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Influence of Processing Methods on Food Components and Glycaemic Index of Cassava-based Traditional Foods

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Abstract: Processing methods affect starch hydrolysis, digestibility, absorption and glycaemic index (GI) of food. Although some studies have reported on the effect of boiling, frying, roasting and baking on glycaemic index of traditional staples, there is limited information on the contribution of drying, fermentation, boiling and steaming on starch bioavailability and glycaemic index. This research work aimed at determining the effect of fermentation, steaming, boiling and drying on starch bioavailability and predicted GI of some cassava-based traditional foods consumed in Ghana. The total starch, amylose, amylopectin, dietary fibre and predicted glycaemic index of the intermediate and finished products were determined according to standard protocols. The analysis established that steaming and boiling increase GI of foods, fermentation has no significant influence on predicted GI of fermented steamed products, and drying has no substantial effect on predicted GI of cassava flour. However, staples or products prepared from solar dried cassava flour would have higher predicted GIs than those of sun dried cassava flour. This work has also provided evidence in support of the fact that total starch and amylopectin give rise to an increase in GI whereas amylose and dietary fibre contents contribute to a decrease in GI of foods. The predicted GIs of raw cassava, boiled cassava (*ampesi*), *akyeke*, cooked *kokonte* with sun dried flour and cooked *kokonte* with solar dried flour were found to be (47.75%), (77.30%), (79.05%), (40.20%) and (61.11%), respectively. Temperature plays a significant role in breaking hydrogen bonds in food molecules causing the release of glucose and subsequently affecting GI. The GI data of these staples may be used in conjunction with other food composition tables for healthy food choices and nutritional counselling. Processors can incorporate more fibre or amylose-containing crops into food products as well as ensure the use of sun or solar drying to produce low glycaemic index food products.

Keywords: Processing Methods, Cassava-based Traditional Staples, Starch Digestibility, Glycaemic Index

1. Introduction

Many processed and traditional foods go through succession of processing operations which may affect their digestibility, absorption and glycaemic index. Processing of cassava involves methods such as cleaning, size reduction, drying, fermentation, cooking methods, heat treatment (pasteurization and sterilization) and many others [1, 2]. These processes improve eating quality, reduce cyanogenic glucosides concentration and its toxicity [3], however, their effects on glycaemic index need to be comprehensively studied.

Research has revealed that, there is great variation in digestion, metabolism and absorption of food (carbohydrate); this variation emanates from the source of the carbohydrate, its composition and the processing methods the foods go through [2, 4]. The glycaemic index (GI) of foods is the measure of the rate of absorption of carbohydrate into the blood after consumption of a meal and is significantly affected by the processing operations [4]. This is because these operations are suggested to cause cell wall disruption, depolymerization, retrogradation, gelatinization and hydrolysis of the carbohydrate to facilitate enzymatic reaction or digestion, for the release of glucose into the blood after consumption or eating [5, 6].

A study on oat and barley flakes revealed that minimal processing operation like size reduction (product thickness) had no significant influence on GI [2], however, Bahado-Singh *et al*. [5] work on sweet potato cultivars established that roasting, baking, frying and boiling have a substantial impact on the GI of these cultivars. Apparently, very limited information is reported on the contribution of drying, fermentation, boiling and steaming on GI of cassava-based traditional foods. A cohort study carried-out on the glycaemic indices of *fufuo, kenkey, banku and tuo-zaafi* also suggested that the differences in GIs of the foods may be due to different processing methods that were used in their preparations [7], but did not account for the extent of the impact of the individual unit operations resulting in the overall GI of the foods. The effects of individual unit operations need to be evaluated separately to actually ascertain the contribution of each operation towards GI reduction or increment. The aim of this work was to determine the influence of processing methods on food components and glycaemic index of cassava-based traditional foods in Ghana.

This paper will contribute to scientific knowledge and effectively enable the use of glycemic index in conjunction with other dietary recommendations for proper management and prevention of diseases.

2. Materials and Methods

2.1. Preparation of Food Staples

Fresh cassava tubers (*Capevars bankye* variety*)* of ten months maturity were obtained from the Crop Research Institute of Ghana at Fumesua-Kumasi. *Ampesi, kokonte* and *akyeke* were prepared following a preliminary standardization process facilitated by a caterer using the schematic flow diagram for local food preparation by Oduro [8]. The food staples were prepared as follows;

(a) *Ampesi* (boiled cassava): 1.5 kg peeled cassava tubers were washed, sliced to a thickness of 2 cm using a stainless steel kitchen knife and boiled for 25 min in 1 L of water with 3 g of salt.

(b) Cooked kokonte: it was prepared from *kokonte* flour. The cassava tubers were chipped using a locally manufactured manual chipper and spread evenly on four separate stainless steel trays (two for sun drying and the other two for solar drying) to dry for 3 days. The sun dried sample was dried at 24 - 30°C from 8:00 am to 5:00 pm each day whereas the solar dried samples was dried continuously in the solar dryer at the temperature of 30 - 62°C. The sample was milled into powder using a locally fabricated hammer mill and was sieved to fine flour of particle size 1 mm. The *kokonte* flour was reconstituted by adding 650 g of the flour to 1.5 L of boiling water while stirring for 5 min to form a smooth cohesive paste.

(c) *Akyeke*: The fresh cassava tubers were peeled, washed and grated using a manual grater. The grated sample was squeezed using a cheese cloth to reduce the moisture content and was left undisturbed for 42 hr to ferment. The fermented dough (cake) was disintegrated and sieved using a 2.00 mm pore-sized sieve. About 200 g of the fermented dough was weighed and cooked by steaming for 8 min to obtain the *akyeke*.

2.2. Sample Preparation and Chemical Analysis

All the food samples including fresh cassava and fermented cassava dough were oven dried at 40°C to less than 15% moisture content, milled and sieved (0.5 mm) to obtain uniform and fine flour for the analysis.

