Article

Effects of Continuous Deep Fat Frying on the Physical and Chemical Properties of Assorted Brands of Edible Cooking Oils Sold in Metropolitan Kampala

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Abstract: Deep fat frying is not novel, but a classical antiquity culinary technique preferred chiefly for its swiftness, amenity, conferment of a crisp texture, attractive sensorial and organoleptic qualities and thus delectableness of the fries. Regrettably, repeated use of oils for deep frying impacts the storage life and nutritional suitability of fries. This concerted study investigated the effects of continuous deep fat frying on the physicochemical properties of ten brands of edible cooking oils: Fortune Butto, Roki, Tamu, Best Fry, Golden Fry, Mukwano, Sunny, Sunvita, Sunlite and Sunseed used in deep frying of potato chips in Kampala, Uganda. Three oil samples from local Irish chip fryers were also collected. The color value (CV) and the acidification of the oils as free fatty acid (FFA), peroxide value (POV), paraanisidine value (AnV) and iodine adsorption value (IV) before and between ten successive deep-fryings using potato chips were determined. The possible reuse of the oils was estimated from the frying round when a quality criterion surpassed national or CODEX specifications for the respective edible cooking oils. For fresh oils, the statistical parameter ranges were: CV (0.4R 3.4Y-7.7R 70Y), % FFA (0.0430-0.1508), POV (0.5951-6.6134 meqO_2/Kg), AnV (0.90-4.30) and IV (57.62-128.35gI_2/100g). By the tenth fry, the values were respectively 3.0R 23Y-20.4R 70Y, 0.2286-0.4817, 11.1138-15.7525 meqO_2/Kg, 10.31-22.16 and 53.66-126.03 gI_2/100g. Reuse of the oils for continuous frying of potatoes on the same day can be done only up to 7 times on average for hard oils and 6 times for soft oils.

Keywords: Color; free fatty acids; iodine absorption value; paraanisidine value; peroxide value.

1. Introduction

Kampala, the central business district and capital city of Uganda is an area of population with an approximated 1.53 million people in mid-2009 growing by 3.9% annually [1]. People in the city are surviving on a vast array of ready-to-eat Ugandan unique deep-fried delicacies namely: fried dough (mandazi), sweet plantain (gonja), edible grasshoppers (nsenene), banana pancakes (kabalagala), Nile perch fish (emputa), chapatti, sausages, chicken, Irish potatoes and cassava chips prepared using repeatedly used edible cooking oils. Sometimes, fresh oil is added to the used oils and in either case, recycling of oil enhances the innocuous contamination and interaction of moisture and air (oxygen) with the oil [2-5].

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1.1 Deep frying

Deep frying (or less commonly deep-fat frying), is a yearthousand food-in-oil culinary procedure performed at elevated temperatures, typically above the boiling point of water between 160^{o}C to 190^{o}C [6]. Material and heat transfers occur concomitantly with the wholly or partly submersed food in the hot fat typically at or in excess of 180^{o}C [7-9]. The heat, augmented by moisture, oxygen and air culminates in food dehydration, further potentiating a complex cascade of physical and chemical changes including breakdown of sugars and proteins via starch gelatinization, protein denaturation, induced flavor and color [9], hydrolysis [10], free radical production, formation of heterocyclic flavouring substances from amino acids, oxidation, somerizations, dietary fibre softening, Millard reaction and caramelization. Hydrolytic degradation ensues the attack of the ester linkage of triacylglycerols by water (a weak nucleophile) almost always entrained in the food to be fried and yields diglycerols, monoglycerols and free fatty acids (FFAs). This is further energized by the yielded fatty acids and other low molecular weight acids [11]. Copious amounts of water has been reported to hydrolyze deep frying oils more rapidly [12] than steam [13]. On average, these reaction cascades increase oil darkening, flow viscosity, density, specific heat, foaming and reduce considerably the smoke point [14].

1.1. Stability of deep fat frying oils

The heat stability of frying oil is governed primarily by two inherent factors: the fatty acid composition and the presence of antioxidants and precursors such as butylatedhydroxyanisole (BHA), *tert*-butylhydroquinone (TBHQ), butylated hydroxytoluene (BHT), propyl gallate (PG) and tocopherols [15]. Antioxidants have been proven to retard room temperature auto-oxidation of oils but are rendered inefficient at typical frying temperatures due to volatilization losses and thermal fissions [16, 17]**.** An ideal frying oil should thus possess little amount of polyunsaturated fatty acids (notably linolenic acids) and prominent levels of oleic acid with moderate amounts of saturated fatty acids as the former are highly susceptible to oxidative degradation during frying [18], potentiating breakdown reactions that often yield harmful polymers [19-21]. Thus, the accompanying changes in the physical and chemical parameters of oils used repeatedly for deep frying has raised global health concerns [22].

