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Quality characteristics and levels of acrylamide in commercial French fries consumed in Nairobi, Kenya

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Abstract

Studies in Kenya have shown that French fries are relied on as a convenient meal by many people across the ages, and recent reports indicate that fried potato products including French fries contain high levels of acrylamide (AA), a probable human carcinogen and neurotoxic substance. The current study was carried out to determine the quality characteristics including moisture content, oil content, color and levels of acrylamide, of French fries consumed in Nairobi. A total of 100 samples were purchased from high, middle and lower-end restaurants/fast-food outlets and each was assessed for these quality parameters. The oil content of French fries ranged from 12.14 % to 27.74 % while the moisture content of the samples ranged from 33.92 % to 63.67%. Acrylamide levels ranged from non-detectable (ND) to 2308.85 µg/kg, with a mean of 338.99 µg/kg. The average acrylamide levels of samples obtained from the high-end outlets (hotels) was 136.15µg/kg being significantly ($p<0.05$) lower than those obtained from the middle (cafeterias) and low (street) outlets which were 412.0µg/kg and 354.18µg/kg, respectively. There were weak correlations between acrylamide and moisture contents ($r= 0.047$), and between the compound and the lightness parameters ($r=0.090$) of the French fries. No relationship was found to exist between acrylamide and the other quality parameters of redness and yellowness. There is need to educate processors on measures which can be taken to reduce the acrylamide levels in the products, given the health risks associated with the compound. The oil contents of the products from some processors also need to be reduced to the current statutory maximum levels of 20%. Regular monitoring and exposure assessments by regulatory agencies would be instrumental in determining the efficacy of the measures put in place.

Keywords: *acrylamide; french fries; oil content; quality*

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Introduction

In Kenya, the potato is the second most important food crop after maize (CIP, 2011), with crisps and French fries being popular snacks (Abong' *et al.*, 2010) when the amount being utilized in other forms such as mashed, roasted and boiled are not taken into account. Even though boiling creates minimal changes in the starch and nutrient composition of the tubers, frying on the other hand creates distinctive flavours, aromas, textures and colour in processed foods thus improving their overall palatability and acceptability (Pedreschi and Moyano, 2005). The effect of frying on nutrient contents vary with temperature, frying medium, size of the product, variety of the potato tubers and source that can be determined by geographical location or agronomic practices. High-carbohydrate foods baked or fried at high temperatures greater than 120°C may contain varying levels of acrylamide (AA), which arises from a reaction of amino acid with reducing sugars such as glucose in the food (Rydberg *et al.,* 2003). The discovery that acrylamide is unintentionally formed in some cooked foods is of great concern because it is a known human neurotoxicant and based on high-dose animal studies, a potential human carcinogen and genotoxicant (FDA, 2006). The mechanism of formation of AA in foods is linked to the Maillard reaction, with the main precursors in this reaction reported to be reducing sugars and the amino acid asparagine. The paradox and scientific challenge in this is that it is the maillard reaction that is also responsible for the development of the desirable and characteristic color and taste of fried potato products (Medeiros Vinci, 2011; Becalski *et al.,* 2004; Stadler *et al.,* 2004). Since deep-fat frying also involves high heat transfer rates and absorption of oil by the products; there is a need to monitor oil and moisture contents together with colour parameters in French fries. Studies have shown high variations in levels of AA in fried potato products. Several factors (from farm to fork) have been found to affect the formation of the compound, e.g., potato cultivar, soil properties and fertilization, climate conditions and maturity of the tuber, post-harvest storage conditions, pre-cooking conditions (blanching, freezing, par frying), size and cut shape of the chips, frying conditions (frying time and oil temperature) that are related to colour (Claeys *et al.,* 2007).

Kenyan potato varieties are unique in terms of physico-chemical characteristics and differ significantly among themselves (Abong' *et al.,* 2009). This therefore implies that by extension our varieties are different from those available elsewhere in the world especially when cultural practices are taken into account. Post-harvest handling and processing parameters as well as behaviors of the varieties obviously vary with processing premises, hence the need to assess the specific quality of French fries in Kenya. With studies showing that many people in Kenya across ages rely on French fries as a convenient meal, the risk of being exposed requires systematic evaluation. Overreliance on fries among other convenient foods could increase tremendously in the next decade as lifestyle and consumer choices change in the fast moving world. However, no information exists on the quality characteristics of French fries in Kenya, including levels of acrylamide. This study was therefore aimed at determining the quality characteristics and relationships between acrylamide and the other quality parameters.

Materials and Methods

Study Area

The current study was carried out in Nairobi County, in the Central Business District (CBD). Nairobi is the most populated city in East Africa and a major political and financial center in Africa. It is home to thousands of Kenyan businesses and over 100 major international companies and organizations, including the United Nations Environment Program (UNEP) and other United Nations (UN) organizations. Nairobi has grown around its CBD, which is located in Starehe constituency. French fries are processed and served along the major corridors and hotels. The central business district hosts some of the largest eateries that serve convenient foods, fries being some of the most common foods due to their affordability, great accompaniment to fried chicken and that people can eat them on the go.

