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Effect of frying temperature and slice thickness on sensory attributes and acrylamide content in potato crisps of selected Kenyan varieties

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Abstract

Acrylamide, a chemical found in several carbohydrates rich foods processed at high temperatures, has been classified as a potential human carcinogen; the need to minimize its presence in the human diet cannot be overemphasized. This study was designed to determine how acrylamide formation is influenced by potato varieties, processing temperatures and slice thickness in potato crisp produced from established Kenyan varieties. Four potato varieties (Kenya Mpya, Sheherekea, Tigoni and Dutch Robjin) were purposively selected due to their suitability for crisp production and were planted at KARLO Tigoni. The potato tubers were harvested at maturity, cured, peeled and sliced into three slice thicknesses (1-0mm, 1.5mm and 2.00mm) and subjected to three frying temperatures of 160°C, 170°C and 180°C until ready. The dry matter of the tubers ranged between 21.5 and 28.4%. The fructose levels ranged from 0.068 - 0.241 %; glucose levels ranged 0.155%- 0.218%; Sucrose levels ranged from 0.61 to 0.87%. In the potato crisps Kenya Mpya variety fried at 160°C of thickness 2.0mm had the highest moisture content of 2.575%. Most of the crisps from the four varieties processed at different temperatures and thicknesses were light colored with lightness (L*) parameters greater than 50 and towards red as shown by positive values of redness parameter (a*) indicating that there was excess browning of the products during frying. Acrylamide levels significantly ($P \leq 0.05$) differed between the varieties and ranged from 3129 to 13480ppb. There was a significant difference in acrylamide levels ($p \leq 0.05$) with temperatures of 180°C resulting in higher acrylamide content compared to those of 160°C and 170°C. Similarly, the slice thickness of 2.0mm had high acrylamide levels and the redness parameter (a*). There was a strong correlation between acrylamide formation and glucose ($r=0.761$) and fructose ($r=0.44$) formation.

Keywords: *Acrylamide; color parameter; frying temperature; processing; reducing sugar; slice thickness; variety*

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Introduction

Potatoes (*Solanum tuberosum)* are a cheap, readily available, high-carbohydrate food perceived by consumers as an important component of a healthy, balanced diet. The potato represents one of the world's major staple food crops and is the most widely grown food crop after rice, wheat and maize (CIP, 2021). In Kenya, for example, potato is the second most valuable cash and food crop after cereal grains (FAOSTAT, 2017). Round potato tubers with lower reducing sugar contents and higher dry matter have been shown to be suitable for crisps processing for most processors because they easily make the required crisp sizes (Abong *et al*., 2011). Acrylamide has been found to be formed in starchy foods heated at higher temperatures either through frying or baking.

The Maillard reaction between the amino acid asparagine and reducing sugars or reactive carbonyls at temperatures above 120°C has been suggested as possible pathway for its formation in these foods (Mottram *et al*., 2002; Tareke *et al*., 2002). The sugars and asparagine levels vary with variety and hence the influence on acrylamide. Factors that influence acrylamide formation include processing temperature, time, content and species of reducing sugars and amino acids, pH, moisture content and frying oils, indicating that acrylamide in foods can be decreased by changing processing technology.

According to Medeiros Vinci *et al.,* (2012) there is little correlation between asparagine content alone and acrylamide formation. Acrylamide levels in fried potatoes derived from 16 different varieties correlated to reducing the sugar content of the potatoes (R^2 = 0.82, n = 96) (De Wilde *et al*., 2006). In addition, reducing sugar contents below 1 g kg^{-1} fresh weight has been taken as indicative of a suitable processing quality. Asparagine concentrations are relatively in excess compared to reducing sugar contents. Thus, reducing sugars represent the limiting factor in acrylamide formation and therefore will largely determine acrylamide formation in potato products. The acrylamide content in chips showed a high correlation with glucose content in the tubers (r^2=0.884, n=20). A similar correlation was observed for fructose (r^2=0.884, n=20). Since acrylamide is formed towards the end of frying, the temperature during the second half of the process is more important than that is regulated by the thermostat. Taubert *et al.,* (2004) found that acrylamide levels increase with increase with frying temperature and cooking time in potatoes with low surface-to-volume ratios (SVR), whereas for potatoes with high surface-to-volume ratios acrylamide levels peak and then the rate of formation decline with further heating. Variation may be a function of the availability of substrate; in low SVR potatoes, there is a larger, steady supply of sugars and asparagine, but in high SVR potatoes, the supply is more quickly depleted. Investigations by several researchers have established existence of a relationship between the acrylamide content and surface colour, as evaluated by the standard CIE L*a*b* parameters or by computer vision. A good correlation between the acrylamide content of fried potatoes and their colour has been shown, though it was observed that this correlation was less close for large surface-to-volume material, such as potato crisps, in comparison with small surface-to-volume material, such as French fries (Pedreschi *et al*., 2010a; Pedreschi *et al*., 2010b).

The current Kenyan varieties have been developed for high yielding, disease tolerance and processing quality but are yet to be evaluated on performance of sensory attributes and acrylamide formation under different processing conditions. This study was thus designed to determine the effect of processing temperature, slice thickness and potato variety on the sensory attributes and acrylamide content.

Materials and Methods

Potato for processing

Four potato varieties (Dutch Robjin, Sherehekea, Kenya Mpya and Tigoni) known to be suitable for processing potato crisps (Abong' *et al.,* 2010) were grown under standard cultural conditions at the National Potato Research Centre (KARI), Tigoni. Harvesting of potatoes was done at maturity followed by curing in dark store for two weeks. Processing was carried out and acrylamide levels, moisture content and color determined immediately after processing. Before processing tubers from each variety were analyzed for reducing sugars and dry matter content.

Crisps processing

About ten potato tubers from each variety were randomly selected from a net bag and peeled using a knife and sliced into 3 sizes of 1-, 1.5- and 2-mm thickness. The slices were washed to remove surface starches then dried with a clean cloth towel and duplicate 200 g samples fried in sunflower oil maintained at fixed temperatures of 160, 170, 180 ^{0}C till ready. The crisps were then removed from oil, drained for 30s and turned into a clean tray, cooled and packaged into labeled plastic bags and sealed before analysis.