Subtly, the frying stability of oils are assessed by physicochemical investigation of changes occurring during heating of the oils at elevated temperatures. The color value of oils, usually expressed as 1 × Red + 1 × Yellow Lovibond units, registers a drastic increase in both the red and yellow units during the incipient phases of heating. According to the results of Baby Latha and Nasirullah [23] using rice bran oil, a threefold increase in red units and nearly fourfold increase in yellow units was found after 2 hours of frying while darkening occurred beyond 2 hours. Physicochemical properties and oxidative degradation of the frying oil during the initial 2 hours of heating registered a steep increment in POV from 0.2 to 6.3 meqO_2/kg, AnV from 5.04 to 19.4 and total polar components from 1 to 4.1% [23]. FFA content of frying oils has been reported to rise with number of fryings [24] and frying time [25]. The formed FFA, glycerol, di- and mono-acylglycerols have been implicated by several authors to energize further thermohydrolysis [26-28]**.** Fatty acids composition, tocopherols and total phenols influences the oxidative stability of oils during frying

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[29, 30] with some polar compounds such as triacylglycerol dimers and oxidation triacylglycerols [31, 32], dimers [33] and polymers [34] reported to accumulate during the frying process. Warner *et al* [35] reported that polar compounds accumulation during potato chips frying in cottonseed oil increased proportionately with increase in the oil linoleic acid content. Mono- and di-acylglycerols in cotton seed oil during frying of potato chips at 155 to 195^{o}C increased initially and then reached a plateau according to the results of Houhoula *et al* [5].

Frequent replenishing of frying oil retards its hydrolysis [36] and increases its frying life; alkalis deployed in cleaning a fryer potentiates oil hydrolytic degradation while the frying time has no appreciable effect on hydrolysis rate [37]. Diop *et al* [38] investigated the effects of deep fat frying on chemical properties of three selected brands of oils (two peanut oils A and B and sunflower oil, C) common in Senegalese preparation of fried meat, fish and potatoes. Their findings revealed that frying affects the chemical stability of cooking oils. The acid value as reported increased after 40 minutes from 0.62 to 1.08 mg/kg after frying fish, from 0.39 to 0.73mg/kg for meat and 0.37 to 0.51 mg/kg for potatoes. Peroxide value increased slightly for A and sharply for B and C oils.

Juárez *et al* [39] assessed some physicochemical changes occurring during discontinuous potato frying using milanesas and churros in partly hydrogenated, soybean and sunflower oils. For 80.5 hours of churros deep fat frying, the oils measured total polar compounds surpassing 25% and the corresponding percentage dimeric and polymeric triacylglycerols surpassed 10% with tocopherol losses of 70%. Xu *et al* [40] compared the oxidative stability of camellia oil composed of saturated fatty acid (SFA), monounsaturated fatty acid (MSFA) and polyunsaturated fatty acid (PUFA) in a ratio of 1:7:1 during potato deep frying with palm and peanut oils composed of SFA, MSFA and PUFA in ratios of 4:4:1 and 2:4:4 respectively. Their evaluations of acid value, IV, POV, AnV, total oxidation (TOTOX) value, tocopherols content and fatty acids composition of the oils registered little alteration of the fatty acid contents of camellia oil with alpha-tocopherol reported to be more thermally labile compared to gamma and delta tocopherols. They concluded that the stabilities of the oils as determined by oxidizability value followed the sequence camellia oil > palm oil >peanut oil. The initially highest recorded AnV was in palm oil, which rose from 0.11 to 0.40. The recorded AnV change was initially high in peanut oil prior to frying but increased more gradually from 0.74 to 1.04 while that of camellia oil rose from 0.17 to 0.55. The IV recorded in peanut oil was the largest though it reduced from 104.74 to 80.52 gI_2/100g. Insignificant changes of 53.83 to 45.36 gI_2/100 g and 65.40 to 55.29 gI_2/100g was registered in palm oil and camellia oils respectively. POV in palm oil registered an increment from 4.98 to 18.86 $meqO_2$/kg while that of peanut and camellia oils changed from 4.75 to 13.24 $meqO_2$/kg and 4.68 to 11.58 $meqO_2$/kg. The least AnV was in camellia oil that increased from 1.70 to 51.78 while peanut and palm oils registered 2.25 to 84.71 and 1.36 to 60.00 respectively. Abdulkarim [41] assessed the frying suitability of high-oleic *Moringa oleifera* seed oil saturated fatty acid (SFA) consisting of SFA: MUFA: PUFA in a ratio of 2:7:0 vis-a-vis soybean, palm olein and canola oils with SFA: MUFA:PUFA ratios of 1.5:2.5:6, 4:4:1 an 1:6:3 respectively. Experimental results showed that the %FFA of the four conventional oils used comparatively in the assessment respectively increased by 66.6, 71.4, 60.0 and 65.0%. TOTOX and AnV values of the oils were registered in the order *Moringa oleifera* seed oil< palm olein < canola and soybean oils [41].