Study type and design

Nairobi's CBD was purposively selected due the high number of fast-food cafeterias present and the large customer base they serve, from the working class to the students in the numerous colleges located in the City Centre. The central business district is a host to small, medium and large businesses and hence the business hub and beehive of activities involving people of different walks of life. Be it workers or people that just frequent town to purchase goods and services, they require food for energy to carry out their activities, most of which are available through convenient foods such as fries. The study was a cross-sectional survey in design and applied qualitative and quantitative data collection methods through laboratory analysis.

Sampling

Simple random sampling was employed in purchasing a total of 100 samples in duplicate from the high, middle and lower-level fast food outlets. For purposes of this study, any outlet charging 0.40 U.S dollars (USD) and below for a packet of French Fries was considered to be a lower end majority of whom mainly did processing at the back yard or streets; while those charging more than 1 USD were considered as high end outlet which were mainly the well-furnished hotels. The middle end outlets were those charging between 0.40 and 1 USD for a packet of French fries, and mainly constituted processors in cafeterias and small hotels. A total of 7 samples were obtained from the lower end (street) outlets, while 68 and 25 samples were obtained from the middle and high-end outlets, respectively. This is because of all the outlets in the CBD, the middle level constitutes the majority compared to the other two, while the lower end outlets were much fewer and hence exhaustive sampling was done. The middle end outlets remain the majority since they are easily accessible and are located within reach of most commuters and workers in Nairobi.

Analytical methods; Determination of moisture content

The moisture content of the French fries was determined by oven drying according to AOAC (AOAC, 1980). The oven used was of model DS0-500D (MRC, Holon, Israel).

Crude fat determination

The crude fat content of the French fries was determined by the soxhlet method according to AOAC (AOAC, 1984), where approximately 5 grams of each sample was extracted for 8 to 10 hours.

Determination of color of crisps

Colour determination of French fries was done using a color spectrophotometer as described by Abong' et al. (2011). The color of the chips was assessed using the CIE Lab L*, a*, and b* color scale using a colorimeter Minolta CR 200b (Osaka, Japan). The 'L*' value which is the lightness parameter indicated degree of lightness of the sample varied from 0=black to 100=white. The 'a*' 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 at least thrice to ensure replication.

Determination of acrylamide

Levels of acrylamide were determined by Gas Chromatography as described by the United States Food and Drug Administration (FDA) method, (Detection and Quantitation of Acrylamide in Foods) (FDA, 2002) using a Flame ionizable detector (G-14B, Shimadzu, Japan).

Acrylamide extraction

About 5g of the crushed samples was combined with 25 ml of 0.1% formic acid solution and the mixture mixed on a test tube shaker (KS250, IKA, Staufen, Germany) for 5 minutes at 300 rpm. The samples were then centrifuged at 3000 rpm for 10 min for easier removal of the oily top layer and to ensure further solubility of the acrylamide compound. The supernatant was filtered using a filter paper (Wattman paper no 41) then passed through a 0.45μm nylon syringe filter to remove any suspended particles.

Clean up stage

Cleaning entailed passing the filtered material through a solid phase extraction (SPE) tube (Carboprep tm 200 SPE tube, 6ml, 500mg) that had been activated by passing 2ml of acetone solvent and then 2ml of 0.1% formic acid. This was followed by passing the filtered sample solution through the tube and then passing 1ml of water fast through the tube. The SPE tube was then vacuum dried for one minute after which 2ml of analytical grade acetone flowing through gravity was passed for elution. The elute was then immediately stored in the refrigerator ready for the Gas Chromatography/ Flame ionization detection (GC-FID) analysis.

Gas chromatography conditions

The column used was a silica fused supelcowax 10 (30 m × 0.53 mm; 0.5 μm film) capillary column. The Gas chromatograph was operated under isochratic conditions; where the detector and injection temperatures were maintained at 260 °C and 250 ^{0}C respectively, and the column initial and final temperatures were maintained at 140 ^{0}C. Nitrogen, the carrier gas, was supplied at 100 bars pressure, at a linear velocity of 62 cm/sec. The pressures of hydrogen gas and air were 60 bars and 50 bars respectively. A calibration curve was prepared in the range of 50–500 µg/kg from acrylamide standard (BDH Chemicals Analar), and measured values expressed as µg/kg of chips. The analysis was carried out in the Biochemistry laboratory and Instrument room of the Department of Food Science and Technology, Jomo Kenyatta University of Agriculture and Technology. The limit of detection for the GC-FID was found to be 4.5 ppb while the Limit of quantification was 50 ppb.