Glucose oxidase/ peroxidase (GOPOD) reagent was obtained from Megazyme Ireland. Amyloglucosidase, α-amylase, urea dimethyl sulfoxide (UDMSO), trichloroacetic acid and all other reagents used for the analysis were purchased from Sigma-Aldrich. The dietary fibre content of the samples was analyzed following the protocol by Prosky *et al*. [9]. Starch content was determined according to Megazyme [10] assay. Eriksson *et al.* [11] protocol was used in analysing the Amylose content. However, Amylopectin content of the samples was estimated by difference. The glycaemic index of the samples was determined according to Goñi *et al.* [12] method.

The predicted glycaemic index of each test food and the control was calculated as the mean GI using glycaemic index estimation module.

2.3. Statistical Analysis

Mean values, standard deviations and significant difference between test samples at 95% confidence level were determined using Microsoft Excel (2010) and Statistical Package for Social Sciences (SPSS) software version 20, respectively. The component and contribution of starch, amylose, amylopectin and dietary fibre contents to the glycaemic indices of the samples were assessed using principal component analysis (PCA).

3. Results and Discussion

The content of total starch, amylose, amylopectin, dietary fibre and predicted glycaemic indices of the fresh cassava, boiled cassava (*ampesi)*, cooked *kokonte* with either sun or solar dried flour, *akyeke*, fermented cassava dough, sun dried *kokonte* flour and solar dried *kokonte* flour samples are presented in Table 1.

3.1. Effects of Processing Methods on Total Starch Content of Samples

The total starch content of the fresh cassava was found to be 42.21%. The starch content of cassava has been reported to be between 26.3 - 39.6% [13] and 38.06% (USDA, 2007) cited in Montagnac *et al*. [14]. The starch content reported in this study was higher compared with reported literature. This difference in starch content may be due to factors such as variety, geographical location, age of plant and environmental conditions [14]. The intermediate products:

sun dried *kokonte* flour sample (38.23%), solar dried *kokonte* flour sample (33.32%) and fermented cassava dough sample (39.81%) had total starch contents lower ($p < 0.05$) than the fresh cassava sample (42.21%). The decrease in total starch content of the samples may be attributed to the different processing methods employed in the study [14]. Processing methods like drying and fermentation convert starches to sugars and other organic acids which contribute to reduction in starch content [15, 16]. It is for this reason that, fermented cassava dough and cassava flour samples had lower starch content than the fresh cassava sample.

Table 1. *Total starch, total dietary fibre, amylose, amylopectin contents and predicted GI for fresh cassava, fermented cassava dough, cassava flour (sun and solar dried), boiled cassava (ampesi), cooked kokonte (sun and solar dried flours) and akyeke samples.*

Sample	Total starch (%)	Amylose (%)	Amylopectin (%)	Dietary fibre (%)	Glycaemic index (%)
Fresh cassava	42.41+.04^{d}	4.23+.09^{bc}	38.18+.52^{d}	1.23+.02^{a}	47.75^{bc}
Fermented cassava dough	39. 81+.24^{c}	3.49+.16^{b}	36.32+.39^{bc}	2.761+.06^{d}	46.47^{b}
Sun dried *kokonte* flour	38.23+.96^{b}	14.74+.33^{g}	23.49+1.07^{a}	1.63+.04^{b}	47.49^{bc}
Solar dried *kokonte* flour	33.32+.09^{a}	8.28+.31^{f}	25.04+.23^{a}	1.21+.01^{a}	48.50^{c}
Cooked *kokonte* (Sun dried flour)	37.19+.24^{b}	2.38+.07^{a}	34. 81+.21^{b}	2.84+.10^{d}	40.20^{a}
Cooked *kokonte* (solar dried flour)	47.07+.80^{f}	4.53+.03^{cd}	42.54+.79^{e}	1.53+.02^{b}	61.11^{d}
Boiled cassava (*Ampesi*)	45.47+.08^{e}	6.91+.33^{e}	38.47+.42^{d}	1.80+.03^{c}	77.30^{e}
Akyeke	42.22+.08^{d}	4.90+.10^{d}	37.21+.29^{cd}	1.19+.05^{a}	79.05^{e}

* Values are means + standard deviation

* Values with the same superscript in a column are not significantly different ($p > 0.05$)

Cooked *kokonte* with solar dried flour recorded the highest starch content (47.07%), followed by boiled cassava (*ampesi*) (45.47%), *akyeke* (42.22%) and cooked *kokonte* with sun dried flour (37.185%) had the lowest. There was a significant difference ($p < 0.05$) among all the finished food samples. Boiled cassava (*ampesi)* (45.47%) and cooked *kokonte* with solar dried flour (47.07%) had a significant ($p < 0.05$) increase in their total starch contents compared with fresh cassava (42.41%). The increase in starch content in boiled cassava (*ampesi)* and cooked *kokonte* with solar dried flour is due to increased degradation of food structure during boiling [17, 18]. This permits amylase penetration into the starch granules to allow for hydrolysis and estimation of more starch [19, 20]. The total starch content of cooked *kokonte* with sun dried flour (37.19%) was significantly lower ($p < 0.05$) than cooked *kokonte* with solar dried flour (47.07%). The variation may be a result of increased degree of starch gelatinization due to high temperature recorded in solar dried (28 – 62°C) kokonte flour than sun dried (23 – 30°C) kokonte flour. Studies have discovered that increasing drying temperature makes starch accessible by hydrolytic enzymes and available for estimation [21]. Cooked *kokonte* with solar dried flour, boiled cassava (*ampesi*) and *akyeke* are high starch yielding foods, and are good for consumers with high energy requirement.

