**Journal of Food and Nutrition Sciences**
2021; 9(3): 64-72
http://www.sciencepublishinggroup.com/j/jfns
doi: 10.11648/j.jfns.20210903.11
ISSN: 2330-7285 (Print); ISSN: 2330-7293 (Online)

# Influence of potato Variety on Phenolic Content, *In-vitro* Starch Digestibility and Predicted Glycaemic Index of Crisps and Chips from Nyandarua County, Kenya

**Marliyn Wangui Muthee, Joseph Ochieng Anyango*, Joseph Wafula Matofari**

Department of Dairy and Food Science and Technology, Egerton University, Njoro, Kenya

**Email address:**
ajochieng@egerton.ac.ke (J. O. Anyango)
*Corresponding author

**To cite this article:**
Marliyn Wangui Muthee, Joseph Ochieng Anyango, Joseph Wafula Matofari. Influence of potato Variety on Phenolic Content, *In-vitro* Starch Digestibility and Predicted Glycaemic Index of Crisps and Chips from Nyandarua County, Kenya. *Journal of Food and Nutrition Sciences*. Vol. 9, No. 3, 2021, pp. 64-72. doi: 10.11648/j.jfns.20210903.11

**Received**: May 1, 2021; **Accepted**: May 19, 2021; **Published**: May 27, 2021

**Abstract:** With the changing of lifestyles globally, the demand for ready-to-eat (RTE) foods has increased. However, most of these RTE foods have been associated with intermediate (55-70) to high glycaemic index (GI) (>70) linked to high incidences of type 2 diabetes. Nyandarua County in Kenya is a major producer and consumer of potato and has the second highest type 2 diabetes prevalence (10.8%). Therefore, there is need to investigate whether there is a relationship between the potato and potato products consumed and the high type 2 diabetes prevalence. Total phenolic content (TPC), dry matter, and the levels of rapidly digestible starch (RDS), slowly digestible starch (SDS) and resistant starch (RS) may vary depending on potato variety and the form of the product, and may affect the rate and extent of starch digestibility, which affects the GI. This study investigated the effects of variety and processing method (product form) on the levels of TPC, dry matter, RDS, SDS, RS and GI in chips and crisps prepared from 3 potato varieties (*Shangi, Dera mwana* and *Dutch Robijn*). Potato variety significantly affected TPC, RDS, SDS and GI but did not significantly affect RS ($p>0.05$). Processing method results in different product forms which significantly affected dry matter content and GI ($p<0.05$). Higher levels of TPC and lower scores of GI were found in chips and crisps prepared from *Dera mwana variety*. Significant positive correlation relationships were observed between GI, and RDS and SDS ($p < 0.05$), and RDS and SDS ($p<0.05$). This study recommends reduced consumption of chips prepared from *Shangi* in favour of *Dera mwana* variety which has better potential for glycemic control.

**Keywords:** Potato, Starch Digestibility, Glycaemic Index, Nyandarua

## 1. Introduction

As a result of lifestyle changes due to time constraints and family responsibilities [1], consumer needs have been changing and the need for convenience has been on the rise [2]. This has resulted in a change in dietary patterns and a rise in the demand for 'convenience' foods or ready-to-eat (RTE) foods [3]. Although these RTE foods conserve time, they have been associated with health issues such as obesity, type 2 diabetes, hypertension and cardiovascular diseases [4]. Type 2 diabetes refers to a condition caused by impaired secretion of insulin and insulin resistance resulting in high glycaemic levels (hyperglycaemia) as there is reduced uptake of glucose [5]. The prevalence of type 2 diabetes in particular is increasing rapidly on a global scale [6], and is becoming a major health concern in Kenya [7]. The prevalence of type 2 diabetes in Kenya is 5.6% nationally with Nyeri and Nyandarua counties recording very high values of 12.6% and 10.8%, respectively [8, 9].

Type 2 diabetes has been associated with consumption of high glycaemic index (GI) diets [10]. GI is a measure of a food's potential to raise blood glucose level and is given as a ratio using glucose as a standard (100%). Potato (*Solanum tuberosum* L.) is the second most consumed crop in Kenya [11], and its processed products have been associated with intermediate (55-70) to high (>70) GI [12]. GI is affected by factors such as resistant starch, amylase inhibition and the rate and extent of starch digestibility. Based on enzyme

activity, starch has been classified into rapidly digestible starch (RDS), slowly digestible starch (SDS) and resistant starch (RS) [13]. RDS refers to the starch hydrolyzed after 20 min while SDS is the amount starch hydrolyzed after 120 min. RS is the starch remaining after 4 h incubation time during *in-vitro* digestion as this is the residence time of food in the small intestine [14]. RDS, SDS and RS have been termed the important fractions of starch in terms of GI. Diets with high SDS and RS are associated with low GI and hence would be important in reducing type 2 diabetes [15].

Potato varieties differ in levels of polyphenol content, starch granule size and phosphorus content, which have been reported to influence GI of foods prepared from those potato varieties [16]. Potatoes high in polyphenols have reduced starch digestibility as these polyphenols have been found to have an inhibitory effect on amylase, and in turn the GI [16, 17]. Processing methods, which may result in different product forms, differ in terms of rate and duration of heating, magnitude of shear forces, and temperature, rate and time for cooling which affect the rate and extent of gelatinization, and hence starch digestibility which is a nutritional quality parameter [18, 19]. For instance, studies have shown that industrial processing reduces the levels of an isomer of chlorogenic acid more compared to fresh preparation in which amylase activity may in turn raise the GI [20, 21]. Differences in the rural and urban prevalence of glucose intolerance and type 2 diabetes have also been established in China, Tanzania and some areas in Kenya [22, 23].

This study investigated the effects of potato variety and product form on the total phenolic content, *in-vitro* digestibility and predicted glycaemic index of chips and crisps.