Data Analysis

Analysis of variance (ANOVA) and least significant difference test (LSD) for the variables was carried out using the Statistical Analysis System (SAS) version 9.1.3. Pearson correlation analysis was also done to determine relationships between acrylamide and the other quality parameters such as moisture content and colour. Where differences existed at $p \leq 0.05$, they were considered to be significant.

Results

Oil content, moisture content and acrylamide levels of French fries

The oil content, moisture content and acrylamide concentrations of French fries samples obtained from Nairobi's CBD were as shown in **Table 1**. The oil content of the samples ranged from 6.16 % (C71) to 27.74 % (B22), with an overall mean of 12.14 %. The mean oil content of samples from the high-end outlets was 13.30 %, with a range of 6.75 % to 27.74 %. Middle-level samples ranged from 6.16 % to 23.6 %, with a mean oil content of 11.62 %; while street samples had a mean of 13.07 % with values ranging from 7.79 % to 20.83 %. There was no significant difference (P>0.05) in the average oil content among the three sample groups. However, there were significant differences (P<0.05) among individual outlets irrespective of category.

The moisture content of the samples obtained from the middle-level outlets (47.72%) significantly differed (P<0.05) from that of the other sample groups, with the high-end samples having the highest mean of 50.67%, and the street samples having an average of 49.82%. The ranges within the categories were 33.92 % to 62.26 % for middle-level outlets; 38.88 % to 63.67 % for high-end outlets and 44.63 % to 57.44 % for the street samples.

Acrylamide levels ranged from non-detectable levels (samples C48, B10 & C70) to 2308.85µg/kg (C28), with an overall mean of 338.99µg/kg. There was no significant difference (p>0.05), between levels in the middle level and street samples, whose mean concentrations were 412µg/kg and 354.18µg/kg respectively. The acrylamide concentration in the middle-level category ranged from non-detectable levels to 2308.85µg/kg, while the street samples had concentrations between 43.00µg/kg to 714.34µg/kg. The high-end samples had significantly lower (P<0.05) mean concentrations of 136.15µg/kg, with a range from non-detectable levels to 427.25 µg/kg.

Table 1. Oil, moisture content and acrylamide concentration (wet weight basis) of French fries from Nairobi

Sample ID	**% oil**	**%Moisture Content**	**Acrylamide Content (µg/kg)**
A1	11.97± 0.16jk	57.44± 0.08de	214.02± 11.18p
A2	7.79± 0.08mn	44.63± 0.07mno	43.00± 1.44q
A3	11.99± 0.07jk	56.28± 0.07ef	714.34± 16.16m
A4	11.44± 0.03jkl	48.92± 0.33jkl	450.69± 302.36lp
A5	15.11± 0.02hi	47.61± 0.54klm	185.45± 9.04p

A6	12.37± 0.16jk	46.49± 0.43lm	431.59± 49.49no
A7	20.83± 0.20ef	47.34± 0.28klm	440.18± 20.51no
B1	17.26± 0.18fg	39.10± 0.00 rs	34.09± 6.03q
B10	10.64± 0.55kl	57.38± 0.16de	ND
B11	12.58± 0.09jk	48.00± 0.24kl	44.39± 3.74q
B12	11.18± 0.17kl	43.52± 0.08no	235.15± 12.24p
B13	21.97± 0.21cd	50.80± 0.08ij	29.79± 3.94q
B14	7.46± 0.18mn	38.88± 0.06rs	57.27± 2.49q
B15	16.09± 0.10gh	63.67± 0.45a	87.52± 1.54q
B16	19.76± 0.17ef	51.82± 0.14hi	148.11± 27.89p
B17	14.39± 0.37ijk	59.98± 0.12bc	302.46± 6.74o
B18	7.18± 0.07mn	48.59± 0.16jkl	266.79± 5.20op
B19	6.75± 0.22op	39.44± 0.13qr	43.30± 0.61q
B2	14.66± 0.16hi	58.76± 0.11cd	53.07± 8.11q
B20	11.48± 0.02jkl	45.78± 0.09mn	119.53± 8.79p
B21	9.85± 0.07lm	55.47± 0.13efg	182.82± 15.55p
B22	27.74± 0.05a	60.71± 0.19bc	22.90± 1.83q
B23	12.66± 0.13jk	43.60± 0.52no	87.70± 30.77pq
B24	15.05± 0.21hi	57.97± 0.18de	10.04± 5.85q
B25	10.25± 0.85klm	54.45± 0.07fg	68.89± 15.34q
B3	19.71± 0.11ef	59.80± 0.19bc	427.25± 12.29no
B4	11.99± 0.22jk	43.46± 0.19nop	336.66± 22.57o
B5	15.57± 0.02hi	49.18± 0.14jk	213.83± 5.75p
B6	7.96± 0.02mn	39.19± 0.08qrs	226.91± 9.84p
B7	8.57± 0.08lm	46.30± 0.06lm	76.71± 1.46q
B8	10.08± 0.06kl	47.50± 0.09kl	8.82± 12.47q
B9	11.60± 0.04jk	63.37± 0.00a	319.84± 12.81o
C1	10.64± 0.10kl	55.64± 0.04fg	218.77± 5.11p
C10	9.20± 0.04lm	47.09± 0.13lm	248.17± 3.73p