3.2. Effects of Processing Methods on Amylose Content of Samples

The amylose contents of the samples were within 2 – 15% and are relatively lower since they are below 20% on the general amylose standard scale [22, 23]. Among the intermediate products; sun dried *kokonte* flour recorded the highest amylose content (14.74%), followed by solar dried *kokonte* flour (8.28%) whiles fermented cassava dough had the least (3.49%). Both *kokonte* flours (sun and solar dried) went through some sort of heat treatment and hence the conversion and hydrolysis of amylopectin at the amorphous regions of the starch granules to amylose was greatest [24]. However, there was significant difference ($p < 0.05$) between the amylose contents of the different flours. This variation may be due to different drying temperatures recorded [25]. The fermented cassava dough sample recorded significantly ($p < 0.05$) lower amylose content compared to the other intermediate products (sun dried *kokonte* flour and solar dried *kokonte* flour) and fresh cassava sample. The reduction in amylose content of fermented cassava dough was due to an increased oxidative depolymerisation of the amylose during the fermentation process [26]. Oxidative depolymerisation involves the use of an enzyme system (glucosidase, amylase, cellulase, chitinase, inulinase, phytase, xylanase, tannase, esterase, invertase or lipase) to hydrolyse glucosides, cell wall or starch and other high molecular weight components of food [27]. These enzymes produced in the course of the fermentation are able to hydrolyse amylose, thereby, reducing its content in the fermented product [26]. This makes fermented products more digestible for consumers and creates market opportunity for food products that involve fermentation.

The amylose contents of the finished products: *akyeke*, boiled cassava (*ampesi*), cooked *kokonte* with sun dried flour and cooked *kokonte* with solar dried flour samples were found to be 4.90%, 6.91%, 2.36% and 4.53% respectively. There were significant differences among the finished products except between *akyeke* and cooked *kokonte* from solar dried flour at 5% significance level. Boiled cassava (*ampesi)* recorded slight increase in amylose content, and this increase may be due to the conversion of amylopectin to amylose and leaching of amylose that occurs during boiling [28, 29]. The low amylose recorded for *akyeke* could be attributed to formation of amylose–lipid complex that occurs during steaming, making amylose less extractable as explained by Holm *et al*. [30] and Leeman *et al*. [31]. The higher amount of amylose recorded in cooked *kokonte* with solar dried flour (4.53%) compared with that of cooked *kokonte* with sun dried flour (2.38%) can be ascribed to leaching of amylose that transpired predominantly in solar drying than sun drying [29, 32, 33].

3.3. Effects of Processing Methods on Amylopectin Content of Samples

The amylopectin content of the samples ranged between 23.49 – 42.54%. Fresh cassava had amylopectin content of 38.18% which was lower than the value of 77.05% reported by Aliyu and Aliyu [34]. This variation in amylopectin content might have resulted from physiological factors such as variety used, age and native structure of the tubers and the method of determination of total starch and amylose since amylopectin was determined by difference [18, 35]. The amylopectin contents of sun dried *kokonte* flour and solar dried *kokonte* flour were 23.49% and 25.04% respectively. The heat generated during the course of drying causes conversion of amylopectin to amylose [29] and starch to other simple sugars [36]. The difference in the amylopectin contents of the two *kokonte* or cassava flours was not significant ($p > 0.05$), implying that the different drying methods (sun or solar drying) have almost equal effects on amylopectin contents of the intermediate products. However, there was high disparities between the amylopectin content of fermented cassava dough (36.32%), *kokonte* flour; sun dried (23.49%) and *kokonte* flour; solar dried (25.04%) at 5% significance level. This is because during drying more of amylopectin is converted to amylose as stated by Vesterinen *et al*. [29] than in the case of fermentation and hence the observed variation.

The amylopectin contents of boiled cassava (*ampesi)*, cooked *kokonte* with solar dried flour, cooked *kokonte* with sun dried flour and *akyeke* samples were 38.47%, 42.54%, 34.81% and 37.21% respectively. There was a significant difference ($p < 0.05$) among the amylopectin contents of boiled cassava (*ampesi)*, cooked *kokonte*; sun dried flour and cooked *kokonte* with solar dried flour. The difference might have resulted from the reduced particle size of the flours and stirring whiles boiling that occurred in the cooking process of *kokonte.* Studies have discovered that reduced particle size, stirring and boiling facilitate starch hydrolysis and conversion of amylopectin to amylose [37, 38]. Cooked *kokonte* with solar dried flour sample recorded the highest amount of amylopectin content (42.54%) relative to cooked *kokonte* with sun dried flour sample (34.81%) due to the degree of amylopectin leaching from starch granules. Leaching of amylopectin from starch granules is optimal at 40-50°C as reported by Tester and Morrison [39], implying that solar dried flour (28 – 62°C) is more susceptible to starch gelatinization and amylopectin leaching during boiling than sun dried flour (23 – 30°C) and this could account for the differences in amylopectin contents of cooked *kokonte* with solar dried flour and cooked *kokonte* with sun dried flour. Starch gelatinization and amylopectin leaching is high at high temperature [21, 39] and solar dried kokonte flour recorded the highest temperature compared with the sun dried sample. *Akyeke* had moderate amount of amylopectin (37.21%) relative to the other finished products. This is because during steaming, there is increased starch hydrolysis as compared to boiling [40].

3.4. Effects of Processing Methods on Dietary Fibre Content of Samples

The dietary fibre contents of the samples ranged between the values of 1.19 – 2.84%. The dietary fibre content of fresh cassava (1.22%) was within the values 0.1 – 3.7% reported by Montagnac *et al*. [14] and varied slightly from the work (1.8%) of Onyenwoke and Simonyan [41]. This variability could be due to the variety and age of cassava used [41, 42]. The intermediate products: solar dried *kokonte* flour, sun dried *kokonte* flour and fermented cassava dough recorded dietary fibre contents of 1.21%, 1.63% and 2.76%, respectively. There were significant ($p < 0.05$) differences in the dietary fibre contents of the intermediate products, and this may be due to differences in unit operations undertaken in each sample. Drying causes leaching of amylose from starch granules giving rise to the potential subsequent formation of retrograded starches [29]. These starches are resistant to enzyme hydrolysis and therefore contribute to an increase in dietary fibre content of the flours. The formation of retrograded starches is dependent on intermittent temperature transitions, and it was prominent in sun drying than solar drying. The fermented cassava dough had highest dietary fibre content amongst all the intermediate products because of the inhibitory activity of the organic acids (produced during the fermentation process) on hydrolytic enzymes [15].