## 2. Materials and Methods

### *2.1. Materials*

Chips and crisps samples were obtained from Nyandarua County, which is a major producer and consumer of potato, and has the second highest type 2 diabetes prevalence in Kenya. It lies between 0° 32' 59.99"N and 36° 36' 59.99"E DMS (Degree Minute Seconds) [24]. Stratified random sampling design [25] was used to collect samples from the rural and urban areas. Samples were collected from a total of 10 wards. Two wards were selected each from 5 sub-counties in Nyandarua County, one being an urban ward and the other, rural. Urban wards selected were Karau, Kipipiri, Kiriita, Gathanji and Engineer, while the rural wards selected were Mirangine, Githioro, Central, Weru and Gathara. These samples were collected during lunch time between 12.00 noon and 2.00 pm (as this is when they are usually consumed), packed in sterile airtight containers, stored in a cool box (4°C) and transported to the laboratory for analysis. Some chips and crisps samples were also prepared in the laboratory under standardized conditions using S*hangi (*Figure 1*), Dera mwana (*Figure 2*)* and *Dutch Robijn (*Figure 3*)* potato varieties. *Shangi* tubers are oval shaped with white flesh, deep eyes and creamy skin while *Dutch Robijn* are round shaped, with red skin, pale yellow flesh and medium to deep eyes [26]. *Dera mwana* tubers are oval shaped with white flesh, creamy white skin and shallow eyes. These tubers were obtained from an individual farmer in Gwakiong'o, found in Mirangine, a rural ward in Nyandarua County and transported to the laboratory for analysis.

***Figure 1.*** *Shangi potato variety.*

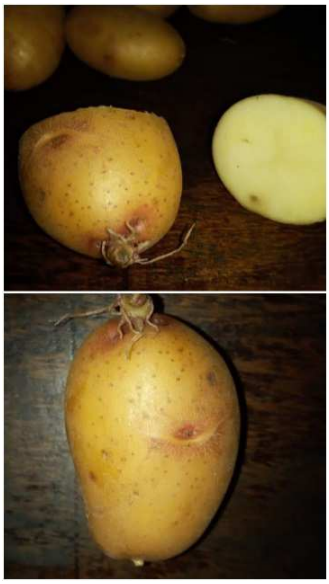

***Figure 2.*** *Dera mwana potato variety.*

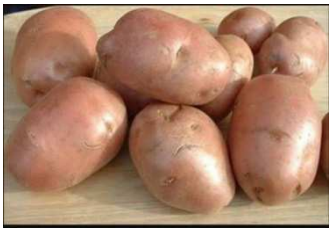

***Figure 3.*** *Dutch Robijn potato variety.*

### *2.2. Chemicals*

Folin-Ciocalteu reagent and gallic acid standard were obtained from Sigma Chemical Co. (St. Louis, MO, USA). A digestible starch and resistant starch assay kit obtained from Megazyme (Megazyme International Ireland Ltd, Wicklow Ireland). All other chemicals used were of analytical grade.

### *2.3. Preparation of Chips and Crisps Under Standardized Conditions*

To prepare chips, 2 kg of each potato variety (*Shangi,*

*Dera mwana* and *Dutch Robijn*) were obtained from farmers in Mirangine ward, Nyandarua County and washed to remove the dirt on the surface. These were then peeled using a kitchen knife, washed and rinsed in clean potable water. The tubers were then cut into strips of approximately 10-15 mm in terms of thickness. These strips were soaked in cold water for 1 min to remove surface starch and put on a strainer to drain off the water and dry. The strips were then fried in 4.5 l oil for approximately 9-11 min at 120°C in an electric fryer (EF-102 CT/110, Hypermatt Ltd, China).

For preparation of crisps, 2 kg tubers of each potato variety were obtained from farmers in Mirangine ward, Nyandarua County and washed to remove the dirt on the surface. These were then peeled using a kitchen knife, washed and rinsed in clean potable water. These were then sliced to a thickness of 0.15 cm and fried in 4.5 l oil at 120°C in an electric fryer (Model EF-102 CT/110) for approximately 8-9 min.

The prepared chips and crisps samples were then allowed to cool to 25°C (room temperature). The chips and crisps were then placed in air-tight containers and stored in the refrigerator at 4°C until they could be analyzed.

### *2.4. Determination of Dry Matter Content of Chips and Crisps*

Total dry matter content of chips, crisps and raw potato tubers was determined by National Forage Testing Association reference method (NFTA 2.2.2.5) as described by Shreve *et al*. [27]. Two (2) g chips, crisps and raw potato from each variety were crushed and placed in aluminum moisture dishes whose weights had already been recorded. The weight of the aluminum dishes and the sample was also recorded. These were then dried in a hot air oven (Memmert, Schwabach, Germany) at 105°C for 3 h after which they were removed and allowed to cool in a desiccator. Their weights were then recorded. Dry matter weight was then calculated from the remaining yield and dry matter content calculated as a percentage of the original sample.

### *2.5. Determination of Total Phenolic Content*

Total phenolic content was determined using Folin-Ciocalteu method for the chips, crisps and raw potato following the procedure described by Karim *et al*. [28] with modifications. One (1) g raw potato, crisps and chip were dried at 60°C for 1 h, after which 0.2 g sample was weighed into 20ml plastic digestion tubes. Ten (10) ml 70% ethanol was then added and mixed vigorously for 1.5 h in a vortex mixer (Fisher Scientific, USA). The mixture was the centrifuged using a Z382K centrifuge (Hermle Labnet, Germany) with a speed of 5000 ×*g* for 10 min. Supernatant (1 ml) was then pipetted into a 100 ml volumetric flask. Ten (10) ml 0.35 M sodium carbonate was then pipetted into each flask. Folin-Ciocalteu reagent (5ml) was then pipetted into the flasks in intervals of 2 min between each flask, and the mixtures topped up to the mark (100 ml). The absorbance was measured at 765 nm using a spectrophotometer (LW-V-200 RS, UV/VIS, Germany) after calibration with the blank (70% ethanol). A gallic acid standard curve was generated and used to determine the concentration of phenols in the samples.

