on moistened cotton wool and allowed to germinate for 2 days. The germinated grains were separated and counted. The Germinating capacity in percentage was found by:

\[
\% \, \text{Germination Capacity} = \left( \frac{200-n}{2} \right) \times 100
\]

Where \( n \) = number of ungerminated seeds.

**Diastatic power determination**

About 3g of the malt grits was weight out and extracted with 27.5cm³ of distilled water and 2.5 cm³ of 0.1N NH₄OH solution, the extract was not filtered but allowed to settle. 3ml aliquot of the supernatant liquid was removed using pipette into 100 ml of 2% buffered starch solution kept at a temperature of 25°C in a 200 ml flask. The flask was shook and allowed for 1hour. The reaction was inhibited by the addition of 0.1N NaOH and the volume made up to 200 ml at 20°C with distilled water. Five ml of mixed Fehling’s solution was pipette into a 15 ml narrow-necked boiling flask the content was mixed and was boiled with moderate heat for 2 min. It was titrated with the 2% buffered starch solution while heating until the blue colour of Fehling’s solution was bleached. Three drops of Methylene blue indicator were added and the titration completed. The end point was indicated by the decolorization of the Methylene blue indicator to red [20].

The Diastatic power (D.P) expressed in degree \( I_1 \cdot B \) was calculated from the expression:

\[
\text{Diastatic Power} = \frac{(200-200)}{(XY \times SX)}
\]

Where:

\( X = \) number of ml of malt extract used to digest starch

\( Y = \) number of ml of converted starch to reduce 5ml of Fehlings solution

\( S = \) titre of starch blank.

**Determination of blank titre for starch**

The undiluted 2% starch solution was titrated against a mixture of 1ml of mixed Fehling’s solution A and B, using the above described technique. The titre was taken as S. The correction to be subtracted from the probable diastatic power of the malt is 200/Sx, where x is the number of ml of malt extract for the conversion. The blank is usually neglected if it is less than 3% of the measured diastatic power of the malt.

**Flour production from sorghum malt and bambara groundnut**

The sorghum malt and bambara groundnut grains were first...
manually aspirated to remove light contaminating materials. It was sorted to remove chaff, stones, rotten seeds and other heavy materials, and then washed in clean potable water until the washed water was no longer dirty. The grains were later dried in the sun for about 4 hours with occasional turning during drying. It was then ground in a locally fabricated attrition mill and sieved through a 500 µm sieve size. The flour was then packed in a low density polyethylene bag and stored at room temperature before extrusion [21].

**Experimental Design**

A Two- factor three levels full factorial design was adopted for the study on effect of feed moisture and barrel temperature on the essential amino acid profile of extrudates from sorghum malt and Bambara groundnut extrudates. The experimental design is given on Table 1.

The outline of the experimental layout with the coded and natural values is presented in Table 2.

Experiments were carried out in triplicates and in a randomized order. ANOVA was adopted to determine the statistical level of significance of each sample and least significant difference for the separation of means.

**Feed moisture adjustment**

The sorghum malt (X1) and bambara groundnut (X2) flours were mixed at 70: 30 weight ratios and the total moisture contents of the blends adjusted to the desired values with a mixer by adding a calculated volume of water required to give the feed moisture. Weights of the components mixed were calculated using the formula below [22]:

\[
\text{C}_{X} = \frac{r_{X} \times M \times (100-W)}{100 \times (100-W_{X})}
\]

--- (3)

\(X_{1}\) = sorghum malt flour.

\(X_{2}\) = bambara groundnut flour.

\(C_{X1}\) = mass of sorghum malt flour in grams

\(C_{X2}\) = mass of bambara groundnut flour in grams

\(r_{X}\) = percentage of sorghum malt flour.

\(r_{X2}\) = percentage of bambara groundnut flour.

\(M\) = total mass of blend in grams.

\(W\) = moisture content of the final blend (w/w) in %.

\(W_{X}\) = moisture content of bambara groundnut (%).

\(W_{Y}\) = weight of water to be added in grams.