Cooked *kokonte* with sun dried flour, boiled cassava (*ampesi)* and cooked *kokonte* with solar dried flour samples recorded considerable amounts of dietary fibre 2.84%, 1.80% and 1.53% respectively. This increase is due to leaching of amylose from the starch granules during the heat application. Boiling has been reported to cause amylose leaching and the potential subsequent formation of retrograded or resistant starches; which form part of the indigestible component of the food (dietary fibre) [20, 33]. However, *akyeke* recorded a decrease in dietary fibre content compared with the other finished products, though the intermediate product (fermented cassava dough) used for its preparation had a high dietary fibre content (2.76%). This is because during steaming, there is complete starch gelatinization and destruction of intermolecular hydrogen bonds thereby reducing the resistant ability of retrograded starches to hydrolytic enzymes [40, 43].

3.5. Combined Effects of Total Starch, Amylose, Amylopectin and Dietary Fibre on Predicted Glycaemic Index of Samples

Principal component analysis (PCA) was conducted on the data sets to reduce the dimension of the data, to visualize the similarities and differences between the samples and to describe which category variable is responsible for the variation in the data sets. This will assist in analysing the contribution of starch, amylose, amylopectin and dietary fibre to the glycaemic indices of the samples. The scores and loadings of a PCA plot help to explain the interrelationships and impacts of variables on the trend or behaviour of a phenomenon [44]. Figures 1 and 2 shows the PCA scores and loading plots of samples and their determined parameters, respectively.

It can be deduced from the two PCA plots that, total starch and amylopectin contents correlated positively with an increase in glycaemic index whereas dietary fibre and amylose contents correlated negatively with a corresponding decrease in glycaemic index of the samples. This implies that high dietary fibre and amylose contents contribute to lower glycaemic index while high total starch and amylopectin contents increase glycaemic index of cassava-based staples, except other factors help to reduce it.

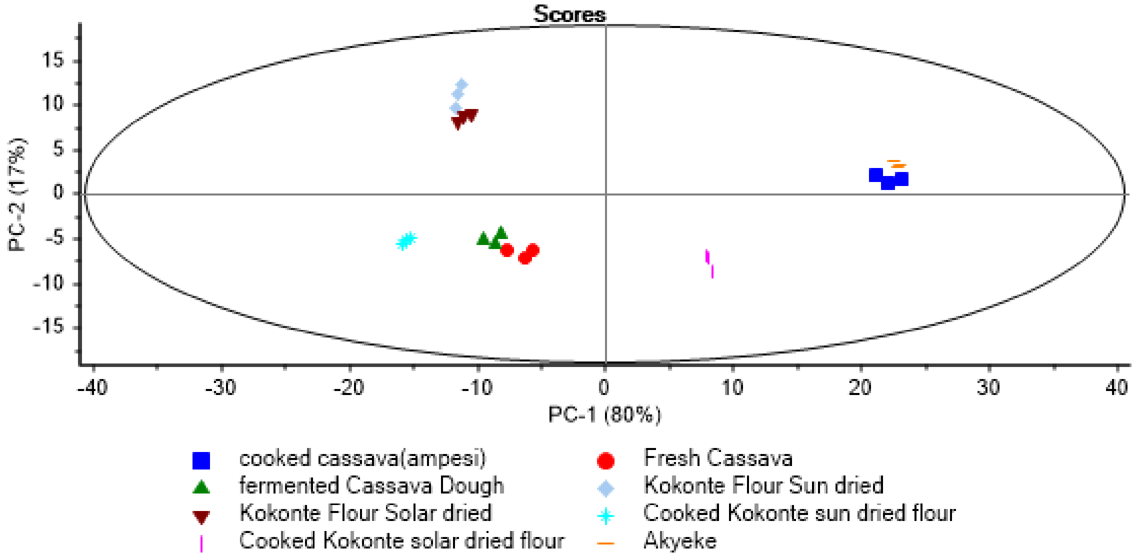

Figure 1. *PCA scores of Glycaemic index of samples.*

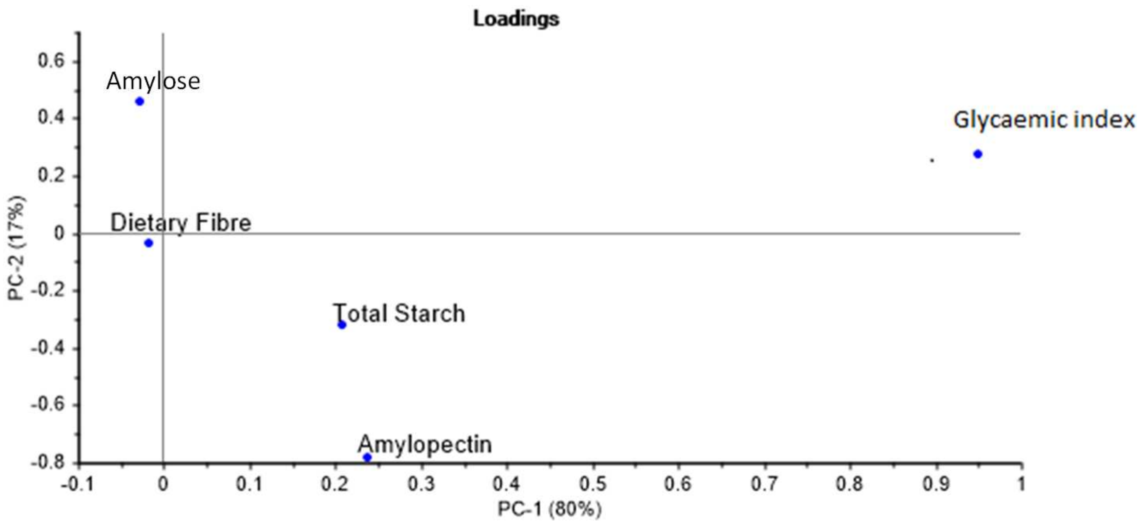

Figure 2. *PCA loadings of total starch, amylose, amylopectin, dietary fibre and GI of samples.*