### *2.6. Determination of RDS, SDS and TDS*

RDS, SDS and TDS were determined according the method described by McCleary [14]. The potato chips and crisps were first defatted followed by enzyme digestion. Approximately 0.5 g sample was weighed using a weighing balance (TX323L, Shimadzu Corporation, Kyoto, Japan) into 50 ml Kirgen polypropylene tubes and a cylindrical 20×6 mm magnetic stirrer bar added to each tube. Ethanol (0.5ml, 95% v/v) and 17.5 ml sodium maleate buffer were then added to the sample. The tubes were then capped and placed in a polypropylene tube holder and placed in a water bath (Model W26, Haake, Germany) set at 37°C and the contents allowed to mix for 5 min with stirring at 170 rpm on a vortex mixer (MX-S Biobase, Jinan, Shandong, China). Pancreatic amylase/amyloglucosidase solution (2.5 ml) was added to each tube and the mixture incubated at 37°C in a water bath (Model W26, Haake, Germany) equipped with a temperature probe (EN13485, Hanna, Woonsocket, U.S.A) with intermittent stirring on a vortex mixer (MX-S Biobase, Jinan, Shandong, China). Digested mixture (1 ml) was drawn using an eppendorf positive displacement pipette for RDS determination after 20 min and 120 min, for SDS determination, then after 240 min for TDS determination. The aliquots were immediately added to 20 ml 50 mM acetic acid solution and mixed thoroughly to stop the enzyme digestion. Each solution (2 ml) was transferred to 2 ml polypropylene microfuge tubes and centrifuged at 15871× *g* for 5 min using a microfuge centrifuge (Mikro 200, Hettich, Tübingen, Germany). Aliquot (0.1 ml) was then transferred to cylindrical 16×100 mm glass test tubes and 0.1 ml diluted amyloglucosidase added to each tube and mixed thoroughly to hydrolyze any remaining maltose. The mixture was then incubated at 50°C for 30 min. Glucose determination/Glucose oxidase/peroxidase (GOPOD) reagent (3 ml) was added to each tube and the mixture incubated at 50°C for 20 min. A reagent blank was also prepared by mixing 0.2 ml 100 mM acetic acid with 3ml GOPOD reagent. D-glucose standards were also prepared in quadruplicate by mixing 0.1 ml D-glucose provided in the Megazyme® kit with 0.1 ml 100 mM acetic acid and 3 ml GOPOD reagent. These were both incubated with the samples at 50°C for 20 min. The absorbance was then measured at 510 nm using the reagent blank as the reference using a spectrophotometer (UV-1900 Model 01304, Shimadzu**,** Kyoto, Japan). RDS, SDS and TDS contents were then calculated as follows:

$$\text{RDS, SDS or TDS (g/100g)} = A \times F \times (EV/W) \times (D/0.1) \times (100 \times 1/10^6) \times 162/180$$

where: A= absorbance read against the reagent blank after 20 min (RDS), SDS (120 min) and TDS (240 min)

F= factor to convert absorbance to µg=88.9284
EV= extraction volume (ml) (Method 1=20.5*)
W= weight of sample in g
D= dilution of sample (1 ml of the sample was added to 20 ml acetic acid)=21
0.1= vol. of sample analyzed
100= conversion to g/100g
$10^6$= conversion from µg to g
162/180= factor to convert from free D-glucose to anhydrous D-glucose found in starch
*Method 1 involved the procedure where 0.5 g of the sample was used in the analysis. An alternative method uses 1 g.

### *2.7. Determination of Resistant Starch*

After 240 min of enzyme digestion (in section 2.6 above), 4ml suspension was removed using a positive displacement pipette and transferred into 50ml polypropylene tubes containing 4ml 95% v/v ethanol and the contents mixed thoroughly by inverting the tubes. The tubes were then placed in a centrifuge (CN-2060, MRC, Israel) and the contents centrifuged for 10min at 2000 ×*g*. The supernatant solution in each tube was decanted immediately and the pellet suspended in 2 ml of 50% v/v ethanol and mixed on a vortex mixer (MX-S Biobase, Jinan, Shandong, China). The 50% v/v ethanol (6 ml) was then added to the each tube and the tubes capped. The contents were centrifuged at 5096 ×*g* for 10 min and the supernatant decanted. The pellets were recovered and free liquid removed by inverting on absorbent paper. The pellets were then re-suspended in 2ml and mixed on a vortex mixer. Ethanol (6ml 50% v/v) was added and the mixture centrifuged at 5096×*g* for 10 min. The supernatant solution was decanted and the tubes covered with parafilm until resistant starch determination.

Cylindrical magnetic stirrer bars (5×15 mm) and 2ml 1.7M NaOH were added to each tube and the tubes placed in an ice bath. The ice bath was then placed on magnetic stirrer (MSH-20A, Daihan Scientific, Seoul, Korea) for 20 min. Buffer (8 ml 1M sodium acetate) was added to each tube while still on the magnetic stirrer and 0.1ml dilute amyloglucosidase (as indicated by the manufacturer) added immediately. The mixture was then incubated in a water bath at 50°C for 30 min with intermittent vortex mixing. The contents in control sample tube were transferred to a 100 ml volumetric flask and a wash bottle containing distilled water used to ensure all the contents had been transferred and the volume topped up to the mark with distilled water. An aliquot (2ml) of the solution was centrifuged at 15581 ×*g* for 5 min in a microfuge. For the other samples, 2ml of the solution (approximately 10.3ml) was centrifuged at 15581 ×*g* for 5 min in a microfuge. Aliquots (0.1 ml) of the centrifuged samples were transferred into 16 × 100 mm glass test tubes after which 3 ml of GOPOD reagent was added. A reagent blank was also prepared by mixing 3ml GOPOD reagent with 0.1ml 100 mM sodium acetate buffer. The samples and reagent blank were then incubated in a water bath at 50°C for 20 min. The absorbance was then read at 510 nm against the reagent blank using spectrophotometer (UV-1900 Model 01304, Shimadzu, Kyoto, Japan). Resistant starch was calculated using the formula below:

$$\text{Resistant starch (g/100g)} = A \times F \times (EV/4) \times (FV/0.1) \times (1/10^{6}) \times (100/W) \times (162/180)$$

where: A= absorbance read against the reagent blank
F= factor to convert absorbance to µg=88.9284
EV= extraction volume (ml) (Method 1=20.5)
4= volume of solution taken after 4h digestion
FV=10.3ml (method 1)
0.1= aliquot taken from the final volume to which GOPOD reagent was added
W= weight of sample in g
100= conversion to g/100g
$10^6$= conversion from µg to g
162/180= factor to convert from free D-glucose to anhydrous D-glucose found in starch