**Conditioning and extrusion process**

A calculated quantity of water was added to the fixed ratio of 70: 30 feed formulation (70% sorghum malt and 30% bambara groundnut) based on the desired feed moisture. It was thoroughly mixed using Hobart mixer (model number A 200) for 10 minutes which ensured there were no lumps formed in the formulation. The conditioned blends were then packed in polythene bags and kept at room temperature for four hours before extrusion. The extrusion was carried out using SLG65 twin screw co-rotating intermeshed extruder (Jinan Saibainu technology dev. Co. Ltd China). The compression level of the screw was 2:1 and length to diameter (L/D) ratio of 20:1. The extruder had three thermocouple heating zones and 3 mm die hole. It was equipped with a feeding hopper attached with a horizontal feeder which supplied the feed at 0.04 kg/s. A cutting knife with a variable speed was also attached to the die head. The formulations were extruded at 100°C, 120°C and 130°C and feed moisture contents of 20%, 25% and 30% respectively. The extrudates were cooled, dried and stored in a polythene bag before further analysis. A total of nine extrusions were run in accordance with the experimental design.

**Determination of specific sugars**

The method of Filli et al. [23] was adapted for the specific sugars determination. About 3 g of each extruded sample was dried to constant weight and defatted. One gram of the sample was dissolved in 20 ml of 6N HCL. This was then poured into a hydrolysis tube with screw cap and hydrolyzed for 22 hour under a nitrogen atmosphere. The acid was evaporated using a rotary evaporator and residue washed three times with distilled water. The extracted sample was dissolved in 1ml acetate buffer of pH 3.1. After dilution to a known volume, the hydrolysate was transferred into a Beckman system (model 6300) high performance amino acid analyzer. Amino acid scores were calculated as gram per 100 gram protein (g/100g protein). Triplicate determinations were carried out and the result averaged.

**Determination of amino acid profile**

The Amino Acid profile was determined using methods described by Gotherd et al. [24]. About 3 g of the extruded sample was dried to constant weight and defatted. One gram of the sample was dissolved in 20 ml of 6N HCL. This was then poured into a hydrolysis tube with screw cap and hydrolyzed for 22 hour under a nitrogen atmosphere. The acid was evaporated using a rotary evaporator and residue washed three times with distilled water. The extracted sample was dissolved in 1ml acetate buffer of pH 3.1. After dilution to a known volume, the hydrolysate was transferred into a Beckman system (model 6300) high performance amino acid analyzer. Amino acid scores were calculated as gram per 100 gram protein (g/100g protein). Triplicate determinations were carried out and the result averaged.

**Statistical analysis**

A two-way ANOVA of the results were carried out using Statistical Package for the Social Sciences [25] for windows Illinois, USA). Means were separated using Duncan Multiple Range Test.

<table>
<thead>
<tr>
<th>Independent variables</th>
<th>Symbols</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed moisture (%)</td>
<td>X1</td>
<td>20</td>
<td>25</td>
<td>30</td>
</tr>
<tr>
<td>Barrel temperature (°C)</td>
<td>X2</td>
<td>100</td>
<td>120</td>
<td>130</td>
</tr>
</tbody>
</table>

**Table 1:** Independent variables and levels for full factorial design

<table>
<thead>
<tr>
<th>Design point</th>
<th>Independent variables</th>
<th>Variables in their natural form</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
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<tr>
<td>4</td>
<td>2</td>
<td>1</td>
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<td>5</td>
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<td>2</td>
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<td>6</td>
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<td>7</td>
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<td>1</td>
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<tr>
<td>8</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

\(X_{F}\) = Feed Moisture, \(X_{B}\) = Barrel Temperature

**Table 2:** Experimental layout with the Coded and Natural values
Results and Discussions

Germination capacity and diastatic power of the sorghum grains

The diastatic power and germination capacity of the malted sorghum was found to be 18 (I OB) and 95% respectively. The diastatic power refers to the strength of the endogenous enzymes in modifying the endosperm with respect to the conversion of the stored food materials. This result is in agreement with the report of SPSS [26]. Stored starches are hydrolyzed to simple sugars and maltodextrins, while proteins to peptides and amino acids. One of the important reasons for the malting is to modify the starches. Sorghum grains have been found to have low glycemic index resulting from the high resistance to digestion due to the fact that the starch granules are embedded in protein matrix. This makes the starches highly resistant [27]. The malting process is therefore aimed at modifying the starch for improved functional properties in the extrudates.