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This research, in addition to assessing the effects of continuous deep-fat frying on the physicochemical parameters of edible cooking oils sold in Metropolitan Kampala reveals the maximum number of times the edible oils can be reused for continuous deep frying of Irish potato chips without posing potential health risk to the final consumers.

2. Materials and Methods

2.1. Apparatus and reagents

The chemicals used in this investigation were of high analytical purity. The assortment of volumetric glassware employed were presterilized in an autoclave and oven dried prior to analysis. Mettler PM200 balance (Marshall scientific, USA) was used for all weighings. Amprobe IR608A non-contact infrared thermometer with laser pointer, -18°C to 400°C (Amprobe, Everett, USA) was used for monitoring temperatures during frying.

2.2. Sampling procedure and sample size

Six one litre samples of hard oil brands (Fortune butto, Roki, Tamu, Best fry, Golden fry and Mukwano) and soft oil brands (Sunny, Sunvita, Sunlite and Sunseed) of approximate manufacturing dates were procured from Mega Standard supermarket, Yusuf Lule road, Kampala-Uganda on 4th May 2017. The brands were chosen based on their common use in deep frying according to a prestudy tour taken and were majorly brands from two giant oil processing companies: Bidco Uganda Limited (BUL)-Jinja Uganda and Mukwano Industries Limited-Kampala Uganda. Hence exactly thirty (30) samples of cooking oils were procured and maintained in their original packaging materials under ambient conditions to avoid any possible degradation. Three oil samples used up to ten times continuous fry from Makindye division of Metropolitan Kampala were collected at intervals from three randomly selected local traders carrying out deep frying of Irish potato chips during their successive fries. Ten (10) kilograms of fresh white (Irish) potatoes (*Solanum tuberosum*), were purchased from Nakasero market, Nakasero Hill, Market square road, Kampala, washed and peeled manually using a clean stainless-steel knife. They were then sliced into cylindrical sizeable pieces (1cm×1cm×3cm) corresponding to that used in the Kampala Irish potato culinary. The analyses were done at the Quality control laboratory of Mukwano Industries Limited, Plot 30, Mukwano Road, Kampala Industrial area.

2.3. Analysis of fresh oil samples

Both physical and chemical parameters of the oil samples were analyzed before being used for deep fat frying.

2.4. Frying method

Exactly 400g of the Irish potato slices were submersed in oil in Skyline VT5424 4L Electric Deep Fryer (Skyline, New Dehli, India) with detachable oil tank and slotted spoon with 1500mL of the heated oil maintained at 140°C for 6 minutes. A frying time of 10 minutes was used with 800g of the Irish fried in 20 minutes.

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2.5. Determination of colour

Colour value (colour index) of the oil samples free from moisture and insoluble impurities were measured in triplicates in a Lovibond Tintometer (The Tintometer Ltd, UK) using a 2.54cm cell operating in the transmittance mode and recorded in Lovibond units.

2.6. Determination of free fatty acids

Exactly 10g of the oil sample was weighed in a 250ml beaker. 60mls of neutralized ethanol was added and then boiled. The solution was then titrated with standardized 0.025M sodium hydroxide using phenolphthalein indicator until the solution just turned pink. The FFA value was expressed as the percentage of oleic acid in the sample [42].

2.7. Determination of Iodine adsorption value

Iodine value was determined according to ISO 3961: 2009 iodometric procedure [43]. 0.2g of oil sample was weighed into a quick fit flask and dissolved in 20ml of chloroform. 25mL of Hanus iodine solution was added to the resultant solution. Few drops of potassium iodide were put on mouth of the flask and then kept in the dark for 30minutes. The sample was then removed and 10mls of 15% Potassium Iodide solution was added followed by 100mls of freshly distilled water. The solution was subsequently titrated with a standard 0.1N Sodium thiosulphate solution while stirring until the golden yellow color appeared. Exactly 5mls of starch indicator was added to the resultant solution and titration was continued until the blue-black solution turned colorless. A blank was conducted where the total halogen content of 25mL of Hanus iodine was determined by a sodium thiosulphate solution without the addition of an oil sample. Iodine value was expressed in grams of Iodine absorbed by 100g of the oil.