### *2.8. Determination of Glycaemic Index (GI)*

Glycaemic index (GI) was determined as described by Germaine *et al*. [29] using a GI prediction equation. The equation uses the hydrolysis index at the 90th min, which has been found to have the best correlation with the actual increase in blood sugar in the *in vivo* method. The hydrolysis index at the 90th min was determined by plotting a graph of digestible starch (%w/w) against incubation time (min). GI was then determined using the hydrolysis at the 90th min, using the formula below.

$$GI_{H90} = (39.21 + (0.803 \times H_{90}) \times 0.7)$$

where: $GI_{H90}$= glycaemic indexat the 90th min
$H_{90}$= hydrolysis index at the 90th min
39.21 and 0.803 are constants
0.7= conversion factor found to give GI values closer to the *in vivo* values

### *2.9. Statistical Analyses*

Data were analyzed using two-way ANOVA followed by a Tukey's Honest Significant Difference (HSD) test to compare means. Pearson correlation was run to study correlation among variables. All statistical analyses were carried out using SPSS Version 22. Values of $p \leq 0.05$ were considered significantly different.

## 3. Results and Discussion

### *3.1. Dry Matter Content of Chips, Crisps and Raw Potato Tubers*

The means and standard deviations for dry matter content of chips and crisps are illustrated in graphically in Table 1 and Figure 4 below. The values observed were similar to those from several studies [30-32]. Potato variety significantly affected the dry matter contents ($p<0.05$). Dry matter contents of *Shangi* potato products were significantly different from products prepared from *Dutch Robijn* potato

but were not significantly different from chips and crisps from *Dera mwana* potato. Chips and crisps prepared from *Dera mwana* and *Dutch Robijn* potato varieties were not significantly different from each other. In terms of product form, chips and crisps were also significantly different ($p<0.05$).

For the raw tubers, *Dera mwana* potato variety had the highest dry matter content (23.99%) followed by *Dutch Robijn* potato with (22.75%) and lastly *Shangi* potato (20.93%). However, these were not significantly different. Thermal processing methods act as catalysts for enzymatic degradation resulting in disruption of the cell integrity explaining the difference between TPC of potato chips and crisps, compared to that of the raw tuber [33].

***Table 1.*** *Effect of variety and product form on in vitro starch digestibility, dry matter content, total phenolic content and glycaemic index.*

| Variety | Product form | RDS (%) | SDS (%) | Resistant starch (%) | Dry Matter (%) | TPC (mgGAE/100g) | Glycaemic Index (%) |
|---|---|---|---|---|---|---|---|
| Shangi | Chips | 25.33±3.13$^{bc}$ | 39.67±1.99$^{b}$ | 1.07±0.29$^{a}$ | 49.29±10.29$^{c}$ | 225.45±62.49$^{b}$ | 58.29±0.68$^{b}$ |
| | Crisps | 23.85±0.21$^{cd}$ | 24.97±6.58$^{d}$ | 1.41±0.95$^{a}$ | 95.79±0.04$^{a}$ | 155.00±14.14$^{b}$ | 53.63±2.26$^{c}$ |
| Dera mwana | Chips | 22.15±4.84$^{d}$ | 28.96±6.58$^{cd}$ | 1.56±0.95$^{a}$ | 42.07±1.18$^{c}$ | 300.00±8.49$^{a}$ | 53.93±2.26$^{c}$ |
| | Crisps | 20.14±1.08$^{d}$ | 33.92±6.58$^{c}$ | 0.74±0.95$^{a}$ | 95.77±0.16$^{a}$ | 465.00±18.38$^{a}$ | 54.34±2.26$^{c}$ |
| Dutch Robijn | Chips | 39.14±0.33$^{a}$ | 52.09±6.58$^{a}$ | 1.16±0.95$^{a}$ | 61.51±0.48$^{b}$ | 315.00±5.66$^{a}$ | 65.07±2.26$^{a}$ |
| | Crisps | 27.43±3.39$^{b}$ | 37.22±2.69$^{bc}$ | 0.53±0.39$^{a}$ | 96.48±1.52$^{a}$ | 311.43±64.46$^{a}$ | 57.67±0.92$^{b}$ |

Values are Means±Standard deviation. Values in a column followed by different superscript letters are significantly different ($p\leq0.05$).