C11	11.77± 0.17jk	52.10± 0.03hi	519.08± 6.17n
C12	10.01± 0.11kl	48.09± 0.15kl	227.63± 1.66p
C13	10.12± 0.25kl	50.59± 0.11ij	274.57± 12.71op
C14	14.07± 0.02ij	61.59± 0.02ab	543.72± 357.86kp
C15	17.75± 0.02fg	52.28± 0.12hi	1161.67± 2.89j
C16	7.08± 0.05mn	56.02± 0.04ef	189.66± 8.78p
C17	12.64± 0.10jk	55.80± 0.01ef	78.43± 5.62q
C18	17.41± 0.44fgh	40.77± 0.11pq	1026.90± 100.98jk
C19	11.44± 0.29jkl	53.14± 0.05gh	608.46± 66.96mn
C2	21.57± 0.32cde	55.16± 0.05fg	53.02± 1.46q
C20	9.18± 0.07lm	50.23± 0.14ij	77.97± 3.76q
C21	14.03± 0.16ij	36.09± 0. 07tu	130.11± 1.55p
C22	8.13± 0.27mn	49.52± 0.56ijk	1015.76± 34.91k
C23	13.60± 0.04ij	62.26± 0.53ab	1301.74± 22.75i
C24	14.81± 0.11hi	59.98± 1.16abcd	111.40± 1.04p
C25	19.40± 0.08ef	53.78± 0.13gh	518.15± 5.59n
C26	11.52± 0.24jkl	37.14± 0.15st	564.08± 22.68mn
C27	10.32± 0.40klm	41.23± 0.21pq	95.30± 1.45q
C28	8.64± 0.05lm	47.87± 0.09kl	2308.85± 816.17ah
C29	16.72± 0.25gh	50.00± 0.02jk	117.36± 8.74pq
C3	11.33± 0.15jkl	50.60± 0.10ij	267.32± 21.87op
C30	10.37± 0.03kl	44.55± 0.08no	112.00± 9.78pq
C31	10.65± 0.15kl	43.80± 0.03no	157.24± 3.90p
C32	12.57± 0.37jk	53.12± 0.08gh	21.45± 18.20q
C33	10.12± 4.39hiop	53.58± 0.37gh	345.66± 15.44o
C34	7.28± 0.02mn	40.58± 0.16pqr	59.91± 12.40q
C37	7.75± 0.01mn	40.42± 0.14pqr	121.85± 3.13p
C38	6.81± 0.04op	46.42± 0.11lm	168.36± 23.29p
C39	23.60± 0.24bcd	44.06± 0.52no	206.93± 6.21p
C4	13.38± 0.07ij	43.84± 0.19no	276.62± 24.97op
C40	10.62± 0.20kl	40.67± 0.09pq	8.91± 6.81q
C41	6.30± 0.14op	41.65± 0.27opq	19.92± 3.73q
C43	8.27± 0.17mn	44.74± 0.19mno	19.23± 4.36q
C44	14.36± 0.05ij	57.91± 0.04de	68.75± 1.45q