2.8. Determination of peroxide value

Peroxide value was estimated according to ISO 3960: 2007 [44] and recorded as milliequivalents of active oxygen/kg of oil.

2.9. Determination of paraanisidine value

Paraanisidine value was determined using the AOCS Official Method Cd 18-90 [45] and expressed in anisidine numbers.

3. Results and statistical analyses

Analyses were performed in triplicate and the statistical average values were calculated using Microsoft Excel 2016.

3.1. Hard oils

The investigated physicochemical properties of the hard oils are given in *Table 1*.

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195 **Table 1.** Changes in the physicochemical properties of the hard oils.

Oil	Sample	CV	%FFA	POV (meq O_2/Kg)	AnV	IV (g of I_2/100g
Fortune	Fresh oil	4.8R 70Y	0.0977	1.6924	2.50	57.67
Butto	First fry	6.0R 70Y	0.1305	3.0157	3.50	57.56
	Second fry	6.3R 70Y	0.1420	3.0481	3.90	56.46
	Third fry	7.1R 70Y	0.1428	3.2682	4.20	56.42
	Fourth fry	7.3R 70Y	0.1522	3.6635	4.80	56.14
	Fifth fry	7.5R 70Y	0.1779	6.0672	5.24	55.57
	Sixth fry	8.0R 70Y	0.2544	8.3062	7.73	55.21
	Seventh fry	8.2R 70Y	0.2613	9.3708	8.94	54.80
	Eighth fry	8.5R 70Y	0.3269	9.9978	10.14	54.65
	Ninth fry	9.0R 70Y	0.3513	10.4800	10.35	54.12
	Tenth fry	9.9R 70Y	0.3776	12.2809	11.84	53.66
Roki	Fresh oil	4.6R 70Y	0.1099	0.7848	1.80	60.06
	First fry	6.1R 70Y	0.1305	1.9309	2.50	59.31
	Second fry	6.1R 70Y	0.1356	2.8011	2.80	59.15
	Third fry	6.5R 70Y	0.1449	3.0712	3.40	58.92
	Fourth fry	7.2R 70Y	0.1527	3.2109	4.00	58.92
	Fifth fry	7.5R 70Y	0.1541	5.3638	4.85	58.51
	Sixth fry	8.2R 70Y	0.1702	5.7558	5.38	57.77
	Seventh fry	8.4R 70Y	0.1865	6.9578	5.83	57.77
	Eighth fry	9.5R 70Y	0.2098	9.7719	6.44	57.60
	Ninth fry	10.0R70Y	0.2472	9.9846	7.47	57.27
	Tenth fry	10.8R70Y	0.2844	11.1138	10.31	57.05
Tamu	Fresh oil	5.0R 70Y	0.0987	0.71370	2.30	58.88
	First fry	6.3R 70Y	0.1365	2.0110	3.80	58.34
	Second fry	6.6R 70Y	0.1443	4.5741	4.20	58.29
	Third fry	6.9R 70Y	0.1527	5.5595	5.30	58.05
	Fourth fry	7.3R 70Y	0.1812	7.6355	6.90	57.50
	Fifth fry	8.5R 70Y	0.1993	10.0566	8.94	57.34
	Sixth fry	8.7R 70Y	0.2939	10.5666	9.70	57.01
	Seventh fry	9.8R 70Y	0.3079	11.0939	11.24	56.96
	Eighth fry	10.0R 70Y	0.3053	11.2413	11.39	56.47
	Ninth fry	10.8R 70Y	0.3305	12.5219	11.59	56.26
	Tenth fry	12.0R 70Y	0.3833	13.0047	14.73	55.51
Golden fry	Fresh oil	5.4R 70Y	0.1247	1.7272	2.60	57.62
	First fry	6.5R 70Y	0.1462	4.0312	3.40	57.62
	Second fry	6.9R 70Y	0.1825	4.5876	4.80	57.57
	Third fry	7.2R 70Y	0.2017	6.0430	6.20	57.66
	Fourth fry	7.8R 70Y	0.2668	7.2802	7.50	57.40
	Fifth fry	8.4R 70Y	0.3029	8.0133	8.40	57.06
	Sixth fry	9.1R 70Y	0.3428	9.3237	10.80	56.90
	Seventh fry	10.0R70Y	0.3374	10.0599	11.40	56.45
	Eighth fry	11.0R70Y	0.3874	10.6783	11.80	56.42
	Ninth fry	11.8R70Y	0.4441	10.9245	12.40	56.47