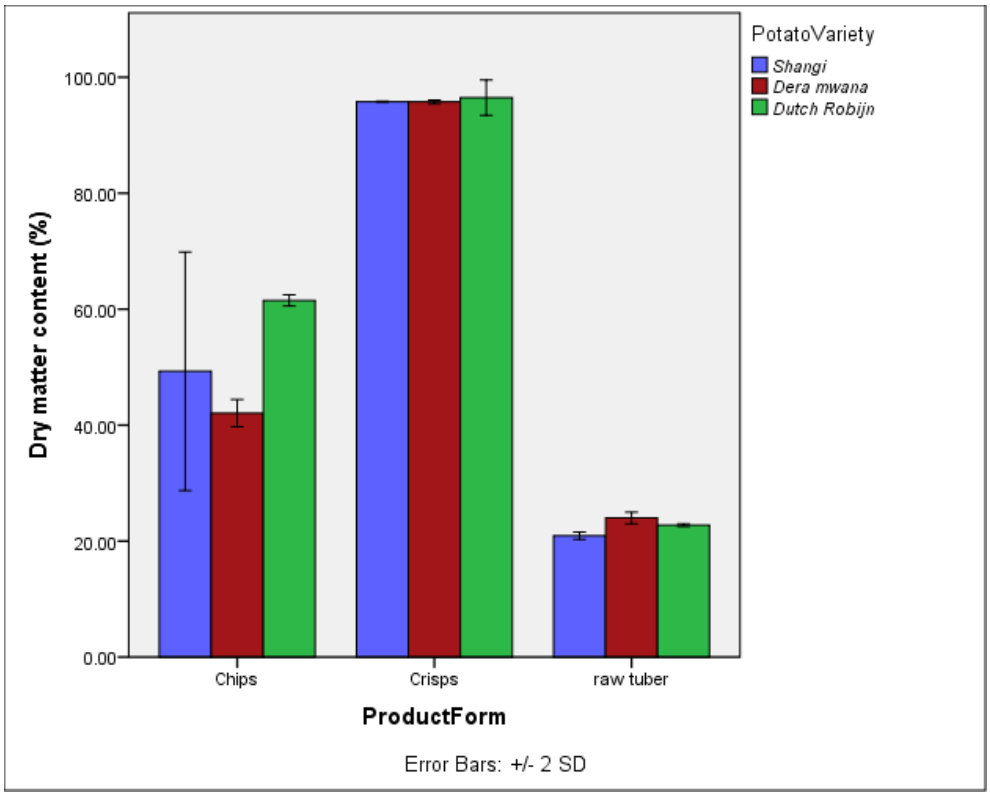


***Figure 4.*** *Bar chart illustrating dry matter content of the chips, crisps and raw tubers from different varieties.*

### *3.2. Total Phenolic Content of Chips, Crisps and Raw Potato Tubers*

The means and standard deviations of total phenolic content (TPC) of chips and crisps analyzed are presented in Table 1 above and Figure 5. The effect of potato variety was found to be significant ($p\leq0.05$), while product form did not significantly affect total phenolic content ($p>0.05$). The interaction effect between potato variety and product form was also significant ($p=0.014$) whereby different TPC levels observed for each variety is affected by the product form. Total phenolic content of *Shangi* potato products was significantly lower than products prepared from both *Dutch Robijn* and *Dera mwana* potato varieties ($p\leq0.05$). However, *Dera mwana* and *Dutch Robijn* potato varieties were not significantly different from each other ($p>0.05$) with respect to total phenolic content. Chips from the *Dera mwana* potato variety retained the most phenolic content after frying followed by *Dutch Robijn* potato while *Shangi* potato variety had the least TPC. Several studies [34-36] found differences among potato cultivars in terms of physicochemical composition. The levels observed were similar to TPC observed in potato varieties analyzed by Kita *et al.* [37]. The values were however notably different from potato chips (French fries) and similar to some raw tubers in Chile but slightly lower as some of these were purple fleshed [38]. There was a significant reduction in TPC in chips and crisps

compared to the raw tubers. This could be due to frying [39] resulting in the greatest TPC losses compared to methods such as boiling, baking, steaming, microwaving and stir-frying.

Varietal differences were also observed in the raw tubers with *Dutch Robijn* potato having 465 mgGAE/100g, *Dera mwana* potato having 490 mgGAE/100g and *Shangi* potato having the least with 415mgGAE/100g as shown in Figure 5 below. This could explain why potato chips and crisps prepared from *Shangi* potato variety had significantly lower total phenolic content (TPC) compared to *Dera mwana* and *Dutch Robijn* potato varieties. Higher levels of TPC were observed in crisps compared to chips and this could be attributed to the significantly higher dry matter content in crisps. During frying, the potatoes are submerged in oil heated at temperatures above 100°C which cause the water to evaporate dehydrating the end product. Potato chips and crisps have varying thickness, with crisps having a higher surface to volume ratio. As a result, moisture content in crisps is reduced to significantly lower levels (<10%) compared to chips thereby concentrating the TPC in crisps.

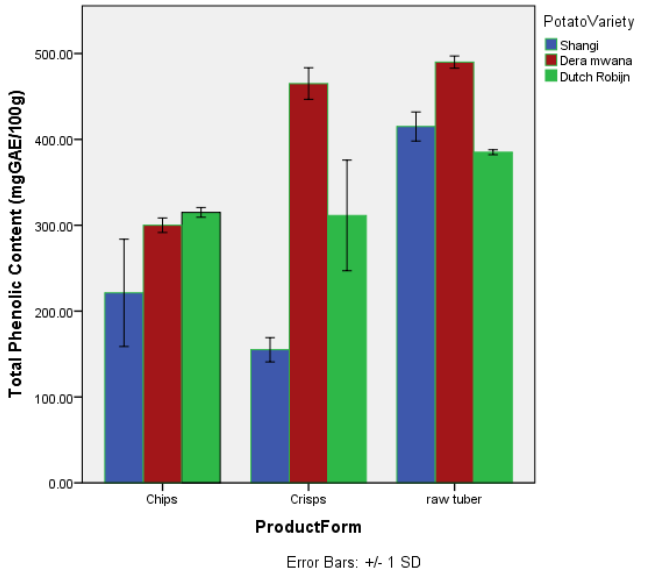


***Figure 5.*** *Illustration of the Total Phenolic Content in chips, crisps and raw tubers from different varieties.*

### *3.3. Digestible and Resistant Starch of RTE Potato Products*

The means and standard deviations observed for RDS, SDS, TDS and resistant starch are illustrated in Table 1. RDS, SDS and TDS are also illustrated graphically in Figure 6. Varietal differences were observed between chips and crisps in terms of RDS, SDS and RS which are the nutritionally important portions of starch and contribute towards glycaemic index. There was a statistically significant effect of interaction between variety and product form in terms of RDS and SDS ($p<0.05$). The interaction effect between variety and product form was however not statistically significant for resistant starch ($p>0.05$). Variety significantly affected the amount of RDS ($p<0.05$) but did not significantly affect the amount of SDS ($p>0.05$). Product form significantly affected the amount of SDS ($p<0.05$), but did not affect the amount of RDS ($p>0.05$). Variety and product form did not have a significant effect on the amount of resistant starch ($p>0.05$). An interaction effect between potato variety and product form was also observed but was not statistically significant ($p>0.05$).