Experimental design

Samples to be analyzed were prepared in accordance with a full factorial experimental design. The design parameters were potato variety (4 levels: Dutch Robjin, Sherehekea, Kenya Mpya and Tigoni), frying temperature (3 levels: 160, 170 and 180°C), and slice thickness (3 levels: 1.0mm, 1.5mm and 2.0mm). Statistical analysis was carried out using SAS version 9.1.3 to determine both inferential and descriptive statistical tests including Analysis of Variance and least significant difference test (LSD) for the variables. Pearson correlation analysis and multiple regression analysis were also performed to determine relationships between acrylamide, colour parameters, moisture and reducing sugars. Where the differences of $p \leq 0.05$ existed, the samples were considered to be significant

Materials and standard preparation

Acrylamide (2-propene amide) [CAS No. 79-06-1] (>99.5%) was obtained from Kobian house (Mombasa Road, Nairobi, Kenya). Individual stock of acrylamide solutions was prepared by dissolving 100 mg of compound in 100ml of acetone and stored in a glass-stoppered bottle at 4 °C. Standard working solutions at various concentrations 800ppm, 400ppm, 200ppm, 100ppm and 50ppm were daily prepared by appropriate acetone dilution of stock solution aliquots. Analytically grade acetone (2-propanone) of molecular formula $(CH_3)_2CO$ [CAS No.67-64-1] used in GC-FID and Acetonitrile of molecular formula C_2H_3N [CAS No.75-05-8] for HPLC (*Sigma*) were obtained from Kobian House Nairobi.

Analytical methods

Determination of dry matter content of raw potato tubers

Four tubers were randomly selected from each of the four varieties. The tubers were then cut into small slices (1-2 mm) and mixed thoroughly. Dry matter contents were determined by drying triplicate 5g at 105°C for 4 hours in a hot air oven (DSO-500D, Israel) according to the method described by AOAC (1980).

Extraction and determination of reducing sugars contents of the raw potato tubers

The levels of reducing sugars in the raw tubers were determined by use of HPLC through modification of the method described by Abong'*et al.,* (2011). Approximately 10 g of homogenized potato pieces were weighed into a 250 ml conical flask and 50 ml of 96 % alcohol were then added and mixed well. The mixture was then refluxed at 100°C for 1 hour, stirring occasionally. The resultant slurry was then filtered, and the filtrate collected. The conical flask was then rinsed 3 times with 5 ml of 80 % alcohol. The filtrate was then transferred into 150 ml pear-shaped flask and the solvent evaporated to dryness at 60°C using a rotary vacuum evaporator (RE200, England, United Kingdom). Approximately 10 ml of distilled water was added to the dried sample. Thereafter the dissolved sample was placed in duplicates of 2 ml into a test tube and 2 ml of diethyl ether added. The mixture was vigorously shaken and allowed to stand before removing the ether layer. This was repeated 3 times. Excess ether was then flashed off using a vacuum (Heraeus, RVT 360, Germany). Equal amounts of acetonitrile was then added to the samples before being stored at 5°C ready for determination of sugars using HPLC. The samples were micro-filtered to remove any debris before injecting 20 µl into a HPLC, SCL-10A (Shimadzu, Tokyo, Japan) fitted with a Refractive Index Detector, RID-6A (Shimadzu, Tokyo, Japan). Chromatographic conditions which included a mobile phase of acetonitrile: water (80:20) pumped through a reverse phase column, NH2100R 250 x 4.6 mm, 5 µm at a working maximum pressure of 150 kgf/cm^2 and flow rate of 1.0 ml/min. Oven temperature was then set at 30°C. Using working standards of sucrose, fructose and glucose, the sugars in the samples were identified and calculated. The results presented were means of duplicate determinations and are given as fructose, glucose and sucrose in g/100 g dry weight.

Determination of the moisture content of the processed potato crisps

Moisture content for the processed products was determined by oven drying according to AOAC

(AOAC, 1980) using the oven model DS0-500D from Israel.

Determination of color of crisps

The potato crisps colour was evaluated using color spectrophotometer according to Abong *et al.*, (2010). The potato crisps color was measured with a color spectrophotometer CR-200b (Minolta, Japan) using the CIE Lab L*, a* and b* color scale. The 'L*'value is the lightness parameter indicating degree of lightness of the sample and varies from 0=black to 100=white. The 'a*'which is the chromatic redness parameter whose value means tending to red color when positive (+) and green color when negative (–). The 'b*'is yellowness chromatic parameter corresponding to yellow color when it is positive (+) and blue color when it is negative (–). Each sample was measured thrice, and the values subjected to statistical analysis.

Determination of acrylamide in the processed crisps

The levels of acrylamide were determined by the modification of the method described by the United States Food and Drug Administration method (US-FDA, 2002) using a Gas chromatography and Flame ionizable detector (G-14B,Shimadzu, Japan) with a chromatopac (C-R8A, Shimadzu, Japan) and the aspirator (GP-5-254-SI).

Acrylamide extraction

The samples were crushed using a pestle in a mortar and approximately 1g was weighed before addition of 10 ml of 0.1% formic acid solution. The mixture was then mixed on a test tube shaker (KS250, Japan) for 5 minutes at 300 rpm followed by centrifugation (H 20000 Tokyo, Japan) at 3000 rpm for 10 min to ensure easier removal of the oily top layer and ensure further solubility of the acrylamide compound. The supernatant was extracted then filtered using a filter paper (Wattman paper No. 47) before being passed through a 0.45µm nylon syringe filter to remove any suspended particles and then stored in a refrigerator awaiting the clean-up and analysis stages.

Clean up stage

The filtered sample was passed through a solid phase extractor tube (Carboprep tm 200 SPE tube, 6ml, 500mg) which was first activated by passing 2 ml of acetone solvent and then 2 ml of 0.1% formic acid. The filtered sample solution was then passed through the tube and allowed to flow under gravity. One milliliter of water was then fast passed through the tube. The SPE tube was then vacuum dried for one minute after which 2 ml of analytical grade acetone flowing through gravity was passed for elution. The eluted sample was stored immediately in the refrigerator ready for the GC-FID analysis. 1 microliter of the elute was injected into the column. The chromatogram obtained from the chromatopac was then interpreted.