	Tenth fry	12.4R70Y	0.4817	11.7157	12.80	56.15
Mukwano	Fresh oil	4.5R 70Y	0.0576	0.7119	0.90	61.59
	First fry	5.8R 70Y	0.1429	3.9388	2.90	61.18
	Second fry	6.2R 70Y	0.1581	4.1649	3.40	60.57
	Third fry	6.5R 70Y	0.1665	4.6978	4.50	60.20
	Fourth fry	6.4R 70Y	0.1755	6.1839	6.20	60.31
	Fifth fry	7.0R 70Y	0.2275	7.4132	6.80	59.92
	Sixth fry	7.4R 70Y	0.2372	7.4361	7.90	59.22
	Seventh fry	8.3R 70Y	0.2534	9.7599	8.70	59.06
	Eighth fry	8.9R 70Y	0.2785	9.9139	10.20	58.71
	Ninth fry	9.5R 70Y	0.3216	11.009	12.69	58.34
	Tenth fry	10.9R70Y	0.3310	11.820	14.73	58.13
Best fry	Fresh oil	5.2R 70Y	0.1376	2.3542	3.40	58.34
	First fry	7.4R 70Y	0.1927	3.1264	4.90	58.16
	Second fry	7.9R 70Y	0.2528	4.2248	5.80	57.94
	Third fry	8.3R 70Y	0.2655	4.5703	7.70	57.25
	Fourth fry	8.8R 70Y	0.2829	5.8642	8.40	57.29
	Fifth fry	9.7R 70Y	0.2854	6.1624	9.11	57.13
	Sixth fry	10.5R 70Y	0.2978	6.9323	12.63	57.03
	Seventh fry	12.0R 70Y	0.2989	8.8926	14.21	57.04
	Eighth fry	15.0R 70Y	0.3595	10.422	16.12	56.87
	Ninth fry	16.0R 70Y	0.3591	11.017	17.03	56.71
	Tenth fry	17.5R 70Y	0.3591	11.952	17.77	56.66

3.2. Soft Oils

The physicochemical properties of the soft oils are given in *Table 2*.

Table 2. Changes in the physicochemical properties of the soft oils.

Oil	Sample	CV	%FFA	POV (meq O_2/Kg)	AnV	IV (g of I_2/100g)
Sunseed	Fresh oil	0.4R 3.4Y	0.1508	6.6134	4.30	58.30
	First fry	1.0R 4.7Y	0.1567	7.8224	5.70	58.02
	Second fry	1.1R 5.4Y	0.1693	8.8646	6.60	58.08
	Third fry	1.2R 6.3Y	0.1829	9.2997	7.40	57.88
	Fourth fry	1.3R 7.2Y	0.1932	10.2907	9.50	57.87
	Fifth fry	2.0R 8.5Y	0.2099	10.8085	10.90	57.83
	Sixth fry	2.1R 9.9Y	0.2152	10.9622	13.80	57.71
	Seventh fry	2.1R 11Y	0.2201	10.9920	16.70	57.72
	Eighth fry	2.4R 13Y	0.2715	12.2302	17.90	57.57
	Nineth fry	2.9R 14Y	0.2769	13.4418	19.50	57.45
	Tenth fry	2.6R 22Y	0.2908	13.6042	20.20	57.40
Sunny	Fresh oil	0.8R 4.9Y	0.0884	1.4980	2.50	128.35
	First fry	1.6R 14Y	0.1163	2.1135	3.70	127.13
	Second fry	1.9R 15Y	0.1407	3.0874	4.00	126.94
	Third fry	2.1R 19Y	0.1571	4.3946	4.90	126.88
	Fourth fry	2.7R 16Y	0.1766	5.0359	6.20	126.70