The values observed for resistant starch were similar to other studies [40, 41] which reported values ranging between 0.3-6.4%. During digestion, starch is hydrolyzed by pancreatic amylases and amyloglucosidases into glucose which results in an increase in blood glucose termed postprandial glycaemic response. RDS results in a rapid increase in blood glucose as it is released after 20 min. The higher the amount of RDS and SDS, the greater the potential of a food to increase blood glucose, as these reflect the amount of glucose released during the amount of time food is still in the small intestines. High amounts of resistant starch have been reported to have hypoglycemic effects which may be important in control of type 2 diabetes [42]. Potato varieties with higher amounts of amylose compared to amylopectin have been reported to result in higher amounts of resistant starch after processing as amylose is digested relatively slower [43]. Other factors that may result in differences in resistant starch levels include potato growing locations, size of potato starch granules and processing methods [44].

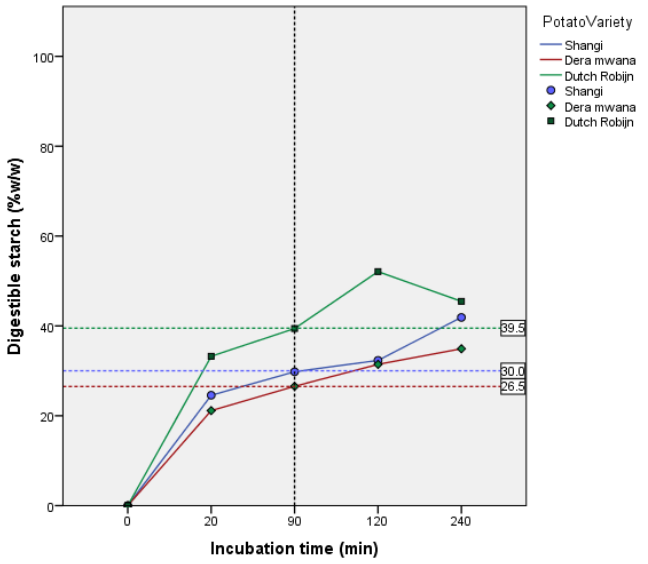


***Figure 6.*** *In vitro starch digestibility of Shangi, Dera mwana and Dutch Robijn potato products. Dotted lines reference the hydrolysis index of chips and crisps from each variety at the 90$^{th}$ minute of incubation ($H_{90}$).*

### *3.4. Predicted Glycaemic Index of RTE Potato Products*

Potato variety and product form had significant effects on the predicted glycaemic index ($p<0.05$). The interaction effect of potato variety and product form was also statistically significant ($p=0.021$). *Dutch Robijn* potato products resulted in the highest glycaemic index of the three potato varieties and were significantly different from

products from *Shangi* and *Dera mwana* potato varieties. Chips and crisps from *Shangi* and *Dera mwana* potato varieties were not significantly different from each other ($p>0.05$). Chips had a higher glycaemic index compared to crisps as shown in Table 1. This could be explained by the high dry matter content in crisps compared to chips which has been reported to have a negative relationship with *in vitro* starch digestibility [45]. The GI levels reported in this current study were slightly lower than those reported for potato chips (63) by Kim [46] and potato crisps (56) and potato chips (63) reported by Esposito *et al*. [47].

The values were also compared with the intermediate GI value of 55 that is associated with type 2 diabetes. Intermediate GI value (55-70) and high GI (>70) are the values associated with high type 2 diabetes [12]. *Dera mwana* potato variety resulted in products with a lower glycaemic index. However this was not significantly different from the intermediate GI. Crisps had lower glycaemic index values but were also not significantly different from the intermediate GI value. From these observations, most of the products have the potential to contribute to high type 2 diabetes incidences. All the products had GI values lower than 70 which is the higher end of the intermediate value. High GI (>70) was not observed in any of the products as can be seen in Table 1.

### *3.5. Correlation Analysis Between Variables*

A Pearson correlation was run to analyze the relationship between RDS, SDS, resistant starch, dry matter content, total phenolic content, and glycaemic index. The coefficient relationships are illustrated in Table 2. A strong positive correlation relationship was observed between GI and RDS ($p<0.05$) and GI and SDS ($p<0.05$). These results confirm that RDS and SDS are the most important fractions of starch that may be associated with GI and in turn type 2 diabetes as previously stated in several studies [13, 17, 43].

A weak negative correlation was observed between TPC and predicted GI but was not significant ($p>0.05$). Moraes [48] reported negative correlations between phenolic content with glycaemic index and no correlations with resistant starch which differs slightly with this study. A weak negative correlation was observed between GI and resistant starch but was however not significant ($p>0.05$). Resistant starch refers to starch that resists digestion in the small intestine. As it is not hydrolyzed to glucose, RS does not result in a post-prandial glycaemic response, hence the negative relationship. This study also observed a moderate positive correlation between dry matter content and total phenolic content, although not statistically significant ($p>0.05$). This corroborates the findings of Lutz *et al*. [49] that retention of phenolic compounds increases with increasing dry matter content.

***Table 2.*** *Relationship between starch digestibility, glycaemic index, TPC and dry matter content.*

| | Dry matter | Correlation coefficient (r) | | | | |
|---|---|---|---|---|---|---|
| | | RDS | SDS | Resistant starch | TPC | Glycaemic index |
| Dry matter | | 0.049 | -0.244 | -0.176 | 0.351 | -0.159 |
| RDS | 0.049 | | 0.552* | 0.077 | -0.05 | 0.795* |
| SDS | -0.244 | 0.552* | | -0.201 | -0.06 | 0.927* |
| Resistant starch | -0.176 | 0.077 | -0.201 | | 0.005 | -0.096 |
| TPC | 0.351 | -0.05 | -0.06 | 0.005 | | -0.159 |
| Glycaemic index | -0.159 | 0.795* | 0.927* | -0.096 | -0.159 | |

*Correlation is significant ($p<0.05$).