Gas chromatography conditions

Supelcowax capillary column was used since it gave good results during determination of the suitable condition for analysis using this column. The injection temperature was maintained at 260°C while nitrogen, the carrier gas, was supplied at 100 bars pressure. The linear velocity of the carrier gas was maintained at 62cm/sec at 100 °C, while the oven temperature was set at 100 °C then held for 0.5 min before it was allowed to increase at a rate of 15 °C/min to attain a final temperature of 200 °C. The retention time of the acrylamide was found to be between 8.4 and 8.7 minutes. The limit of detection for the GC-FID was found to be 4.5ppm while the Limit of quantification was 45ppm.

Sensory evaluation of the processed potato crisps

Coded samples were presented to 10 panelists and scores for colour, texture, flavour, oiliness and overall acceptability on a 7-point hedonic scale ranging from 1 (dislike very much) to 7 (like very much) according to Larmond (1977).

Data quality control

To ensure quality data was achieved: all analysis was done in triplicates or duplicates, equipment and instruments were calibrated daily before use to limit erroneous results. The standards used for acrylamide and reducing sugars determination were prepared under specified conditions. In addition, where time and temperature were critical in the analysis, these parameters were closely monitored to limit deviations. Data entry was done promptly, cleaning, and repetition where necessary to minimize errors.

Data analysis

Both descriptive and inferential statistical tests including analysis of variance (ANOVA) and least significant difference test (LSD) for the variables were carried out using the Statistical Analysis System (SAS) version 9.1.3. Pearson correlation analysis and multiple regression analysis were also performed to determine relationships between acrylamide and moisture and between acrylamide and colour parameters. Where the differences of $p \leq 0.05$ existed, the samples were considered to be significant.

Results

Percentage dry matter contents of the four Kenyan potato varieties

The tubers used for processing crisps had dry matter levels ranging from 21.5% (Kenya Mpya) to 28.4 % (Sheherekea) and there was a significant ($p \leq 0.05$) difference between the varieties (Figure 1). There was a significant difference ($p \leq 0.05$) between the varieties Sheherekea, Tigoni and Kenya Mpya varieties. No significant difference ($p > 0.05$) existed between Sheherekea and Dutch Robjyn and similarity between Dutch Robjin and Tigoni varieties. In addition, no significance difference ($p > 0.05$) was observed in dry matter content between the varieties Tigoni and Kenya Mpya.

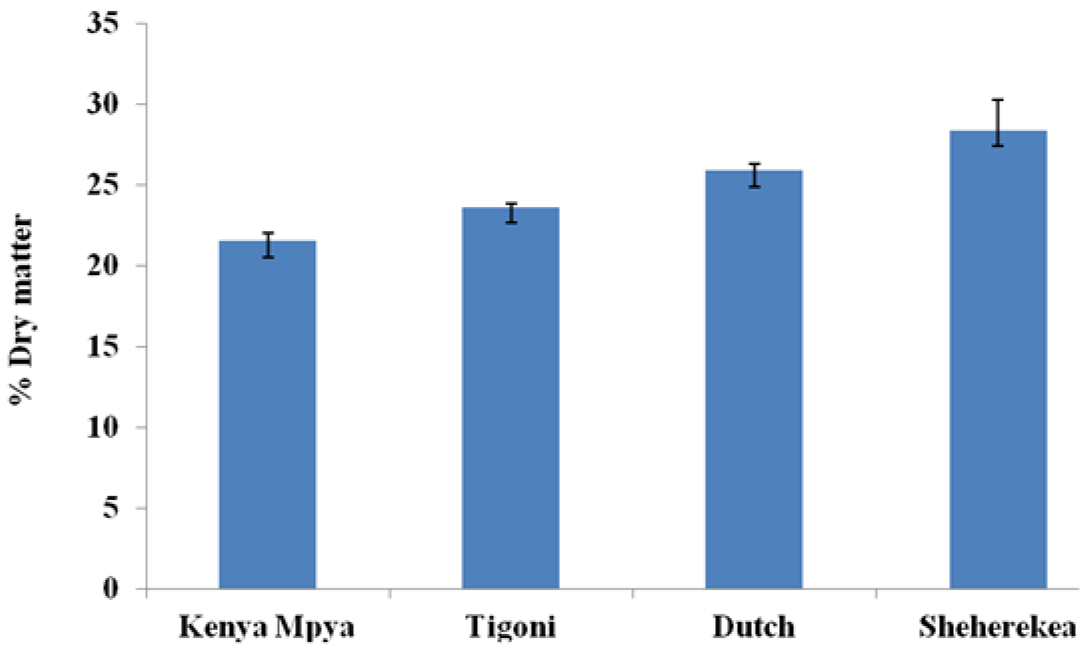

Figure 1. Percentage dry matter content of four Kenyan potato varieties. The bars represent the standard error bars

Levels sugars on dry weight basis expressed as g/100g from the four potato varieties

Kenya Mpya had the highest levels of sucrose, fructose and glucose while Tigoni had the lowest level of fructose and Sheherekea lowest levels of both sucrose and glucose. Fructose levels significantly differed significantly across all the varieties $p \leq 0.05$ with Kenya Mpya recording high levels of fructose of 0.241% compared to Tigoni which had 0.068% (Table 3.1). The glucose levels were higher in Kenya Mpya variety (0.218%) and low in Sheherekea (0.155%). There was no significance difference ($p > 0.05$) in glucose levels between Kenya Mpya, Dutch Robjin and Sheherekea but the three varieties differed significantly ($p \leq 0.05$) with Tigoni in glucose levels. The levels of Sucrose ranged from 0.606% in Sheherekea to 0.868% in Kenya Mpya. No significant difference ($p > 0.05$) existed between Sheherekea, Kenya Mpya and Dutch Robjin but significant difference ($p \leq 0.05$) existed between Kenya Mpya and Tigoni in sucrose levels.