3.6. Effects of Processing Methods, Total Starch, Amylose, Amylopectin and Dietary Fibre on Predicted Glycaemic Index of Samples

From Table 1, fresh cassava, sun dried *kokonte* flour, cooked *kokonte* with sun dried flour, solar dried *kokonte* flour and fermented cassava dough had predicted glycaemic index values of 47.75%, 47.49%, 40.20%, 48.50% and 46.47%, respectively. Their GI values are described as low because they fall within the low (0 – 55%) glycaemic index chart [20]. The analysis revealed that, fresh cassava has high amount of starch and amylopectin than amylose and dietary fibre, and was therefore, expected to have a GI value more than what was reported in the study. This deviation may be due to the fact that, the cassava was raw and the botanical or gross structure of cassava was intact, making starch inaccessible for hydrolysis into glucose by the hydrolytic enzymes [33]. The lower and slower the release of glucose from uncooked and unprocessed starch, the lower glycaemic response and the estimated glycaemic index [45]. Consumers and patients with diabetic conditions can resort to consumption of foods with minimal processing. Processors may consider limiting the level of processing operations in order to produce low glycaemic index products.

Sun *dried Kokonte* flour and solar dried kokonte flour recorded a lower glycaemic index. They all had considerable amounts of amylose and dietary fibre and therefore expected to have a lower glycaemic index values [46, 47]. Sun dried *Kokonte* flour recorded significant ($p < 0.05$) amount of amylose and dietary fibre than solar dried *kokonte* flour. However, the difference in the glycaemic indices of *kokonte* flour (sun dried) and *kokonte* flour (solar dried) was insignificant ($p > 0.05$). This suggests that cassava flour producers can employ sun or solar drying in their operations in order to produce low glycaemic index flour.

Fermented cassava dough; an intermediate product used in preparation of *akyeke,* also recorded a lower glycaemic index value of 46.47% and shown a slight decrease from the fresh cassava (47.75%), yet there was no significant difference ($p > 0.05$) between them. The fermented cassava dough has higher quantities of amylopectin and starch, and was therefore expected to elicit good amount of glucose upon hydrolysis [7, 17] but differed. This observed variation might have resulted from the high dietary fibre content [46] and the production of organic acids during the course of the fermentation [15]. These organic acids are postulated to inhibit the activity of hydrolytic enzymes during starch hydrolysis and hence the reduced GI recorded [15]. Consumers and diabetic patients should cultivate the habit of consuming fermented and high dietary fibre foods to augment their health and medical conditions. Processors may also look at incorporating more fibre into food products, in order to reduce their GIs.

This study revealed *akyeke* (79.05%) and boiled cassava; *ampesi* (77.03%) to be high (70 – 100%) glycaemc index foods [20] and having high concentrations of total starch and amylopectin which are major contributing factors to high glycaemic index foods. The value recorded for *akyeke* varied slightly from the work (63.0%) done by Kouame *et al*. [48] who used in-vivo method of GI determination. The difference in this case is due to the method of analysis and preparation of food. The GI of *akyeke* was significantly higher than that of *ampesi* though they all went through some form of heat treatment operation. Studies have revealed that steaming causes high degree of gelatinization than boiling [43]. The *akyeke* was prepared by steaming fermented cassava dough, and this contributed to an increase in the GI. Steaming has been reported to cause complete gelatinization of starch and destroy the intermolecular hydrogen bonds between organic acids produced in the course of the fermentation process [40, 43].

Boiled cassava (*ampesi)* also had a high glycaemic index value of 77.30% and is well correlated with 78.70% reported by Pirasath *et al*. [49]. Boiled cassava (*ampesi*) has high amounts of total starch and amylopectin, and therefore expected to produce more glucose into blood and compound the adverse effect of glucose on diabetic patients and regular consumers [50]. Boiling of food stuff in water has been suggested to modify the physical and chemical states of starch and improve its digestibility by hydrolytic enzymes [51]. It has been established that, starch granules absorb water and swell (gelatinization) during boiling which disrupts the crystalline structure of starch irreversibly, making it susceptible to hydrolysis by amylase and hereafter an increase in glycaemic index of such foods [32, 52]. It has also been appreciated that the cooking method, amount of water and duration of boiling (cooking) significantly affect the level of gelatinization and digestibility of the starch, and this also account for differences in glycaemic index of some boiled staples [33, 40]. Boiled cassava (*ampesi)* can be consumed with other food ingredients with lower glycaemic index or consumers may minimize its consumption to reduce effects on their health.

The predicted glycaemic indices of cooked kokonte with sun dried flour and cooked kokonte with solar dried flour were 40.20% and 61.11% correspondingly. Cooked *kokonte* with solar dried flour contains higher amounts of total starch and amylopectin, and less of dietary fibre compared with cooked *kokonte* with sun dried flour. It is therefore expectant of cooked kokonte with solar dried flour to elicit more glucose, glycaemic response and glycaemic index. The GI of the cooked *kokonte* with sun dried flour was significantly ($p < 0.05$) lower than that of solar dried, and this variation could be accounted for by the differences in their total starch, amylopectin and dietary fibre contents as well as drying temperature. Studies have shown that drying reduces the moisture content; which causes partial starch gelatinization, loss of starch granules and low digestibility [25], giving rise to low or moderate glycaemic index products [53]. The heating and cooling regimes or transitions involved in drying has been reported to facilitate formation of high resistant starches concentration [37, 38] and amylose-lipid complex thereby reducing starch hydrolysis [30]. This may be responsible for the low and moderate glycaemic index recorded in cooked *kokonte* with sun dried flour (23 – 30°C) and cooked *kokonte* with solar dried flour (28 – 62°C), respectively. The higher temperature of the solar dried *kokonte* flour might have contributed to an increased starch hydrolysis, glucose response and moderate glycaemic index value. Consumption of cooked *kokonte* may decrease the risk of postprandial blood glucose rise, and prove to be more efficacious in the management of type 2 diabetes mellitus and cardiovascular diseases.