# 4. Conclusion

This study demonstrates that potato chips and crisps prepared from *Shangi, Dera mwana* and *Dutch Robijn* potato varieties have different amounts of total phenolic content (TPC), RDS, SDS and dry matter which significantly affects the rate and extent of starch digestibility and predicted glycaemic index. The findings of this study also show that the glycaemic index of potato chips and crisps lie in the intermediate range (55-70). Comparatively, *Dera mwana* variety results in the highest amount of retained TPC and lower levels of RDS and SDS and thus is recommended for processing of chips and crisps as it has the best potential in glycemic control. *Dutch Robijn* variety has the highest potential to raise blood glucose, and its consumption may have to be reduced for glycemic control. In summary, this study recommends consumption of products prepared from the *Dera mwana* variety and reduced consumption of *Shangi* and *Dutch Robijn* potato varieties. This study recommends promotion of *Dera mwana* variety to processors and farmers in place of *Shangi* variety is the most popular.

# Abbreviations

TPC- Total Phenolic Content
RDS- Rapidly Digestible Starch
SDS- Slowly Digestible Starch
RS- Resistant Starch
GI- Glycaemic Index

# Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

# Acknowledgements

The authors would like to thank Kenya Climate Smart Agricultural Project (KCSAP) for funding this work.

# References


[1] I. Rahkovsky, Y. Jo, and A. Carlson, "Consumers Balance Time and Money in Purchasing Convenience Foods," *United States Departmeny Agric.*, no. 251, pp. 1–35, 2018.

[2] J. Ringquist *et al.*, "Deloitte. Capitalizing on the shifting consumer food value equation," 2016.

[3] J.. Abong and J.. Kabira, "The current status of the potato value chain in Kenya," *Trends and Opportunities in the Production, Processing and Consumption of Staple Foods Crops in Kenya*, 2013.

[4] World Health Organization, "Global health risks," *World Heal. Organ.*, pp. 1–70, 2009.

[5] "Type 2 diabetes mellitus," *Nat. Rev. Dis. Prim.*, vol. 1, no. 1, p. 15039, 2015.

[6] L. Schwingshackl *et al.*, "Food groups and risk of type 2 diabetes mellitus: a systematic review and meta-analysis of prospective studies," *Eur. J. Epidemiol.*, vol. 32, no. 5, pp. 363–375, 2017.

[7] I. Salawu and A. Mukhtar, "Reducing the Dimension of Growth and Yield Characters of Sweet Potato (Ipomoea batatas L.) Varieties as Affected by Varying Rates of Organic and Inorganic Fertilizer," *Asian J. Agric. Res.*, vol. 2, no. 1, pp. 41–44, 2008.

[8] L. N. Kamau, M.. Mathiu, J.. Mbaria, P.. Gathumbi, and S.. Kiama, "Knowledge and demand for medicinal plants used in the treatment and management of diabetes in Nyeri County, Kenya.," *J. Ethnopharmacol.*, vol. 189, no. 2016, pp. 218–229, 2016.

[9] MOH, "Ministry of Health," Nairobi, Kenya, 2013.

[10] G. Livesey *et al.*, "Dietary glycemic index and load and the risk of type 2 diabetes: Assessment of causal relations," *Nutrients*, vol. 11, no. 6, pp. 1–34, 2019.

[11] MoALF&I, "National root and tuber crops development strategy 2019-2022," 2019.

[12] R. A. Ebere, J. K. Imungi, and V. N. Kimani, "Glycemic Responses to Stiff Porridge (Ugali) Meals Consumed in Western Kenya," vol. 63, pp. 55–63, 2017.

[13] J. Singh and A. Dartois, "Starch digestibility in food matrix: a review," *Trends Food Sci. Technol.*, vol. 21, no. 4, pp. 168–180, 2010.

[14] B. V McCleary, "Total Dietary Fiber (CODEX Definition) in Foods and Food Ingredients by a Rapid Enzymatic-Gravimetric Method and Liquid Chromatography: Collaborative Study, First Action 2017. 16," *J. AOAC Int.*, vol. 102, no. 1, pp. 196–207, 2019.

[15] C. Cai, Y. Tian, Z. Yu, C. Sun, and Z. Jin, "In Vitro Digestibility and Predicted Glycemic Index of Chemically Modified Rice Starch by One-Step Reactive Extrusion," *Starch/Staerke*, vol. 72, no. 1–2, pp. 1–11, 2020.

[16] A. Furrer, D. P. Cladis, A. Kurilich, R. Manoharan, and M. G. Ferruzzi, "Changes in phenolic content of commercial potato varieties through industrial processing and fresh preparation," *Food Chem.*, vol. 218, pp. 47–55, 2017.

[17] B. Nayak, J. D. J. Berrios, and J. Tang, "Impact of food processing on the glycemic index (GI) of potato products," *FRIN*, vol. 56, pp. 35–46, 2014.

[18] D. D. Ramdath, E. Padhi, A. Hawke, T. Sivaramalingam, and R. Tsao, "The glycemic index of pigmented potatoes is related to their polyphenol content," *Food Funct.*, vol. 5, no. 5, pp. 909–915, 2014.

[19] J. Jane *et al.*, "Effects of Amylopectin Branch Chain Length and Amylose Content on the Gelatinization and Pasting Properties of Starch 1," no. 3258, 1999.

[20] F. Zhu and Q. Xie, "Structure and Physicochemical Properties of Starch," in *Physical Modifications of Starch*, vol. 2, Auckland, New Zealand: Springer Nature Singapore, 2018, pp. 6–12.

[21] A. N. Furrer, M. Chegeni, and M. G. Ferruzzi, "Impact of potato processing on nutrients, phytochemicals, and human health," vol. 8398, 2018.

[22] D. L. Christensen *et al.*, "Prevalence of glucose intolerance and associated risk factors in rural and urban populations of different ethnic groups in Kenya," *Diabetes Res. Clin. Pract.*, vol. 84, no. 3, pp. 303–310, 2009.

[23] F. Bragg *et al.*, "Association between diabetes and cause-specific mortality in rural and urban areas of China," *JAMA - J. Am. Med. Assoc.*, vol. 317, no. 3, pp. 280–289, 2017.

[24] Latitude. to, "Latitude and longitude of Nyandarua County," *Latitude. to*, 2020. [Online]. Available: https://latitude.to/articles-by-country/ke/kenya/34900/nyandarua-county. [Accessed: 19-Aug-2020].

[25] C. Teddlie and F. Yu, "Mixed Methods Sampling A Typology With Examples," *J. Mix. Methods Res.*, vol. 1, no. 1, pp. 77–100, 2007.