Table 1. Sugar levels in the four potato varieties expressed in g/100g on dry weight basis

Variety	Fructose	Glucose	Sucrose
Kenya Mpya	0.241±0.001a	0.218±0a	0.868±0.001a
Dutch Robjin	0.147±0.001b	0.185±0a	0.679±0.002ab
Sherehekea	0.137±0.003c	0.155±0a	0.606±0.002ab
Tigoni	0.068±0.001d	0.161±0.003b	0.622±0.022b

Values are means of three determinations ± standard deviation.
Values with the same letters in the same column are not significantly different at 5% level of significance

Moisture content of the processed potato crisps as affected by frying temp and slice thickness

The moisture content ranged from 0.243% in crisps processed from the Variety Tigoni fried at 180°C and slice thickness 1.5mm to 2.575% from Kenya Mpya variety fried at 160°C and slice thickness 2mm (Table 2). Highest moisture content was reported in potato crisps processed from Kenya Mpya variety and the lowest levels in those processed from Tigoni. The moisture content of the processed crisps showed a significant difference ($p \leq 0.05$) between varieties with Kenya Mpya recording the highest moisture content and Tigoni the lowest moisture content. The higher the temperature of frying the lower the moisture content as potato crisps processed at temperature of 180°C attained the lowest moisture content compared to those that were fried at 170°C and 160°C. There was a significant difference ($p \leq 0.05$) in moisture content between crisps processed at 180°C and those processed at 170°C and 160°C, though no significant difference ($p > 0.05$) existed between those processed at 160°C and 170°C. Similarly, the greater the slice thickness the higher the moisture content as the slice thickness of 2.0mm had the highest moisture content and significantly differed ($p \leq 0.05$) with those from the slice thicknesses of 1.0mm and 1.5mm. The moisture content of the potato crisps with slice thicknesses of 1.0mm and 1.5mm showed no significance difference at 95% confidence interval.

Table 2. Moisture content of processed potato crisps from four Kenyan potato varieties

Variety	Frying Temperature	Slice thickness	% Moisture content	Variety	Frying Temperature	Slice thickness	% Moisture Content
Dutch Robjin	160°C	1.0mm	0.431±0.09bcd	Sherehekea	160°C	1.0mm	1.501±0.05lm
		1.5mm	0.445±0.05c			1.5mm	1.305±0.04k
		2.0mm	1.348±0.14jklm			2.0mm	1.331±0.12jkl
	170°C	1.0mm	1.501±0.03lm		170°C	1.0mm	1.162±0.16hijk

		1.5mm	0.433±0.09bcd			1.5mm	1.099±0.08hij
		2.0mm	1.531±0.10lmn			2.0mm	1.03±0.09hi
	180°C	1.0mm	0.892±0.07fgh		180°C	1.0mm	1.192±0.18ijk
		1.5mm	0.987±0.07ghi			1.5mm	0.986±0.16ghi
		2.0mm	0.866±0.11fgh			2.0mm	1.071±0.16ghi
Kenya Mpya	160°C	1.0mm	1.856±0.06op	Tigoni	160°C	1.0mm	0.595±0.24bcde
		1.5mm	1.872±0.07opq			1.5mm	0.572±0.18cdef
		2.0mm	2.575±0.67pqr			2.0mm	0.952±0.20fghi
	170°C	1.0mm	1.289±0.13jkl		170°C	1.0mm	0.82±0.33cdefgh
		1.5mm	1.433±0.16klm			1.5mm	0.898±0.28efghi
		2.0mm	1.514±0.08lm			2.0mm	0.878±0.20efghi
	180°C	1.0mm	1.112±0.13hij		180°C	1.0mm	0.382±0.00b
		1.5mm	1.187±0.08ij			1.5mm	0.243±0.18a
		2.0mm	1.096±0.08hij			2.0mm	0.465±0.16bcde

Values are means of three determinations ± standard deviation.
Values with the same letters in the same column are not significantly different at 5% level of significance.

The color parameters of crisps processed from the four varieties

Eighty-nine (89 %) of the potato crisps processed from the four potato varieties were light colored with L*>50 (Table 3). The lightest crisp was of slice thickness 2mm from Dutch Robjin fried at 180°C with a lightness level of 63.7. The least yellow was the crisp from Tigoni variety fried at 170°C and slice thickness of 2mm. The highest value of yellowness parameter was from the crisps produced from Dutch Robjin fried at 180°C with a slice thickness of 1.5mm. Most of the samples tended towards red as the redness parameter veered towards the positive indicating high degree of browning. Crisps produced from the potatoes fried at 160°C at a slice thickness of

1.5mm from Sheherekea variety had the highest degree of redness of 11, though not significantly different among varieties. This is an indication of excessive browning while those processed from the same variety and temperature but thickness of 1.0mm had the least browning due to the negative value -0.6. The positive value of the yellowness parameter b* is an indication that all the potato crisps in the processed tend towards yellow. All the varieties were light in colour and no significance $p \leq 0.05$ difference existed between them. The redness parameter in all varieties had positive values and in Sherehekea and Kenya Mpya which had the highest values of a* had no significant differences between them but the two differed significantly ($p<0.05$) with Dutch and Tigoni. Kenya Mpya had the highest value of the yellowness parameter while Tigoni had the least and there was no significance difference among Dutch Robjin, Sheherekea and Kenya Mpya but the three significantly differed with Tigoni. Temperature has a great influence on the CIE colour parameters with frying temperature of 170°C having the highest lightness parameter and no significance difference ($p>0.05$) existing among the three frying temperatures. Temperatures of 180°C had the highest redness parameter while that of 160°C recording the lowest a* values. No significance difference ($p>0.05$) existed in the redness parameters between the 160°C and 170°C frying temperatures but the two significantly differed with that at 180°C. The b* values differed significantly ($p \leq 0.05$) across the three frying temperatures with 180°C giving the highest and 160°C the lowest yellowness parameter values. The thicker the potato crisp the less light it was since the slices of 2.0mm were least light. Between slice thickness 1.0mm and 1.5mm there was no significance difference ($p>0.05$) but the two thicknesses significantly differed ($p \leq 0.05$) in the lightness parameter with the thickness of 2.0mm. The redness parameter and the yellowness parameter varied linearly with the thickness of the potato chips; the thicker the potato slices the higher the values of a* and b*. Least browning and least yellowing were detected in the potato crisps processed at 1.0mm while those of 2.0mm had higher average values of a* and b*. In the redness parameter, the values significantly differed ($p \leq 0.05$) among the three levels of thickness while in the yellowness parameter there was no significance difference in the between the thicknesses 2.0mm and 1.5mm but the two differed significantly with 1.0mm thicknesses.