C45	13.56± 0.18ij	53.39± 0.03gh	401.85± 14.90o
C47	16.56± 0.02gh	60.80± 0.12bc	118.44± 4.31pq
C48	15.09± 0.00hi	50.39± 0.03ij	ND
C5	14.35± 0.31hij	41.33± 0.43pq	274.22± 25.02op
C50	10.09± 0.08kl	43.98± 0.16no	154.42± 1.45p
C51	17.95± 0.04fg	41.39± 0.03pq	354.31± 18.30o
C53	7.24± 0.30mn	48.28± 0.01kl	33.16± 19.80q
C54	12.75± 0.12jk	43.04± 0.05op	37.80± 6.76q
C55	11.67± 0.22jkl	50.28± 0.16ij	1371.99± 318.56 fj
C56	7.52± 0.51mn	44.27± 0.02no	56.34± 8.11q
C57	11.33± 0.44jkl	47.59± 0.35klm	57.59± 11.87q
C58	9.46± 0.23lm	46.23± 0.17lm	29.33± 2.29q
C59	8.65± 0.15lm	47.56± 0.42klm	71.96± 34.88q
C6	13.39± 0.12ij	42.07± 0.11op	990.67± 59.75k
C60	12.63± 0.21jk	46.58± 0.21lm	144.00± 1.46p
C61	13.30± 0.24ij	55.80± 0.12ef	1889.22± 874.83bk
C62	8.52± 0.34lm	35.73± 0.27tu	170.46± 2.51p
C63	10.43± 0.13kl	49.12± 0.01jk	349.06± 3.58o
C64	9.31± 0.13lm	46.67± 0.17lm	758.87± 11.26l
C65	12.28± 0.22jk	44.60± 0.04mno	195.54± 30.19p
C66	7.96± 0.05mn	42.48± 0.30op	252.80± 39.31op
C67	6.61± 0.14op	44.25± 0.13no	244.33± 31.97op
C68	6.17± 0.04op	38.32± 0.06rs	46.29± 1.84q
C69	10.16± 0.08kl	41.54± 0.23pq	73.79± 4.32q
C7	10.53± 0.04kl	58.85± 0.11cd	654.98± 6.01m
C70	13.72± 0.21ij	52.77± 0.06ghi	ND
C71	6.16± 0.17op	33.92± 0.10uv	1760.08± 131.60eg
C72	8.12± 0.16mn	40.51± 0.11pqr	197.12± 9.29p
C73	9.15± 0.14lm	44.76± 0.19mno	1419.96± 116.13gi
C74	9.61± 0.02lm	48.25± 2.10ijlm	214.93± 54.98op
C8	18.60± 0.07fg	44.69± 0.15mno	732.86± 4.08m
C9	13.51± 0.24ij	53.25± 0.15gh	1714.98± 282.16dh

[1]Values are means of two determinations ± standard deviation.
[2]The values with similar letters in the same column are not significantly different at 5% level of significance.
[3] The letter C means that the samples were from middle level outlets.

Colour parameters for French Fries

The colour parameters for French Fries from Nairobi's CBD are indicated in Table 2. The color parameters did not differ significantly ($p>0.05$) among the three main sample categories, however there were variances between samples from different outlets. . The lightest samples had values of up to 77.7 (C73 & B17), while the least value for the L* parameter was 43.5 (sample C2). The ranges within the categories for the L* parameter was 57.25 to 68.25 in street samples;

46.60 to 77.70 in high end samples and 43.50 to 77.70 in middle level samples. The average values for this parameter in high level, middle level and street samples were 61.59, 62.41 and 62.24 respectively. The samples had an overall mean of 0.01 for the redness parameter (a*), indicating a low degree of browning, except for samples B1, C13 and C3 which had uniquely high values of greater than 7. Street samples had an average value of 0.04 with a range of -1.85 to 2.10; while middle level samples ranged from -4.60 to 7.75 with an average of -0.25. High end samples had a mean of 0.72, with a range from -4.65 to 7.20.The overall mean value for the yellowness parameter was 27.44 with a range from 19.70 to 38.35. Street samples had a mean of 27.03 with a range of 23.20 to 31.30; while middle level samples ranged from 19.70 to 37.30 with an average of 27.26. High end samples had a mean of 28.05 and ranged from 20.45 to 38.35.

Table 2. Colour of French fries sold in Nairobi's CBD

Sample ID	L*	a*	b*
A1	59.90± 6.65bc	-0.20±6.36ac	29.20± 0.00b
A2	65.50± 10.04ac	-1.70± 1.70b	23.20± 1.13c
A3	57.25± 1.34c	0.10± 1.41b	26.25± 2.76bc
A4	64.15± 3.46bc	1.35± 1.06ab	27.80± 0.57bc
A5	68.25± 2.62ab	-1.85± 0.07b	26.25± 3.18bc
A6	62.45± 1.77b	2.10± 0.57ab	31.30± 2.40ab
A7	58.15± 0.07c	0.50± 0.99b	25.20± 0.71c
B1	50.45± 0.07d	7.20± 2.12a	32.25± 5.44ac
B10	64.60± 3.11b	-4.65± 3.61bc	28.70± 0.99b
B11	51.40± 6.08cd	4.20± 2.40a	24.90± 0.28c
B12	56.95± 3.18c	0.05± 2.33ab	28.60± 2.26bc
B13	65.40± 0.57b	2.45± 0.21a	28.05± 0.35b
B14	71.15± 0.78a	-0.90± 1.70b	24.60± 0.85c
B15	70.40± 1.41ab	1.85± 0.21ab	35.50± 0.71a
B16	62.60± 0.14b	2.65± 0.92ab	33.05± 3.04ab
B17	77.70± 1.56a	-2.45± 0.21b	27.60± 2.26bc
B18	56.75± 4.31bd	0.50± 0.71b	24.25± 5.44bc
B19	60.30± 1.98bc	1.80± 0.00a	27.60± 0.42bc
B2	57.10± 0.14c	1.10± 2.26ab	25.20± 2.40bc
B20	56.80± 0.57c	4.10± 0.71a	33.35± 2.76ab
B21	57.65± 4.45bc	1.30± 1.70ab	30.80± 7.92ac
B22	58.05± 1.20c	3.65± 3.04ab	29.85± 3.89ac
B23	69.45± 0.07a	-1.65± 0.07b	38.35± 1.20a
B24	58.35± 3.75bc	2.30± 2.55ab	29.45± 1.63b
B25	46.60± 2.26d	-0.05± 0.21b	21.60± 0.99cd
B3	70.10± 3.11a	-2.45± 0.78b	26.45± 1.48bc
B4	68.05± 3.04ab	-1.50± 1.27b	26.50± 2.26bc
B5	59.20± 1.41c	1.60± 2.83ab	25.45± 1.91bc
B6	64.75± 3.04b	-2.75± 0.92b	20.45± 3.04cd