	Fifth fry	2.9R 19Y	0.1875	6.7514	7.60	126.69
	Sixth fry	3.0R 23Y	0.1917	7.9430	9.40	126.33
	Seventh fry	3.0R 24Y	0.2173	9.0678	10.40	126.27
	Eighth fry	3.3R 24Y	0.2435	10.3814	12.80	126.24
	Nineth fry	3.5R 27Y	0.2477	10.8668	15.50	126.08
	Tenth fry	3.6R 27Y	0.2540	11.7032	17.50	126.03
Sunvita	Fresh oil	0.9R 5.1Y	0.0430	1.4714	2.80	126.96
	First fry	0.9R 6.7Y	0.0892	3.3087	3.50	126.10
	Second fry	0.9R 7.5Y	0.1503	3.8037	4.70	123.03
	Third fry	1R 9.1Y	0.1666	4.9809	5.70	124.88
	Fourth fry	1.1R 11Y	0.1937	5.2830	6.80	123.96
	Fifth fry	1.3R 11Y	0.1991	5.9740	7.75	123.27
	Sixth fry	1.7R 14Y	0.2136	8.2301	10.46	122.59
	Seventh fry	2.1R 15Y	0.2576	10.11	14.89	121.81
	Eighth fry	2.4R 20Y	0.3081	11.53	15.78	121.48
	Nineth fry	2.8R 22Y	0.3078	14.68	16.49	121.48
	Tenth fry	3.0R 23Y	0.3396	15.37	18.66	120.28
Sunlite	Fresh oil	0.7R 5Y	0.0963	1.2723	2.60	126.80
	First fry	0.7R 5.5Y	0.1098	2.0882	2.92	126.46
	Second fry	0.8R 5.8Y	0.1319	3.9624	3.50	125.98
	Third fry	1.0R 6.0Y	0.1458	4.4835	4.30	125.79
	Fourth fry	1.3R 6.8Y	0.1603	5.9978	5.80	125.73
	Fifth fry	1.5R 6.8Y	0.1720	7.5574	6.90	125.47
	Sixth fry	1.8R 7.2Y	0.2001	9.0822	8.30	125.29
	Seventh fry	2.0R 7.5Y	0.2159	10.5798	10.0	124.89
	Eighth fry	2.4R13.0Y	0.2599	11.2972	12.72	124.57
	Nineth fry	2.56R 13Y	0.2828	11.9001	14.68	124.55
	Tenth fry	2.9R14.5Y	0.3202	12.7721	16.02	124.21

3.3. Oils From Outside Chips Fryers

The physicochemical properties of oils from outside chips fryers are presented in *Table 3*.

Table 3. Changes in the physicochemical properties of oils from outside chips fryers.

Oil	Sample	CV	%FFA	POV (meq O_2/Kg)	AnV	IV (g of I_2/100g)
First fryer	Fresh oil	6.8R 70Y	0.1399	3.1037	4.30	58.42
	First fry	7.4R 70Y	0.1499	3.5849	5.10	58.42
	Second fry	7.9R 70Y	0.1556	4.4937	6.80	58.38
	Third fry	8.1R 70Y	0.1698	5.8645	7.50	58.30
	Fourth fry	8.9R 70Y	0.2013	8.6028	7.90	58.34
	Fifth fry	9.7R 70Y	0.2432	9.0689	9.00	58.15
	Sixth fry	10.7R 70Y	0.2449	10.738	10.40	57.67
	Seventh fry	12.0R 70Y	0.2466	11.0264	14.20	57.66
	Eighth fry	12.9R 70Y	0.2635	12.2278	16.50	57.55
	Nineth fry	14.8R 70Y	0.3094	14.6568	17.50	57.55
	Tenth fry	15.2R 70Y	0.3334	15.7525	19.90	57.35

Second fryer	Fresh oil	4.5R 70Y	0.1007	0.5951	2.80	59.43
	First fry	6.0R 70Y	0.1282	0.9021	3.40	59.23
	Second fry	6.0R 70Y	0.1300	1.5840	3.80	58.90
	Third fry	6.2R 70Y	0.1354	2.2182	4.50	58.97
	Fourth fry	7.1R 70Y	0.1398	2.9961	5.10	58.55
	Fifth fry	7.3R 70Y	0.1403	3.3954	6.30	58.37
	Sixth fry	7.8R 70Y	0.1625	4.4962	6.50	58.27
	Seventh fry	8.2R 70Y	0.1687	5.1984	7.40	58.15
	Eighth fry	8.7R 70Y	0.1812	6.5811	8.50	58.10
	Nineth fry	9.0R 70Y	0.2014	6.9981	9.10	58.10
	Tenth fry	9.5R 70Y	0.2286	7.995	10.70	58.12
Third Fryer	Fresh oil	7.7R 70Y	0.0496	1.1957	2.70	128.16
	First fry	9.0R 70Y	0.1362	1.6099	3.60	127.18
	Second fry	10.1R 70Y	0.1535	1.7636	3.90	126.33
	Third fry	10.9R 70Y	0.1634	2.0909	4.80	124.79
	Fourth fry	12.5R 70Y	0.1697	2.5227	5.90	124.22
	Fifth fry	14.3R 70Y	0.2030	2.4450	7.46	123.30
	Sixth fry	16.0R 70Y	0.2980	2.9739	8.65	121.40
	Seventh fry	17.0R 70Y	0.3235	6.0875	14.20	120.13
	Eighth fry	18.8R 70Y	0.3874	6.3546	17.98	118.77
	Nineth fry	19.2R 70Y	0.4165	7.1760	20.70	119.00
	Tenth fry	20.4R 70Y	0.4748	8.5800	22.16	119.14