*Table 3***.** *Color parameters of crisps processed from the four potato varieties*

Variety	Frying temperature	Slice Thickness	L	a*	b*
Dutch Robjin	160°C	1.0mm	49.7±3.5bcdef	1±0.9ab	23.6±0.6ef
		1.5mm	51.7±4.3cdefg	4±4.1abcdefgh	26.7±1.1ghi
		2.0mm	51.3±3.7cdef	8.4±3.4efghijk	29.1±3.4ghijklm
	170°C	1. 0mm	56.2±3.8efghi	3.1±1.9abcde	23.5±2defg
		1.5mm	51.4±3.1cdef	7.6±2.4efghi	28.±0.4ij
		2.0mm	53.5±5.1cdefgh	10±1.5hijk	31±1.5jklm
	180°C	1.0mm	53.3±5.5cdefgh	1.1±1ab	28.4±3.2ghijkl
		1.5mm	58.5±1.8ghi	1.7±0.3b	34.5±0.5o
		2.0mm	63.7±5.7hijklmn	1.8±1.2abc	34.3±1.4mnop
Kenya Mpya	160°C	1.0mm	52.8±2.8defg	0.6±1.6ab	24.6±2.7defghi
		1.5mm	57.3±3.9fghij	0.7±0.7ab	24.8±1.8efgh

		2.0mm	51.4±4.8bcdefg	10±1.2hijk	31.2±4.8hijklmnop
	170°C	1.0mm	54.6±2.5efgh	3.8±1.1cde	31.5±3.4ijklmno
		1.5mm	54.6±0.7fg	6.4±3.6cdefghi	32.9±3.2klmnop
		2.0mm	55.7±4.4efghi	2.6±0.6bc	31.1±4.4hijklmno
	180°C	1.0mm	50.6±5.5bcdefg	4.3±0.8de	28.7±1.8ghijk
		1.5mm	53.1±4.5defgh	8.5±1.5ghi	33.2±2.2lmno
		2.0mm	49.8±1.4cde	7.9±2.6fghij	32.2±2.7kmno
Sheherekea	160°C	1.0mm	51.9±1.3def	-0.6±0.3a	18.8±0.8ab
		1.5mm	48.8±1.5cd	11.1±3.1hiklm	29.1±2.8hijkl
		2.0mm	52.4±1.6def	5.3±3.7cdefgh	29.1±3.3ghijklm
	170°C	1.0mm	55.9±4.8efghi	0.8±1.4ab	26.6±1.2fghi
		1.5mm	50.5±3.3cdef	6.9±2.8defghi	30.3±0.9jkl
		2.0mm	52.1±4cdefg	9.6±3.8fghijklm	31.7±4.2iklmnop
	180°C	1.0mm	55±2.5efgh	3.7±0.5cd	31.2±1.1klm
		1.5mm	54.1±4.5defgh	6.3±3.3cdefghi	30.2±1jkl
		2.0mm	48.8±3bcde	7.5±2.1efghi	31.3±1.7kjklm
Tigoni	160°C	1.0mm	55.7±3.1efgh	2.1±2.2abcd	28.1±3.4ghijkl
		1.5mm	56.6±1.5gh	2.3±2.3ab	27.6±4.4efghijk
		2.0mm	50.8±5.1bcdefg	6±0.5ef	27.6±2.2ghijk
	170°C	1.0mm	55.3±0.7fg	-0.2±0.3a	21.4±1.1cd
		1.5mm	58.9±4.3fghijk	2.6±3.2abcdef	26.9±2.3fghij
		2.0mm	48±2.1bcd	4.6±2.1cdef	26.8±2.9fghijkl
	180°C	1.0mm	53.9±3.6defgh	4.5±0.6de	27.5±2.0ghij
		1.5mm	51±1.9de	5.3±2.3cdefg	27.7±2.7ghijk
		2.0mm	51.8±1.2de	6.2±1.6efg	29.4±1.3ijk

[1]Values are means of three determinations± standard deviation.
[2]Values with the same letters in the same column are not significantly different at 5% level of significance.

Levels of acrylamide in the crisps from the processed potato crisps from four Kenyan varieties

Potato crisps from Kenya Mpya variety fried at 180°C and slice thickness 1.0mm recorded the highest levels of acrylamide (13480 ppb) with Dutch Robjin fried at 170°C and sliced at 1.0mm recording the lowest levels of the acrylamide (3129 ppb) (Table 4). The acrylamide levels differed significantly (p≤0.05) across all the varieties with Kenya Mpya having the highest levels of acrylamide and the lowest levels being recorded in Dutch Robyjn. Temperature influences significantly acrylamide formation and the higher the temperature the higher the levels of acrylamide formed. Potato crisps fried at temperatures of 180°C recorded the highest levels of acrylamide followed by 170°C and the least levels were those processed at 160°C. The levels of acrylamide significantly varied (p≤0.05) across the three temperatures. The thicker the slice of the potato crisp the higher the degree of acrylamide formation as observed in the analysis carried out. Higher levels of acrylamide were formed at 2.0mm thickness and least levels at 1.0mm. The levels of acrylamide formed differed significantly (p≤0.05) at 95% confidence interval across the three thicknesses.

Table 4. Levels of acrylamide in crisps from four potato varieties grown in Kenya

Variety	Frying Temperature	Slice Thickness	Acrylamide	Variety	Frying Temperature	Slice Thickness	Acrylamide
Dutch Robjin	160°C	1.0mm	3150±64ab	Shehere kea	160°C	1.0mm	3149±192ab
		1.5mm	4094±52cd			1.5mm	4073±937abcde
		2.0mm	5130±127ef			2.0mm	6051±323ghi
	170°C	1.0mm	3129.±434ab		170°C	1.0mm	5671±1200defghi
		1.5mm	3332±29b			1.5mm	5009±471def
		2.0mm	4813±67e			2.0mm	5599±803efgh
	180°C	1.0mm	4599±119de		180°C	1.0mm	7148±1521ghijklm
		1.5mm	4874±88e			1.5mm	7883±10l
		2.0mm	4917±199ef			2.0mm	9164±473mno
Kenya Mpya	160°C	1.0mm	3233±332ab	Tigoni	160°C	1.0mm	3702±489bcd
		1.5mm	5934±246gh			1.5mm	5209±399efg
		2.0mm	8783±860lmno			2.0mm	4987±93ef
	170°C	1.0mm	7048±1022hijkl		170°C	1.0mm	3776±74c
		1.5mm	11396±1091pqrst			1.5mm	4895±740defg

	2.0mm	12127.±1395qrstuv		2.0mm	5058±946defg
180°C	1.0mm	13480±1030tuvwx	180°C	1.0mm	5933±555fgh
	1.5mm	12351±893rstuv		1.5mm	3627.±3.5c
	2.0mm	13150±1504stuvw		2.0mm	5412±529efg

[1]Values are means of six determinations± standard deviation.
[2]Values with the same letters in the same column are not significantly different at 5% level of significance.