Reducing sugar content of extrudates

The values for Glucose and Maltose sugars are shown on Table 3. The values ranged from 222.16 mg/100 g to 453.51 mg/100 g in glucose to 680.70 mg/100 g to 835.70 mg/100 g in maltose. These values show significant difference at p ≥ 0.01. The values increased with increased feed moisture, while increase in barrel temperature decreased the reducing sugar content. This might be as a result of the depletion due to maillard reaction. This reaction has a positive relationship with temperature; as the temperature increased, the rate of the reaction also increased. Increased in feed moisture might have resulted in the increased breakdown of starch into simpler sugars as a result of high shear and solubility. Water also a by-product of maillard reaction will negate the reaction as it accumulates. This may increase the retention of the sugars. Maltose which is the predominant reducing sugar in the blend is less reactive than glucose and the pentose sugar Xylose (which is the most reactive).

Amino acid profile of extruded blends

The mean results for amino acid profile of the extrudates are shown on Table 4. lysine and methionine are generally known to be limiting in cereals and legumes respectively. The result showed that the mean values observed for lysine ranged from 3.6 g/100 g to 4.5 g/100 g representing samples containing 20% moisture that was extruded at 130°C and samples containing 25% moisture that was extruded at 120°C, while methionine has the values from 1.4 g/100 g to 2.68 g/100 g representing samples containing 20% moisture that was extruded at 130°C and samples containing 30% moisture that was extruded at 100°C. These results were significantly influenced by the process variables moisture content and temperature at p ≥ 0.01. From the result it is observed that, temperature has a negative effect on the amino acids contents especially lysine; as the process temperature was increased, the amino acid values (especially lysine which is critical) decreased in quantity. Lysine content however increased marginally as the feed moisture was increased, which showed a positive relationship between feed moisture and the amino acids. These behaviour is in agreement with the work of Iwe [10]. The increase in temperature without corresponding increase in feed moisture favours maillard reaction which involves the amino acids, consequently their depletion which leads to losses in the amino acid values. Moisture can however retard maillard reactions; this is because they are by products of the reaction and so increase in feed moisture will favour the reverse reaction.

Excessive maillard browning during extrusion cooking could result in losses of lysine up to 50% was reported by Bruno de Cindio et al. [8]. However changes in the lysine and indeed other essential amino acids obtained in this work showed minimal depletion and in some instances appreciation of the amino acids as in threonine, arginine, valine and phenylalanine, this is in agreement with the work of Guy [28]. Extrusion at low temperature ranges of 100°C to 130°C and high feed moisture in the range of 20% to 30% could also favour the retention of both reducing sugars and the amino acids. The denaturation of proteins

<table>
<thead>
<tr>
<th>Sample</th>
<th>Lysine</th>
<th>Histidine</th>
<th>Threonine</th>
<th>Arginine</th>
<th>Valine</th>
<th>Methionine</th>
<th>Isoleucine</th>
<th>Leucine</th>
<th>Phenylalanine</th>
</tr>
</thead>
<tbody>
<tr>
<td>FAO/WHO</td>
<td>4.2</td>
<td>2.4</td>
<td>2.6</td>
<td>2.0</td>
<td>4.2</td>
<td>2.2</td>
<td>4.2</td>
<td>4.8</td>
<td>2.8</td>
</tr>
<tr>
<td>M0T0</td>
<td>3.7 ± 0.2</td>
<td>2.4 ± 0.4</td>
<td>4.1 ± 0.3</td>
<td>4.9 ± 0.1</td>
<td>5.5 ± 0.5</td>
<td>2.6 ± 0.2</td>
<td>3.9 ± 0.1</td>
<td>8.9 ± 0.6</td>
<td>5.0 ± 0.5</td>
</tr>
<tr>
<td>M1T1</td>
<td>3.7 ± 0.3</td>
<td>2.2 ± 0.3</td>
<td>3.6 ± 0.2</td>
<td>5.1 ± 0.5</td>
<td>4.9 ± 0.6</td>
<td>1.8 ± 0.3</td>
<td>3.6 ± 0.4</td>
<td>7.9 ± 0.4</td>
<td>5.2 ± 0.2</td>
</tr>
<tr>
<td>M2T1</td>
<td>3.8 ± 0.3</td>
<td>2.1 ± 0.6</td>
<td>3.1 ± 0.3</td>
<td>4.7 ± 0.4</td>
<td>4.2 ± 0.3</td>
<td>1.5 ± 0.4</td>
<td>3.5 ± 0.4</td>
<td>6.8 ± 0.3</td>
<td>4.1 ± 0.3</td>
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<tr>
<td>M3T1</td>
<td>4.0 ± 0.4</td>
<td>2.6 ± 0.3</td>
<td>5.9 ± 0.3</td>
<td>6.4 ± 0.3</td>
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<td>4.5 ± 0.3</td>
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<tr>
<td>M1T2</td>
<td>4.0 ± 0.7</td>
<td>1.9 ± 0.5</td>
<td>3.4 ± 0.6</td>
<td>4.7 ± 0.5</td>
<td>4.5 ± 0.5</td>
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<td>7.5 ± 0.4</td>
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<tr>
<td>M2T2</td>
<td>4.5 ± 0.6</td>
<td>2.2 ± 0.6</td>
<td>3.8 ± 0.6</td>
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<td>M3T2</td>
<td>4.4 ± 0.5</td>
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<td>4.9 ± 0.6</td>
<td>5.8 ± 0.2b</td>
<td>4.9 ± 0.6c</td>
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<td>M1T3</td>
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<td>M3T3</td>
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<td>3.4 ± 0.3</td>
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<tr>
<td>Mean</td>
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<td>2.25</td>
<td>3.69</td>
<td>5.47</td>
<td>5.07</td>
<td>2.12</td>
<td>3.715</td>
<td>8.56</td>
<td>4.94</td>
</tr>
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</table>