4. Discussion

4.1. Color

There is no standard specification for colour as per Uganda National Bureau of Standards (UNBS) for edible oils. However, most edible oil refining companies (including Mukwano group of companies) have internal colour specifications of 7.5R 70Y maximum. Sunseed, Sunvita, Sunlite and Sunny cooking oils passed colour parameter specifications even after the tenth fry. Mukwano after the 6^{th} fry, Fortune Butto, Roki and Best fry after the 5^{th} fry, while Tamu after the 4^{th} fry and Golden fry after the 3^{rd} fry fell out of specifications (Tables 1 and 2). Oil from the first and second outside chips fryers fell out of colour specifications after a fry while oil from the third outside chips fryer did not meet the specifications (Table 3). The physical change in the color value of oils is a rather intuitive and swift visual index implicatory of a trend of oil deterioration. Of the fresh oil samples, oil from the third outside chips fryer had the highest color reading of 7.7R 70Y (Table 3) while the lowest color reading was obtained from the oil from the Sunseed with a color reading of 0.4R 3.4Y (Table 2). The color readings increased steadily. By the ninth fry, the color recitation for oil from the third outside chips fryer could hardly be determined experimentally (Table 3) and by the tenth fry, the oil from the second outside chips fryer had become reasonably dark. Generally, by the tenth fry, all the oils had changed the color of the fried food product. Available empirical data shows that unsaturated carbonyl compounds (including ketones, conjugated dienoic acids) and degraded oxidation compounds such as hydroxides and hydroperoxides induce oil darkening [46-48].

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Another close cause of the observed colour regression could be attributable to the dispersion of Millard pigments from the fries [49]. Choe and Min [8] also hinted that polymerized fats accumulated in a fryer during frying causes foam and gum formation as well as oil darkening. Oil darkening, albeit, an experimentally valuable index while monitoring deterioration of oils heated at elevated temperatures has been underscored to not be solely attributable to oxidative degradation by Che Man and Tan [50]. Non-enzymatic browning of potato chips has been reported to be proportionate to the amount of reducing sugars in the potato, as both browning and Maillard reactions are stimulated by the level of oxidation of the food and the entrained characteristic heme pigments [51]**.** More so, the Maillard reaction enhances nutrient losses and the ensuing browning intensity it impacts on the fries is proportionate to the proteinaceous loss of the amino acids: lysine, histidine and methionine. This result is in agreement with the diagnostic statements of Orthoefer and Cooper [52] that assorted frying oils and the food fried darken oils to varying degrees during deep frying.

4.2. Free fatty acids

The chief composition of oils is fatty acids and degree of unsaturation is the very first factor influencing the oxidative stability of frying oils despite other oil intrinsic and external factors [30]**.** For fresh oils, the lowest FFA of 0.0430 was observed in Sunvita while the highest recorded FFA of 0.1508 was in Sunseed (Table 2). Roki, Best fry, third chips fryer oil and Sunvita were still within the maximum % FFA specification of 0.30 after the tenth fry. Sunlite after the 9th fry, Mukwano and oil from second outside chips fryer after the 8th fry while Fortune Butto, Sunny and oil from first outside chips fryer after the 7th fry had % FFA greater than the maximum FFA specification of UNBS. Tamu and Sunseed after the 6th fry and Golden fry after the 4th fry had the % FFA greater than the maximum FFA specification of 0.30. The differences observed in the fresh oil FFA values could be attributed to blending of several edible oils by the manufacturing companies. Blending of assorted edible oils is known to alter the fatty acid profile of oils [53, 54] and can steeply retard oxidation of oils during deep-fat frying. The increase in free fatty acid values of oils can be attributed to the breakdown of long carbon chains into shorter carbon chains due to thermal and oxidative decomposition of oils at elevated temperatures. During elevated temperature heating of oils, FFA formation is attributed to the cleavage and oxidation of double bonds to form carbonyl compounds, which are subsequently oxidized to fatty acids of low molecular masses [55-57]. It is preferred frequently by food processors for indication of oil acidity and oil authenticity verification [14, 58]. Filtration of frying oils have been reported to reduce FFA content of oils and improve their frying stability. The results of this study is concordant with that of Stevenson *et al* [59] who reported that edible oils with %FFA less than 0.05% and POV of 1.0 meqO_2/kg or less are best suited for deep frying.