Pearson correlation values between acrylamide content, percentage moisture content and colour parameters

There was a weak positive relationship between moisture content and acrylamide (r=0.287).
A positive relationship existed between acrylamide and the redness (a*) (r=0.467) and yellowness (b*) (0.527) parameters (Table 5). A very weak negative relationship existed between both moisture content & acrylamide and the L* value of the colour parameter. No relationship existed between moisture and a* and b* colour parameters.

Correlation values between the sugars and acrylamide content

There was a positive correlation between glucose, fructose, sucrose and the acrylamide levels. The correlation between fructose and the acrylamide levels was a weak positive relationship (r=0.444) (Table 6). The correlation values among the reducing sugars and the acrylamide content showed a great significance difference (p>0.05). The correlation values between the acrylamide values and sucrose showed significant difference (p≤0.001).

Table 5. Correlation between acrylamide content, moisture content and colour parameters for potato crisps processed from the four potato varieties

Parameters	Moisture content	Acrylamide
Moisture content	1	0.287a
Acrylamide	0.287a	1
L	-0.156a	-0.184
a*	0.093a	0.467*
b*	0.0889a	0.527**

N=36; a not significant at p>0.05
* Significantly different at p≤0.05
**significant at p≤0.001

*Table 6**.** Pearson correlation (r) values between acrylamide content, reducing sugars and sucrose for potato crisps processed from the four potato varieties.*

Parameters	Fructose	Glucose	Sucrose	Acrylamide
Frucose	1	0.834*	0.963**	0.444*

Glucose	0.834*	1	0.952*	0.762*
Sucrose	0.963**	0.952*	1	0.639**
Acrylamide	0.444*	0.762*	0.639**	1

N=4; * significantly different at $p \leq 0.05$
**significant at $p \leq 0.001$

Sensory analysis for the potato crisps processed under different temperatures and slice thickness

The most acceptable crisp was processed from Kenya Mpya 170°C at 2.0mm which had a score of 5.5 similarly was its colour also. The crisps with texture that was much preferred was from Tigoni processed at 170°C and thickness of 2.0mm with a score of 5.5 while the best flavour was from Dutch Robjin processed at 180°C and thickness of 2.0mm with a score of 5.3. the oiliness that scored highly i.e 5.1 was from Dutch Robyjn processed to 1.5mm and temperature of 170° C. In sensory evaluation, Sheherekea had the lowest score (3.8) in preference by the panelists in colour (Table 3.7). This can be attributed to the high reducing sugars that it possessed and also uneven browning on the surface. Kenya Mpya was the most preferred in terms of flavor with a score of 4.7 while Sheherekea was the least scored 3.5. In the overall acceptability there existed no significance difference between Dutch Robjin, Tigoni and Kenya Mpya but the three significantly differed with Sheherekea Dutch Robjin scored highly (4.5) followed while Sheherekea was the least accepted score of 3.9. In the slice thickness, 2.0mm was highest in acceptability, texture and flavor with a score of slightly greater than 4 ($p \leq 0.05$). There was no significant difference $p > 0.05$ in the colour of the three thicknesses (scores of 4.3, 4.1 and 4.1). In oiliness the 2.0mm scored poorly, less than four and this can be related to the high moisture content, longer time taken to be fried fully, and thus a soggy product that may as well contain more acrylamide leading to consumer safety concerns.

Table 7. Sensory attributes of the potato crisps processed from the four varieties

Variety	Frying Temperature	Slice thickness	Colour	Flavour	Texture	Oiliness	Overall acceptability
Dutch Robjin	160°C	1.0mm	3.2±1.2b	3.5±1.4c	3.6±1.5bc	3.2±1.2a	4.5±1.1cd
		1.5mm	4.1±1.4de	4.2±1.1de	4.6±1.0ef	3.9±1.4bc	4.5±0.7cd
		2.0mm	4±1.2d	3.9±1.7d	4.2±1.1de	3.6±1.3b	4.6±0.7d
	170°C	1.0mm	4.5±1.6d	4.4±1.3ef	4.4±1.3de	4.1±1.4cd	4.5±1.1cd
		1.5mm	3.9±1.2cd	2.7±1.2a	2.9±1.8a	3.9±1.4bc	3.5±1.2ab
		2.0mm	4.7±2.1de	3.7±1.8cd	4.3±1.6de	4.3±1.7cd	4.2±1.6c
	180°C	1.0mm	4.3±1.5de	3.8±1.5cd	4.7±1.8ef	4.4±1.4d	4.6±1.8cdef