B7	61.60± 2.26bc	2.70± 1.27ab	24.95± 4.17bc
B8	64.05± 5.16b	-1.30± 0.42b	25.25± 0.35c
B9	60.25± 1.20bc	-1.65± 2.47b	28.50± 0.71b
C1	63.45± 3.61bc	-1.40± 0.85b	24.30± 1.13c
C10	57.15± 6.58bd	-2.45± 0.78b	31.10± 0.42b
C11	50.65± 1.48d	6.35± 1.63a	30.15± 1.48b
C12	70.80± 2.97ab	-3.40± 1.41bc	31.75± 2.90ab
C13	52.05± 0.49d	7.40± 0.57a	36.30± 1.70a
C14	63.15± 0.49b	-1.7± 2.26b	25.80± 1.98bc
C15	69.50± 6.22ab	-1.15± 0.49b	28.10± 1.84bc
C16	55.20± 2.83cd	1.30± 0.71ab	23.20± 3.11cd
C17	60.25± 1.48cd	-0.05± 0.35b	26.90± 0.57bc
C18	63.75± 13.08ad	-3.85± 0.49bc	22.80± 12.59af
C19	59.75±17.89ae	-1.55± 2.19b	22.95± 4.31cd
C2	43.50± 3.11de	4.75± 1.77a	23.30± 3.39cd
C20	66.55± 4.74ab	-1.05± 1.91b	25.35± 4.31bd
C21	65.45± 0.92b	-4.6± 0.14c	19.70± 0.57d
C22	57.65± 14.50ae	-1.55± 2.47b	20.55± 1.63cd
C23	65.80± 1.13b	-2.95± 0.35b	29.40± 0.99b
C24	47.60± 9.90ce	-0.25± 0.21b	20.40± 4.10cd
C25	59.20± 5.23bc	-0.6± 2.40ab	26.05± 1.20c
C26	62.10± 1.41bc	-1.7± 0.14b	28.35± 0.35b
C27	57.30± 2.12c	-0.7± 1.56b	26.85± 0.21c
C28	73.15± 0.78a	-1.7± 0.85b	23.90± 2.55cd
C29	55.65± 7bd	-0.25± 4.17ac	22.20± 1.8cd
C3	49.25± 2.05d	7.75± 0.21a	37.30± 1.56a
C30	73.20± 3.11a	-4.55± 0.21c	23.10± 0.85c
C31	67.55± 1.48b	-2.85± 0.49b	35.15± 1.06a
C32	57.05± 1.2c	-1.3± 0.85b	24.20± 3.54bd
C33	55.60± 4.53cd	2.85± 1.20ab	24.45± 2.62c
C34	71.10± 3.96ab	-4.3± 0.14bc	25.00± 1.27c
C37	67.55± 4.17ab	-4.30± 1.56bc	32.70± 1.56ab
C38	69.05± 4.88ab	-1.10± 0.00b	29.35± 1.20b
C39	59.75± 2.05cd	-0.05± 1.63b	25.90± 0.42c
C4	66.85± 4.88ab	-2.45± 2.47bc	30.15± 1.34b
C40	70.80±0.99a	-2.50± 0.57b	26.45± 1.34bc
C41	62.85± 1.06b	0.95± 0.92ab	32.00± 2.12ab
C43	73.05± 4.45ab	-0.20± 1.56b	27.15± 0.64bc
C44	55.25± 3.04cd	4.55± 0.35a	29.15± 2.90bc
C45	60.10± 0.14c	0.65± 0.64b	27.70± 0.57bc
C47	55.90± 0.85c	-0.3± 0.71b	23.85± 0.21c