[26] NPCK, "POTATO VARIETY NATIONAL POTATO," 2017.

[27] B. Shreve, N. Thiex, and W. M, "NFTA Reference Methods. National Forage Testing Association," 2006.

[28] Z. Karim, M. Holmes, and C. Orfila, "Inhibitory effect of chlorogenic acid on digestion of potato starch," *Food Chem.*, vol. 217, pp. 498–504, 2017.

[29] K. A. Germaine, S. Samman, C. G. Fryirs, P. G. Griffiths, S. K. Johnson, and K. J. Quail, "Review Nutritional Comparison of Fresh, Frozen and Canned Fruits and Vegetables," *J. Sci. Food Agric.*, vol. 88, no. 2, pp. 652–658, 2008.

[30] A. D. Garmakhany, H. O. Mirzaei, Y. Maghsoudlou, M. Kashaninejad, and S. M. Jafari, "Influence of Partial Drying on Oil Uptake & Quality Attributes of French Fries," *J. Agric. Sci. Technol.*, vol. 4, no. 1, pp. 7–10, 2010.

[31] I. Goni, A. Garcia-Alonso, and F. Saura-Calixto, "A Starch Hydrolysis Procedure To Estimate Glycemic Index," *J. Nutr. Res.*, vol. 17, no. 3, pp. 427–437, 1997.

[32] F. Pedreschi, V. H. Segtnan, and S. H. Knutsen, "On-line monitoring of fat, dry matter and acrylamide contents in potato chips using near infrared interactance and visual reflectance imaging," *Food Chem.*, vol. 121, no. 2, pp. 616–620, 2010.

[33] C. M. Donado-Pestana, J. M. Salgado, A. de Oliveira Rios, P. R. dos Santos, and A. Jablonski, "Stability of Carotenoids, Total Phenolics and In Vitro Antioxidant Capacity in the Thermal Processing of Orange-Fleshed Sweet Potato (Ipomoea batatas Lam.) Cultivars Grown in Brazil," *Plant Foods Hum. Nutr.*, vol. 67, no. 3, pp. 262–270, 2012.

[34] S. de Haan, G. Burgos, R. Liria, F. Rodriguez, H. M. Creed-Kanashiro, and M. Bonierbale, "The Nutritional Contribution of Potato Varietal Diversity in Andean Food Systems: a Case Study," *Am. J. Potato Res.*, vol. 96, no. 2, pp. 151–163, 2019.

[35] B. Kumari, B. K. Tiwari, M. B. Hossain, D. K. Rai, and N. P. Brunton, "Ultrasound-assisted extraction of polyphenols from potato peels: profiling and kinetic modelling," *Int. J. Food Sci. Technol.*, vol. 52, no. 6, pp. 1432–1439, 2017.

[36] E. S. Tolessa, "Importance, Nutrient Content and Factors Affecting Nutrient Content of Potato," *Am. J. Food, Nutr. Heal.*, vol. 3, no. 3, p. 6, 2018.

[37] A. Kita, A. Bakowska-Barczak, G. Lisińska, K. Hamouz, and K. Kułakowska, "Antioxidant activity and quality of red and purple flesh potato chips," *LWT - Food Sci. Technol.*, vol. 62, no. 1, pp. 525–531, 2015.

[38] S. Trujillo-Agudelo *et al.*, "Evaluation of the application of an edible coating and different frying temperatures on acrylamide and fat content in potato chips," *J. Food Process Eng.*, vol. 43, no. 5, pp. 1–11, 2020.

[39] J. Tian *et al.*, "Domestic cooking methods affect the phytochemical composition and antioxidant activity of purple-fleshed potatoes," *Food Chem.*, vol. 197, pp. 1264–1270, 2016.

[40] I. Goñi, L. Bravo, J. A. Larrauri, and F. Saura Calixto, "Resistant starch in potatoes deep-fried in olive oil," *Food Chem.*, vol. 59, no. 2, pp. 269–272, 1997.

[41] K. von Grebmer *et al.*, "Global Hunger Index," 2018.

[42] R. Pinhero, R. Pazhekattu, K. Whitfield, A. G. Marangoni, Q. Liu, and R. Y. Yada, "Effect of genetic modification and storage on the physico-chemical properties of potato dry matter and acrylamide content of potato chips," *Food Res. Int.*, vol. 49, no. 1, pp. 7–14, 2012.

[43] M.. Sajilata, S.. Singhal, and P.. Kulkarni, "Starch — A Review," *Compr. Rev. Food Sci. Food Saf.*, vol. 5, no. 1, pp. 1–17, 2006.

[44] S. Lockyer and A. P. Nugent, "Health effects of resistant starch," *Nutr. Bull.*, vol. 42, no. 1, pp. 10–41, 2017.

[45] L. F. Ferraretto, K. Taysom, D. M. Taysom, R. D. Shaver, and P. C. Hoffman, "Relationships between dry matter content, ensiling, ammonia-nitrogen, and ruminal in vitro starch digestibility in high-moisture corn samples," *J. Dairy Sci.*, vol. 97, no. 5, pp. 3221–3227, 2014.

[46] I. J. Kim, "Glycemic Index Revisited," *Korean Diabetes J.*, vol. 33, no. 4, p. 261, 2009.

[47] K. Esposito, M. I. Maiorino, C. Di Palo, and D. Giugliano, "Dietary glycemic index and glycemic load are associated with metabolic control in type 2 diabetes: The CAPRI experience," *Metab. Syndr. Relat. Disord.*, vol. 8, no. 3, pp. 255–261, 2010.

[48] É. A. Moraes *et al.*, "Sorghum flour fractions: Correlations among polysaccharides, phenolic compounds, antioxidant activity and glycemic index," *Food Chem.*, vol. 180, pp. 116–123, 2015.

[49] M. Lutz, J. Hernández, and C. Henríquez, "Phenolic content and antioxidant capacity in fresh and dry fruits and vegetables grown in Chile," *CyTA - J. Food*, vol. 13, no. 4, pp. 541–547, 2015.