		1.5mm	5±1.4fg	4.6±1.1ef	4.9±1.4fghi	5.1±1.7ef	5.1±1.5ef
		2.0mm	4.6±1.3e	5.3±0.8gh	5±1.2fg	5±1.3ef	5.4±1.2f
Kenya Mpya	160°C	1.0mm	3.8±1.3cd	4.1±1.6de	3.7±2.1c	3.8±1.5bc	3.6±1.3ab
		1.5mm	4.6±1.5e	4.8±1.7fg	4.9±1.1fghi	4.5±1.3de	4.7±0.9cde
		2.0mm	4.1±1.3de	4.4±1.0ef	4.2±1.4de	4.7±1.8de	4.6±1.3cdef
	170°C	1.0mm	3.6±1.6c	4.7±1.5f	4.6±1.4ef	3.5±1.5ab	3.6±1.5ab
		1.5mm	3.1±1.3ab	4.4±1.3ef	4.8±1.3ef	4.7±1.2de	4.6±0.8cde
		2.0mm	5.4±1.2g	4.8±1.1fg	5.1±1.1fg	5±1.2ef	5.5±1.3fg
	180°C	1.0mm	4.1±1.4de	5±1.0fg	3.5±1.6bc	3.3±1.5ab	4±1.4bc
		1.5mm	3.9±1.3cd	4.9±1.1fg	5.2±1.0fg	5.1±1.0ef	4.8±1.2de
		2.0mm	3.5±2.0bc	4.9±1.4fg	4.9±1.4fghi	4.8±1.2de	4.7±1.5cde
Sheherekea	160°C	1.0mm	3.5±1.5bc	3.8±1.6cd	4.2±0.8de	3±1.6a	3.6±1.2ab
		1.5mm	4±1.4d	3.6±1.8cd	4.5±1.4e	4.4±1.7d	4.2±1.9c
		2.0mm	3.9±1.1cd	2.8±1.4ab	3.8±1.5c	3.3±1.3ab	3.5±1.3ab
	170°C	1.0mm	3.9±1.4cd	3.3±1.6bc	3±1.4ab	3.4±1.6ab	3.4±1.2a
		1.5mm	4.4±1.6e	4±1.9de	4.1±1.4d	3.8±1.5bc	4±1.5bc
		2.0mm	4.2±1.1de	3±1.9ab	3.5±1.4b	3.5±1.7ab	3.4±2.0a
	180°C	1.0mm	4.2±1.0de	3.4±1.7bc	3.7±1.6c	4.2±1.0cd	3.8±1.8b
		1.5mm	3.4±1.1bc	3.1±2.0b	3.1±1.7a	3.2±1.4a	3.6±1.9ab
		2.0mm	4.2±1.7de	4.3±1.3e	3.6±1.1bc	3.7±0.9bc	3.6±1.2ab
Tigoni	160°C	1.0mm	3.3±1.5bc	4.1±1.2de	3.9±1.5c	3.3±1.5ab	3.9±1.3bc

	1.5mm	4±1.5d	3.5±1.4c	3.6±1.3bc	3.2±1.4a	3.9±1.0bc
	2.0mm	4.1±1.6de	4±1.2de	4.8±1.7ef	3.9±1.2bc	4.5±1.4cd
170°C	1.0mm	5.3±1.9g	4.1±2.0de	4.6±1.6ef	4.2±1.2cd	4.7±1.6cde
	1.5mm	4.8±1.6f	4.3±1.3e	4.6±1.6ef	4.4±1.5d	5±1.1de
	2.0mm	5±1.1fg	5.1±1.6g	5.5±1.0gh	4.6±1.2de	5.3±1.2ef
180°C	1.0mm	4.2±1.0de	4.3±1.3e	4.7±2.0ef	5±1.2ef	4.8±1.1de
	1.5mm	4.6±1.3e	4.2±1.2de	4.2±1.0de	4.3±1.8cd	4.2±1.3c
	2.0mm	3.6±1.6c	3.6±1.6cd	4.2±1.6de	4.3±1.6cd	4±1.3bc

[1]Values are means of ten determinations± standard deviation.
[2]Values with the same letters in the same column are not significantly different at 5% level of significance
[3]Evaluation was done on 7-point hedonic scale. A score of 4 was the acceptable lower limit.

Discussion

Characteristics of potatoes used in crisps processing

The levels of dry matter content in the four varieties used in this study are within what was recommended (greater than 20%) for crisp production by Kabira and Lemaga (2003). The amount of dry matter content indicates the level of maturity of the tubers and the lower the dry matter content the lesser the physiological maturity of the tubers. Low dry matter content in potato tubers depends on the variety but may also result from early tuber harvesting. This may lead to accumulation of high levels of reducing sugars due to conversion of starch to sugars.

Typically, early harvested, 'new' potatoes have very thin skins, low dry matter percentages of about 16 % and high concentrations of reducing sugars compared with tubers harvested at maturity (Seal *et al.*, 2008). Low dry matter content affects the general quality of the crisps as more heat will be needed to evaporate the water and will result in too oily and soggy crisps. While high dry matter content will result in too hard and dry crisps that is unacceptable. Thus it affects the texture and oiliness of the product which ultimately determines the overall acceptance of the product by the consumers.

The colours of the crisps are influenced to a large extent by the reducing sugar of the tubers used in their production. Reaction between reducing sugars and the amino acids present in the tubers are responsible for the non-enzymic browning (Maillard reaction) of fried potato products that determines not only the colour but also the acrylamide content. High levels of reducing sugars greater than 0.05% on wet weight basis are not acceptable for the processing of crisps. The lower the levels of reducing sugars the lesser the browning of crisps after processing. Reducing sugar levels are influenced by maturity levels thus early harvesting of the tubers results in higher levels of reducing sugars as not enough reducing sugars have been converted to starch. Storage also influences the levels of reducing sugars with reducing sugar levels accumulating to higher levels when stored at low temperatures (cold senescence). Starch levels are high when tubers are harvested at maturity and this inhibits browning since less Maillard reactions take place. The levels of sucrose and the reducing sugars obtained were within the range of those reported by Seal *et al*. (2008). Higher levels of reducing sugars in Kenya Mpya resulted in darker crisps colour than in Tigoni. Sucrose concentrations were greater than the 0.15% and thus the possibility that the levels were higher at harvest, and some were converted to the reducing sugars.

Potato crisps characteristics

Moisture content of the processed potato crisps

The differences in moisture contents indicate that when frying not all the water evaporated from the potato crisps. In general, these values were within the range reported by Abong *et al.,* (2009) and are also less than the recommended 5% by the East Africa Standards (EAS) (2010). The moisture content of the potato crisps is normally lowered to levels below 2·5 % resulting in core temperatures above 120°C. Therefore, acrylamide is formed through the whole product resulting in higher contents in crisps than in French fries despite shorter frying times. The moisture content of the potato crisps influences the acceptability of the product and also the stability of the crisps. High moisture content results in low shelf life due to rancidity caused by lipid oxidation. Therefore, lower moisture contents in this study indicate the crisps may have higher shelf life and may not be prone to rancidity.