Key: M1=20% Moisture, M2=25% Moisture, M3=30% Moisture. T1=100°C, T2=120°C, T3=130°C, M0T0=unextruded blend.
and depletion of the antinutritional factors in the cause of the extrusion might have contributed to the appreciation in the values of lysine and other amino acids.

Comparing the essential amino acid profile for the extrudates Table 4 with the recommended values of Nicole et al. [29] and provisional pattern as cited by FAO/WHO [30], the result showed higher values of threonine, arginine, valine, leucine and phenylalanine. They however indicated adequate quantities of lysine, histidine, methionine and isoleucine in most of the extrudates when compared with values. From the result of this study it shows that the level of lysine contents of extrudates increased generally because of inclusion of bambara groundnut flour in the formulation which resulted in increasing the nutritional quality of the product. These values would have been lower if it were just sorghum which is limiting in lysine as a single cereal product. Similar observations have been reported by other authors for blends of cereals and legumes [31]. Lysine was reported to increase by 75% as a result of supplementation of millet with cowpea at (83:17) [32]. They also reported similar increase of other essential amino acids as a result of supplementation; these amino acids include histidine, threonine, valine and i/leucine. Legumes provide a larger protein intake and amino acid balance when consumed with cereals, which significantly improves the protein quality [33]. Protein content of extrudates increased proportionally with increase in the amount of cowpea flour in sorghum [34].

Digestibility is considered the most determinant of protein quality in adults, according to [35]. Although digestibility test was not conducted in this study reported, that protein digestibility value of extrudates is higher than non-extruded products. The possible cause might be denaturation of proteins and inactivation of antinutritional factors that impair digestion especially in bambara groundnut which was used as a basic ingredient in this study. The nutritional value of vegetable protein is usually enhanced by mild extrusion cooking conditions, owing to increase in digestibility [36]. Benefits of beans extrusion – cooking are deactivation of heat labile inhibitors [37]. An advantage of destruction is the destruction of antinutritional factors, especially trypsin inhibitors, haemaggulitins, tannins and phytates, all of which inhibit protein digestibility. Extrusion has been shown to be very effective in reducing or eliminating lectin activity in legume flour [38]. Thus, extrusion cooking is more effective in reducing or eliminating lectin activity as compared with traditional aqueous heat treatment.

Conclusion

The blends of 70% sorghum malt and 30% bambara groundnut were extruded at 100, 120 and 130°C Barrel temperature with feed moistures of 20, 25 and 30% respectively. The process variables have been found to have both positive as well as negative influence on the extrudates. Feed moisture increase was found to increase the reducing sugar content in all the extruded blends but, these properties were negatively affected by increase in barrel temperature. From the results obtained, it can be concluded that increase in the feed moisture has a positive effect on the retention of the essential amino acids while high barrel temperature without corresponding increase in feed moisture resulted in high losses of the essential amino acids. The amino acids profile in the blends met the FAO/WHO [1973] recommended pattern for essential amino acids. The research was based on scientific procedures which can be interpreted for applications with respect to its originality and strategically for an industry-driven programme with the focus of yielding results that can be translated directly into real products for mitigating food security problems in Sub Saharan Africa where malnutrition is prevalent and present a serious problem.

References