C48	69.60± 0.85ab	-1.35± 0.92b	27.00± 2.83bc
C5	58.55± 2.47bc	1.25± 1.91ab	32.95± 9.83ac
C50	71.40± 0.57a	-1.45± 0.35b	33.45± 0.49a
C51	67.15± 2.33ab	0.75± 2.62ab	28.90± 0.42b
C53	61.10± 1.98bc	0.95± 0.49b	26.55± 0.07c
C54	64.05± 1.63b	-0.2± 1.27b	26.25± 4.74b
C55	63.35± 1.20b	1.05± 2.05ab	26.45± 0.49c
C56	65.70± 1.27b	-0.65± 1.63b	28.15± 7.42ad
C57	66.60± 4.38ab	-1.15± 0.35b	28.60± 1.41bc
C58	56.70± 0.28c	-0.70± 0.14b	25.70± 0.71c
C59	65.25± 1.34b	0.15± 0.21b	31.60± 1.27ab
C6	46.65± 4.31de	1.75± 0.64ab	24.40± 2.97bd
C60	63.75± 3.32bc	0.80± 0.00b	26.10± 1.56bc
C61	57.15± 0.78c	0.95± 0.64b	26.65± 0.49c
C62	63.90± 0.85b	-0.90± 1.27b	25.30± 8.20ad
C63	61.60± 1.13bc	1.35± 1.63ab	30.45± 0.21b
C64	58.45± 2.19c	1.90± 0.85ab	26.40± 1.13bc
C65	62.25± 3.04bc	-0.35± 2.33ab	27.55± 1.34bc
C66	64.20± 1.56b	-1.15± 0.21b	25.45± 0.07c
C67	67.70± 1.84ab	-0.20± 0.42b	24.90± 1.13c
C68	67.40± 0.85b	-0.65± 0.07b	23.15± 3.04cd
C69	66.80± 3.25ab	-0.75± 0.64b	27.80± 0.57bc
C7	56.75± 5.16bd	1.25± 1.91ab	28.90± 1.98bc
C70	63.50± 1.98b	-2.95± 0.64b	26.25± 0.35c
C71	66.80± 0.99b	2.40± 0.85ab	35.40± 2.12a
C72	66.80± 0.57b	-2.05± 2.05b	23.45± 0.49c
C73	77.70± 0.42a	-3.35± 1.77bc	26.15± 3.32bc
C74	59.20± 1.41c	2.75± 1.06ab	28.50± 1.27bc
C8	64.90± 1.70b	0.95± 0.92ab	28.40± 3.25bc
C9	64.25± 5.02bc	0.70± 0.14b	29.85± 3.75ac

[1]Values are means of two determinations ± standard deviation.

[2]The values with similar letters in the same column are not significantly different at 5% level of significance.

[3] The letter C means that the samples were from middle level outlets.

The correlation between acrylamide and the other quality parameters is as shown in Table 3. There were weak correlations between acrylamide and moisture contents, and the lightness parameters of the French fries, r= 0.04734 and 0.09022, respectively. There were negative correlations between the compound and the other quality parameters of redness and yellowness. A positive correlation (r= 0.36895) was also found to exist between moisture and oil contents of the samples.

Table 3. Correlation between acrylamide concentration and moisture and colour of French fries sold in Nairobi CBD

Parameter	Acrylamide
Moisture	0.04734
L*	0.09022
a*	-0.03965
b*	-0.00613
Acrylamide	1

(N=200)

Discussion

The crude fat content of most of the samples was found to be below the 20% limit set by the East African Standards (EAS, 2010). However, the oil content of 5% of the samples exceeded this limit which could be a concern considering consumers' increasing awareness of the link between high oil consumption and increasing health risks such as heart diseases and diabetes. The higher oil contents may be due to processors' lack of knowledge of optimal frying conditions which is necessary to produce French fries with low fat contents. For example, studies have shown that with lower cooking temperatures, the crust fails to form on the surface allowing more fat to penetrate to the core of the French fries. When the oil temperature is 10^0C lower than the range of 180°C- 185°C, products absorb 40% more fat. The oil content is also determined by the quality of raw tubers, immature tubers generally have low dry matter content and high amount of water and will tend to absorb more oil that those with high dry matter content. By extension, the low dry matter can also be related to the variety of the potato tubers and agronomical practices involved during the growing period. Apart from the quality of raw potatoes, oil content can also be determined by the handling during processing, lack of adequate drainage of fried fries can lead to more oil retention on the surface of the fries. Raw potatoes are high in moisture (78%), but the moisture content was reported to decrease sharply by as much as 20% over a 3 min frying time and then more slowly to the final moisture content. During deep-fat frying, water in the crust evaporates; and for the flow of vapour to continue, sufficient water has to move from the core to the crust of the food while the latter remains permeable. The fact that vapors leave voids for the fat to enter later is the reason why uptake of oil is largely determined by the moisture content of the product (EAS, 2010). This explains the positive significant ($P< 0.05$) correlation between moisture content and oil content ($r= 0.37$).