Colour of the processed potato crisps

Colour of potato crisps is determined by the levels of reducing sugars and the amino acids whose interaction result in non-enzymic browning. Higher levels of reducing sugars result in dark brown crisps as opposed to the golden-brown color. All the potato varieties used for the crisps production resulted in crisps of lightness parameter greater than 50. The redness parameters (a*) of the crisps were all positive indicating browning due to either excessive reducing sugars concentration with highest levels recorded in Sheherekea and Kenya Mpya which no significant ($p<0.05$) difference between the levels. These two varieties had the highest levels of reducing sugars. The lowest value of the redness parameters was recorded in the Tigoni variety which had the lowest levels of reducing sugars. These findings are in tandem with the findings that the higher the reducing sugars the higher the non-enzymic browning due to Maillard reaction which results in darker and bitter products which are unacceptable to the consumers. There was no significant difference in the lightness parameter (L*) of the potato crisps processed at the three temperatures; with the L* in all the temperatures being greater than 50 indicating that all the products were light. The higher the frying temperature the higher the browning indicated by the redness parameter of the potato crisps which was highest in those fried at 180°C and the lowest being those processed at 160°C. This indicates excessive browning due to the high processing temperatures. The thicker the slice thickness the higher degree of browning as indicated by the higher values of the redness parameter (a*) since the amount of the precursors interacting are more than in the thin slices.

Acrylamide levels in potato crisps

There was a significant difference in the levels of acrylamide in crisps from the four potato varieties. The potato variety influences the amount of acrylamide levels formed due to differences in reducing sugars, the dry matter content, cold-sweetening and senescence-sweetening were also found to be variety-dependent. Kenya Mpya recorded the highest levels of acrylamide with Dutch Robjyn recording the lowest levels of acrylamide formed. Acrylamide formation is influenced by the levels of reducing sugar in the potato tubers and since Kenya Mpya had the highest concentration of reducing sugars thus the high levels of acrylamide formed. Irreversible combination of reducing sugars and asparagine through the maillard reaction results in acrylamide formation in plant-based food stuffs (De Wilde *et al.*, 2006). Reducing sugars are the limiting factor in acrylamide formation since the asparagine levels in raw potatoes only vary within a certain range, while the reducing sugars depend on variety, maturity, and storage among other growing and processing conditions (Abong *et al.,* 2009).

The temperatures of processing the potato crisps were between 160°C and 180°C which had been found to be the optimal temperatures for acrylamide formation as reported by various authors thus the high levels. The levels of acrylamide in the current study are quite higher than those reported by European Food Safety Agency (EFSA, 2005). This can be attributed to the high frying temperatures where there is optimal development of acrylamide. Frying the potatoes at temperatures lower than 160°C reduces the concentration of acrylamide produced, but quality characteristics of the product like texture, colour and oil content, are negatively affected and consequently the acceptability of the product by the consumer may be reduced. Though, temperatures higher than 200ºC or prolonged processing time may cause a decrease of acrylamide level due to intensified degradation reactions of acrylamide to glycidamide (Rydberg *et al.*, 2003).

There was significance in the levels of acrylamide depending on the thickness of the potato crisp. The thicker the slice the higher the acrylamide content this can be attributed to the higher concentrations of the reactants than the thinner slices. There was a strong positive relationship between fructose and sucrose with the acrylamide levels where for glucose and 0.639 for sucrose while there exists a moderate positive relationship between fructose and acrylamide r=0.442. This is in agreement with the findings that the concentration of reducing sugars determines the extent of formation of acrylamide as potatoes are generally high in the amino acid asparagine. The concentration of sucrose in potatoes destined for processing into chips at harvest should be less than 1·5 mg/g to minimize accumulation of reducing sugars in long term storage at intermediate temperatures. Temperatures during production affect the levels of acrylamide formation. According to Pollien et al. (2003) fructose was reported to be more efficient than glucose in forming acrylamide. It was also concluded that acrylamide is formed in comparable amounts with several mono- or disaccharides. There exists a weak positive relationship between the moisture content and acrylamide formation. This is because the lower the moisture content the higher the dry matter and thus the reactants are brought close together and thus higher rate of acrylamide formation. With the decrease in the moisture, the formation of acrylamide was increased accordingly (Ye *et al.*, 2010).

A positive correlation between acrylamide and the redness parameter a* r=0.332 is in agreement with those reported by various authors who correlated the colour of crisps as an indication of the acrylamide content (Viklund *et al.*, 2007). This also confirms that acrylamide formation is a as a result of maillard reactions which determines browning. There is a less close correlation between acrylamide and colour for large surface-to-volume material, such as potato crisps, in comparison with small surface-to-volume material, such as French fries as observed above, thus the weak relationship between the redness parameter and the acrylamide content. In the sensory evaluation, the highest scores were just slightly above 5.0 indicating "like slightly." And thus no variety came out as the most liked since none scored above 7.0 (like very much). This can be attributed to the high frying temperatures and the reducing sugars which was quite high resulting in browning of the products. There is significance difference within each product range indicating difference in preference by the panelists. Kenya Mpya was the overall preferred in terms of colour and acceptability (>5). Thus processing of this variety at 170°C and slice thickness of 2.0mm is the most preferred for the crisps production. Dutch Robjyn variety is the most used variety in the production of potato crisps in Kenya and this can be attributed to its desirable flavor and oiliness. Low scores exhibited by other varieties and temperatures can be attributed to excessive browning and oiliness. Texture of the potato crisps is determined by the dry matter content of the tubers and can be hard or soggy. Kenya Mpya scored highly on the textural and oiliness acceptance due to its high dry matter content with Tigoni recording the least score. Crisps processed at temperatures of 170°C scored highly in colour compared to the other temperatures. In texture and overall acceptability there was no significant difference at the three temperatures while flavor and oiliness processing at 170°C and 180°C showed no significant difference but differed greatly with processing at 160°C. The colour is the most important parameter that determines the acceptability of not only the potato crisps but also most products.

Conclusion

Potato tubers for crisps processing should be harvested when mature as indicated by low levels of reducing sugars and high percentage dry matter content. Higher reducing sugars results in excessive browning of the potato crisps and thus the higher the redness parameter.

Harvesting of potato tubers should be done at maturity when the levels of reducing sugars are at their lowest in order to minimize acrylamide during processing. There is a linear relationship between acrylamide levels and the levels of reducing sugars, the processing temperature and the slice thickness of the crisps. Slice thicknesses of 1.5mm and 2.0mm are mostly preferred in the processing of these potato crisps by consumers.

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Statement of Competing interests

The authors have no competing interests in the study.

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