4. Conclusion

Processing methods or operations affect starch digestibility and glycaemic index of food samples. Steaming and boiling increase the GI of foods, fermentation (period of 42 hrs) has no significant effect on GI of fermented steamed cassava products, and drying of cassava has no substantial effect on GI of cassava flour. However, staples or products prepared from solar dried cassava flour would have higher GIs than those of sun dried cassava flour. High total starch and amylopectin give rise to an increase in GI whereas high amylose and dietary fibre contents contribute to a decrease in GI of foods.

The predicted GIs of cassava (47.75%), boiled cassava (*ampesi)* (77.30%), *akyeke* (79.05%), cooked *kokonte* with sun dried flour (40.20%) and cooked *kokonte* with solar dried flour (61.11%) were established. The dietary fibre content of *Capevars bankye* flour was found to be 1.631% and 1.214% for sun and solar drying processes, respectively. The GI data of these staples may be used in conjunction with other food composition tables for food choices and nutritional counselling. Processors can incorporate more fibre or amylose-containing crops as well as ensure the use of sun or solar drying to produce low glycaemic index food products.

Conflict of Interest

We (the authors) declare that we do not have any conflict of interest.

Ethical Review

This study does not involve any human or animal testing.

Appendix

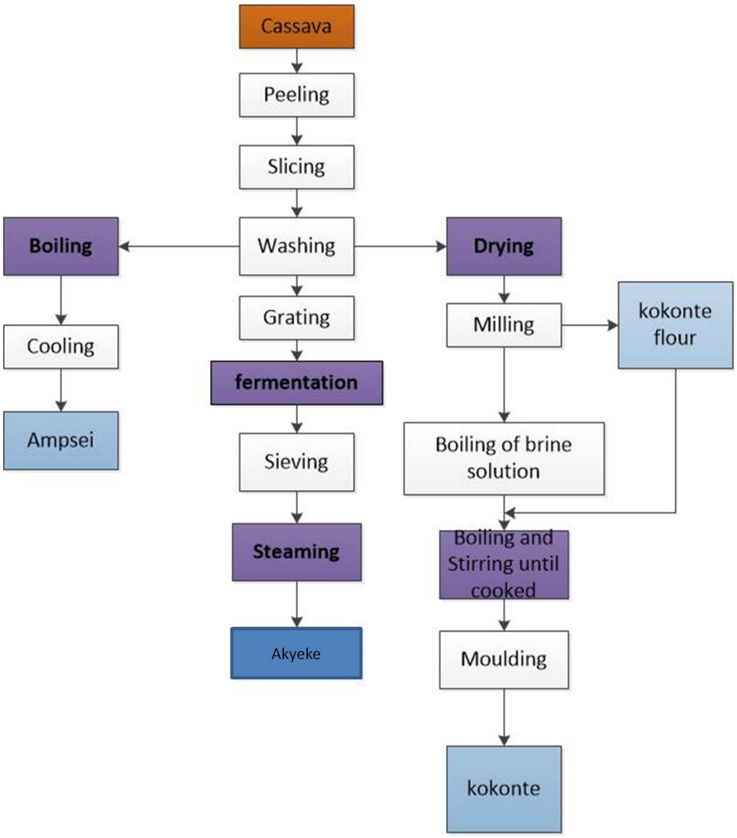

Figure 3. *Schematic flow for the preparation of ampesi, akyeke and cooked kokonte.*

References

[1] Food and Agriculture Organization (FAO) (2011) 'Processing and Preservation; Junior Farmer Field and Life School - Facilitator's guide', pp. 1-44. Available at: JFFLSmodule_8_L02.

[2] Granfeldt, Y., Eliasson, A. and Bjo, I. (2000) 'Human Nutrition and Metabolism An Examination of the Possibility of Lowering the Glycemic Index of Oat and Barley Flakes by Minimal Processing', (May), pp. 2207–2214.

[3] Food and Agriculture Organization (FAO) and International fund for Agricultural Development (IFAD) (2005) 'A review of cassava in Africa with country case studies on Nigeria, Ghana, the United Republic of Tanzania, Uganda and Benin', Proceedings of the Validation Forum on the Global Cassava Development Strategy, Publishing Management Service, Information Division, FAO - Rome 2: 1–66.

[4] Omoregie, E. S. and Osagie, A. U. (2008) 'Glycemic indices and glycemic load of some Nigerian foods', Pakistan Journal of Nutrition, 7 (5), pp. 710–716. doi: 10.3923/pjn.2008.710.716.

[5] Bahado-Singh, P. S., Riley, C. K., Wheatley, A. O. and Lowe, H. I. C. (2011) 'Relationship between processing method and the glycemic indices of ten sweet potato (Ipomoea batatas) cultivars commonly consumed in Jamaica', *Journal of Nutrition and Metabolism*, 2011. doi: 10.1155/2011/584832.

[6] Chung, H., Lui, Q., Pauls, K. P., Fan, M. Z. and Yada, R. (2008) 'In vitro starch digestibility, expected glycemic index and some physicochemical properties of starch and flour from common bean (Phaseolus vulgaris L.) varieties grown in Canada', *Food Research International*. Elsevier Ltd, 41 (9), pp. 869–875. doi: 10.1016/j.foodres.2008.03.013.

[7] Eli-Cophie, D., Agbenorhevi, J. K. and Annan, R. A. (2017) 'Glycemic index of some local staples in Ghana', *Journal of Food Science and Nutrition*, 5 (1), pp. 131–138. doi: 10.1002/fsn3.372.

[8] Oduro, I. N. (2016) 'Tropical Roots and Tubers – Production, Processing and Technology', 1, pp. 447–474.

[9] Prosky L., Asp N. G., Schweizer T. F., DeVries J. W. and Furda I. (1988)' Determination of insoluble, soluble, and total dietary fiber in foods and food products: interlaboratory study'. *Journal- of Association of Official Analytical Chemists*; 71 (5): 1017-1023.