The moisture content of the French fries was found to be consistent with that reported by Abong *et al.,* (2011) with some deviation for 3% of the samples which had notably higher values exceeding 60%, and approximately 21% with moisture levels lower than 45%. Moisture levels affect the quality of French fries as it affects both the perishability and texture of food (Sandulachi, 2012). This means that the samples with higher moisture contents are likely to go bad much faster given that high moisture encourages growth of microorganisms which could be pathogenic and spoilage or both. On the other hand, fries with moisture contents lower than 45% will be crunchier and have longer shelf life since the amount of water may not support all microorganisms with exception of moulds and yeasts.

Worldwide, a large variation has been found in acrylamide concentration in potato-based foods. This cannot be accounted for only by the difference of processing conditions. The reaction of reducing sugars with asparagine is thought to be a major path for acrylamide formation in carbohydrate-rich foods. However, because the asparagine content in raw potatoes is relatively in excess and has been shown to vary within a narrow range, the amount of reducing sugars, therefore, becomes the limiting factor (Amrein *et al.,* 2007; Mestdagh *et al.,* 2008). It is important to note that acrylamide is ubiquitous in most fried and roasted foods and no one can purport to eliminate it from food products. The only thing that regulators can do is to capacity build and advise the processors to minimize the levels of acrylamide. It is known that sugar content in potato tuber increases during cold storage due to starch degradation; "low temperature sweetening." This sugar level change during the storage should in turn affect acrylamide formation during cooking (Chuda *et al.,* 2003).

The acrylamide levels of about half the samples were consistent with those reported by FDA (FDA, 2015), with 36% found to be much lower. A few (14%), however, were beyond the indicative level of 600 μg/kg for French fries set by the European Commission (EC, 2011). This highlights how varied French fries in the Kenyan market are in terms of acrylamide concentration and the need for mitigation measures so as to protect the consumers of the health risks associated with the compound. One of the reasons for the low acrylamide levels in the fries in Nairobi can be attributed to the low-reducing sugar of the raw potatoes used in processing of different fries.

Kenyans do not often use cold-temperature storage of potatoes, since it is not a common practice in both Kenyan households and commercial establishments. The cold storage infrastructure is poorly developed and may only become a factor when most traders and processors develop and adopt its usage. Acrylamide has been shown to increase exponentially with frying temperature and time, and consequently, French fries cooked by lowering the frying temperature from 190 to 150 or 120^0 C are characterized by decreased levels of acrylamide (Pedreschi *et al.,* 2006). As a matter of fact, acrylamide begins to form at temperatures of 120 degrees Celsius and above. The formation is encouraged when the moisture content is low, hence, the low or no levels have been reported in boiled food products. The relatively high levels of acrylamide in the middle and lower-end outlets may be due to higher temperature and processing time parameters in comparison to higher-end outlets which are more likely to have (sophisticated) equipment with timers and in-built thermometers, a scenario that is not common in the middle and lower outlets (Abong' *et al.,* 2015. The personnel (chefs) in the high-end outlets are also usually trained for their jobs and are therefore likely to be more aware of the required processing parameters, as opposed to their counterparts in the other outlets who learn on the job and most probably rely basically on their human senses and personal experiences to determine how well the product is done. Most of the low end processors use firewood or charcoal as sources of heat. They also utilize the normal cooking materials that have no temperature control mechanisms. These small-scale processors also do use their oils several times and, in many cases, use oils that have been extensively broken down, meaning that the products may not only have acrylamide but other products of oil breakdown such as polycyclic aromatic hydrocarbons, peroxides of different natures and possible trans fatty acids arising from heat isomerization. It is apparent that a concerted effort needs to be made to ensure lower levels of acrylamide in fries. From the farms that need to produce good quality, low reducing sugar and high dry matter potatoes to the processors who need to know how to control processing parameters and proper drainage of oil from ready fries. Different nodes of the potato value chain must be involved if the effort to reduce acrylamide is to be realized.

Conclusion

Oil and moisture contents of most of French fries samples in Nairobi were within required limits. There may be need, however, to educate processors on the optimum frying conditions so that consumers get the best quality achievable for French fries. Acrylamide levels of French fries from middle level and street outlets are higher than those of French fries obtained from high end outlets. There were weak positive correlations between acrylamide and moisture contents, and between acrylamide and the lightness (L*) parameters of the French fries. However, a negative correlation was seen between the acrylamide and the other quality parameters of redness and yellowness.

It is recommended that further research should be carried out to establish how correlation between the redness parameter and acrylamide levels is affected under different processing conditions. Processors should be educated on general processing parameters and measures to reduce the presence of AA in the products as the various regulatory agencies such as Ministry of Health and Kenya Bureau of Standards ensure that the codes of conduct is adhered to. Regular monitoring of products and exposure assessments should be carried out for products in the Kenyan markets to determine the efficacy of the acrylamide reduction measures.

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