[10] Megazyme International (2011) 'Total Starch Assay Procedure; amyloglucosidase/ α-amylase method', 11: pp. 1-24. Available from: https://secure.megazyme.com/files/BOOKLET/ K-TSTA-50A/K-TSTA-100A 06/17 _DATA. pdf. Accessed 2018 January 21

[11] Eriksson, E., Koch, K., Tortoe, C., Akonor, P. T. and Baidoo, E. (2014) 'Physicochemical, Functional and Pasting Characteristics of Three Varieties of Cassava in Wheat Composite Flours', *British Journal of Applied Science & Technology*, 4 (411), pp. 1609–1621. doi: 10.5923/j.fph.20140405.02.

[12] Goñi, I., Garcia-Alonso, A. and Saura-Calixto, F. (1997) 'A starch hydrolysis procedure to estimate glycemic index', *Journal of Nutrition Research*, 17 (3), pp. 427–437. doi: 10.1016/S0271-5317(97)00010-9.

[13] Richardson, V. A. K. (2013) 'Quality Characteristics, Root Yield And Nutrient Composition of Six Cassava (*Manihot Esculenta Crantz*) Varieties', *Gladstone Road Agriculyural Centre*, (18), pp. 1–13.

[14] Montagnac, J. A., Davis, C. R. and Tanumihardjo, S. A. (2009) 'Nutritional value of Cassava for Use as a Staple Food and Recent Advances for Improvement', *Comprehensive Reviews in Food Science and Food Safety* 8, pp. 181-194.

[15] Ostman, E. (2003) 'Fermentation as a Means of Optimizing the Glycaemic Index; Food Mechanisms and Metabolic Merits with Emphasis on Lactic Acid in Cereal Products', Reprocentralen, Center of Chemistry and Chemical Engineering, Lund University, Sweden. ISBN 91-7422-016-0

[16] Ihekoronye, A. I. and Ngoody, P. O. (1985), Tropical Roots and Tubers in: Integrated Food Science and Technology for the tropics, Macmillan, London, 266-282.

[17] Arvidsson-Lenner, R., Asp, N. G., Axelsen, M., Bryngelsson, S., Haapa, E., Järvi, A., Karlström, B., Raben, A., Sohlström, A., Thorsdottir, I. and Vessby, B. (2004) 'Glycaemic index', *Scandinavian Journal of Nutrition*, 48 (2), pp. 84–94. doi: 10.1080/11026480410033999.

[18] Bjorck, I., Granfledt, Y., Liljeberg, H., Tovar, J. and Asp, N. G. (1994) 'Food properties affecting the digestion and absorption of carbohydrates', *American Journal of Clinical Nutrition*, 59, 699S-705S

[19] Urooj, A. and Puttraj, S. (1999) 'Digestibility index and factors affecting rate of starch digestion in vitro in conventional food preparation', Starch/Staerke 1999; 51: 430-435.

[20] Eleazu, C. O. (2016) 'The concept of low glycemic index and glycemic load foods as panacea for type 2 diabetes mellitus; prospects, challenges and solutions', *Journal of African Health Sciences*, 16 (2), pp. 468–479. doi: 10.4314/ahs.v16i2.15.

[21] Harper, J. M. (1995) 'Extrusion technology: current status and future potential', *South African Journal of Food Science and Nutrition*; 7 (4): 135-141.

[22] Chen, M. and Bergman, C. J. (2007) 'Method for determining the amylose content, molecular weights, and weight- and molar-based distributions of degree of polymerization of amylose and fine-structure of amylopectin q', 69, pp. 562–578. doi: 10.1016/j.carbpol.2007.01.018.

[23] Odenigbo, A. M., Ngadi, M., Ejebe, C., Nwankpa, C., Danbaba, N., Ndindeng, S. and Manful, J. (2013) 'Study on the Gelatinization Properties and Amylose Content of Rice Varieties from Nigeria and Cameroun', *International Journal of Nutrition and Food Sciences* 2 (4), pp. 181–186. doi: 10.11648/j.ijnfs.20130204.14.

[24] Numfor, F. A., William, M. W. and Steven, J. S. (1995) 'Physicochemical changes in cassava starch and flour associated with fermentation: Effect on textural properties', *Journal of Agricultural Chemical Society,* 47: 86-91.

[25] Jaisut, D., Prachayawarakorn, S., Varanyanond, W., Tungtrakul P. and Soponronnarit S. (2008) 'Effects of drying temperature and tempering time on starch digestibility of brown fragrant rice', *Journal of Food Engineering,* 86 (2): 251-258.

[26] Maldonado, P., Grosmaire, L., Dufour, D., Giraldo, A., Sánchez, T., Calle, F., Alonso, M., Santander, M., Ceballos, H., Louis, J. and Tran, T. (2013) 'Combined effect of fermentation, sun-drying and genotype on breadmaking ability of sour cassava starch', Carbohydrate Polymers. Elsevier Ltd., 98 (1), pp. 1137–1146. doi: 10.1016/j.carbpol.2013.07.012.

[27] Jin, S. Yuan, S., Kim, Y., Choi, I. and Kim, G. (2014) 'Effects of fermentation on the antioxidant activity in plant-based foods', Food Chemistry, Elsevier Ltd, 160, pp. 346–356. doi: 10.1016/j.foodchem.2014.03.112.

[28] Holm, J., Lundquist, I., & Bjorck, I. (1988), Degree of starch gelatinization, digestion rate of starch in vitro and metabolic respose of rats, *American Journal of Clinical Nutrition*, 47: 1010-1016.

[29] Vesterinen, E., Suortti, T. and Autio, K. (2001) 'Effects of Preparation Temperature on Gelation Properties and Molecular Structure of High-Amylose Maize Starch', *American Association of Cereal Chemists*, 442 (C), pp. 442–446.

[30] Holm, J., Bjorck, I. and Ostrowska S. (1983), Digestibility of amylose-lipid complexes in vitro and in vivo, *Starke*, 35: 294-7.

[31] Leeman, M., Ostman E. and Bjorck, I. (2008) 'Glycemic and satiating properties of potato products', *European Journal of Clinical Nutrition*, 62: 87-95.

[32] Englyst, H. N., & Cummings, J. H. (1987) 'Digestion of polysaccharides of potato in the small intestine of man', *American Journal of Clinical Nutrition*, 45, 423–431

[33] Nayak, B., Berrios, J. D. J. and Tang, J. (2014) 'Impact of food processing on the glycemic index (GI) of potato products', FRIN. Elsevier Ltd, 56, pp. 35–46. doi: 10.1016/j.foodres.2013.12.020.

[34] Aliyu, B. A. and Aliyu, K. B. (2014) 'Re-inventing the production of adhesive from Cassava starch as a career opportunity in chemistry education', *International Letters of Natural Sciences*, 18, pp. 12–19. doi: 10.18052/www.scipress.com/ILNS.18.12.

[35] Bahado-Singh P. S., Asemota H. N., Morrison E., Ahmad M. H. and Wheatley, A. O. (2006) 'Food processing methods influence the glycaemic indices of some commonly eaten West Indian carbohydrate-rich foods'. *British Journal of Nutrition*, 2006; 96: 476-81

[36] Batra, M., Sharma, S. and Seth V. (1994) 'The glycemic index of fermented and non-fermented legume-based snack food', *Asia Pacific Journal of Clinical Nutrition*, 3: 151-154.

[37] Ogbo, F. C. and Okafor, E. N. (2015) 'The resistant starch content of some cassava based Nigerian foods', *Nigerian Food Journal*. Elsevier, 33 (1), pp. 29–34. doi: 10.1016/j.nifoj.2015.04.007.

[38] Donlao, N. and Ogawa, Y. (2016) 'Impact of postharvest drying conditions on in vitro starch digestibility and estimated glycemic index of cooked non-waxy long-grain rice (Oryza sativa L.)', *Journal of Science, Food and Agriculture*; (May), pp. 1–6. doi: 10.1002/jsfa.7812.

[39] Tester, R. F. and Morrison, W. R. (1990) 'Swelling and Gelatinization of Cereal Starches. I. Effects of Amylopectin, Amylose, and Lipids '', *American Association of Cereal Chemists*, 67 (October 1988), pp. 551–557

[40] Daomukda, N., Moongngarm, A., Payakapol, L. and Noisuwan, A. (2011) 'Effect of Cooking Methods on Physicochemical Properties of Brown Rice', *International Conference on Environmental Science and Technology press*, Singapore, 6: 1–4.

[41] Onyenwoke, C. A. and Simonyan, K. J. (2014) 'Cassava post-harvest processing and storage in Nigeria : A review', *African Journal of Agricultural Research*, 9 (53), pp. 3853–3863. doi: 10.5897/AJAR2013.8261.

[42] Sarkiyayi, S. and Agar, T. M. (2010) 'Comparative analysis on the nutritional and anti-nutritional contents of the sweet and bitter cassava varieties', *Advance Journal of Food Science and Technology*, 2 (6): 328-334. ISSN: 2042-4876

[43] Kale, S. J., Kale, P. N. and Jha, S. K. (2017) 'Effects of Parboiling Steps on Starch Characteristics and Glycemic Index Of Basmati', *International Journal of Agriculture Sciences*, (October), pp. 4826-4831. ISSN: 0975-3710

[44] Tharwat, A. (2017) 'Principal component analysis - a Tutorial', ResearchGate, (January 2016), pp. 1–42. doi: 10.1504/IJAPR.2016.079733.

[45] Brand, J. C., Nicholson, P. L., Thorburn, A. W. and Truswell, A. S. (1985) 'Food processing and the glycemic index', *American Journal of Clinical Nutrition*, 42: 1192-1196.

[46] Scazzina, F., Siebenhandl-ehn, S. and Pellegrini, N. (2013) 'Review Article: The effect of dietary fibre on reducing the glycaemic index of bread', *British Journal of Nutrition*, pp. 1163–1174. doi: 10.1017/S0007114513000032.

[47] Lu, Z. X., Walker, K. Z. and Muir, J. G. (2000), Arabinoxylan fiber, a byproduct of wheat flour processing, reduces the postprandial glucose response in normoglycemic subjects, *American Journal of Clinical Nutrition*, 71: 1123–1128.

[48] Kouamé, A. C., Kouassi, K. N., Yao, D. N. and Amani, N. G. (2015) 'Glycaemic Index and Load Values Tested in Normoglycemic Adults for Five Staple Foodstuffs: Pounded Yam, Pounded Cassava-Plantain, Placali, Attieke and Maize Meal Stiff Porridge', (Gl 29), pp. 1267–1281. doi: 10.3390/nu7021267.

[49] Pirasath, S., Balakumar, S. and Arasaratnam, V. (2015) 'Endocrinology & Metabolic Syndrome Glycemic Index of Traditional Foods in Northern Sri Lanka', 4 (1), pp. 1–6. doi: 10.4172/2161-1017.1000154.

[50] Jenkins, D. J. A., Wolver, T. M. S., Buckley, G., Lam, K. Y., Giudici, S., Kalmusky, J., Jenkins, A. L., pattern, R. L., Bird, J., Wong, G. S. and Josse, R. G. (1988) 'Low glycemic index starchy foods in the diabetic diet', *American Journal of Clinical Nutrition* 48, 284-254.

[51] Kouassi, N. K., Tiahou, G. G., Abodo, J. R. F., Camara-Cisse, M. and Amani, G. N. (2009) 'Influence of Variety and Cooking methods on Glycemic Index of Yam', *Pakistan Journal of Nutrition,* 8 (7): 993-999.

[52] Soh, N. L. and Brand-Miller, J. (1999) 'the glycemic index of potatoes: The effect of variety, cooking method and maturity', *European Journal of Clinical Nutrition*, 53, 249–254.

[53] Omolola, A. O., Jideani, A. I. O. and Kapila, P. F. (2015), Quality properties of fruits as affected by drying operation, *Critical Reviews in Food Science and Nutrition*, 57: 95-108.