4.3. Peroxide value

For peroxide values of fresh oil samples, oil from the second outside chips fryer had the lowest peroxide value (0.5951meqO_2/Kg) while the highest peroxide value of 6.6134 meqO_2/Kg was observed in Sunseed. Aside from the nature of the oil, fresh oils to be utilized in deep fat frying should have a Codex regulatory maximum POV of 15meqO_2/Kg [60]. The peroxide values increased significantly during the successive fries. The increase in the peroxide values of oils following frying

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is because of oxidation of carbon atoms adjacent to the double bonds in the triacylglyceride structure leading to the formation of hydroperoxides. These hydroperoxides, are the direct cause of anisidine value shoot up as they decompose further to secondary oxidative components which constitute the paraanisidine components. Peroxide value is implicative of incipient oxidation which directly translates to the buildup and breakdown of oxidation products. Peroxides are reasonably unstable, and fissions at typical frying temperatures. In addition, it is a useful biomarker of the preliminary stages of rancidity occurring under mild conditions and the freshness of the lipid matrix. Thus, the greater the POV, the faster will the oxidation of the oil occur [61]. After the fifth fry, the peroxide value of all oils was still concordant with the maximum Codex standard POV for vegetable oils. However, only Best fry and Sunseed after the tenth fry were still in the maximum Codex standard POV of 10meq O_2/Kg. Roki after the 9th fry, while Fortune Butto and Mukwano after the 8th fry fell out of specifications (Table 1). Sunvita and oil from first outside chips fryer were out of specifications after the 7th fry; Golden fry, Sunny and Sunlite were all out of specifications of POV after the 6th fry. Oil from second outside chips fryer after the fifth fry was out of specification while Tamu and oil from third outside chips fryer fell out of the maximum Codex standard POV after the 4th and 3rd fry respectively. The observed increase in peroxide value during heating of oils have been reported by other authors [14, 62, 63]. Furthermore, polyunsaturated oils exhibit readily depressed stability at elevated temperatures because the unsaturated fatty acids are readily oxidized to peroxides [63, 64]. Empirical data shows that the peroxide values of fresh oils may be higher than the Codex standard primarily owing to improper storage and packaging that triggers degradation via photo-oxidation. Self-oxidation may supposedly occur in storage due to chemical interaction with air, peculiarly oxygen [65].

4.4. Paraanisidine value

Oxidative degradation of oils is innocuously deleterious as it impacts sensorial and organoleptic attributes of fries [66]. Primary oxidation quantifies the amount of hydroperoxides as peroxide value (POV). Further degradation of hydroperoxides yields aldehydes, ketones, carboxylic acids, short chain alkanes and alkenes better quantitatively described by paraanisidine value (AnV). For fresh oils, the lowest value of 0.90 was observed in Mukwano vegetable cooking oil (Table 1) while the highest recorded AnV was 4.30 in Sunseed and oil from first outside chips fryer (Tables 2 and 3 respectively). Golden fry, Tamu, Best fry, Sunny, Sunlite, Fortune Butto, Mukwano, Sunvita, Roki and oil from first and second outside chips fryer after the tenth fry were still within the range (0.00 to 20.00) after the tenth fry. Only the oil from third outside chips fryer and Sunseed exceeded the maximum value after the 9th and 8th fry respectively. Secondary oxidation products are principally non-volatile aldehydes, principally 2,4-dienals and 2-alkenals [67, 68] which anisidine value is a quantitative measure. The AnV was observed to increase gradually between the successive fries. Initial stages of heating resulted in faster increase of AnV followed by a gradual increment. This could be due to further decomposition of the carbonyls and polymerization reactions. Similar results have been reported by Xu *et al* [40] in their comparison of oxidative stability of edible oils under continuous deep frying conditions.

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4.5. Iodine adsorption value

At fresh conditions, the maximum IV observed was in sunny cooking oil (128.35gI_2/100g) (Table 2) and the least was observed in Golden fry vegetable oil (57.62gI_2/100g) (Table 1). The iodine adsorption value, iodine number or sometimes iodine index, is chemically the mass of iodine in grams that is consumed by 100 grams of a chemical substance by mass as oleic acid. Iodine numbers are often used to determine the amount of unsaturation in fatty acids. The higher the Iodine index (the greater the unsaturation), the faster is the tendency of oil oxidation during heating at elevated temperatures as in deep frying [69]. Iodine index, is a frequently measured vital analytical measure of the unsaturation of an edible cooking oil [70]. It was observed that IV decreased slightly during deep frying. Golden fry, Tamu, Best fry, Sunny, Sunlite, Fortune button, Mukwano, Sunvita, Roki, Sunseed and oil from first, second and third outside chips fryer even after the tenth fry were still within specifications. The observed decrement in the Iodine index is concordant with the decrement in double bonds attributed to oxidation and thermal decomposition.

4.6. Frying stability of the edible cooking oils

The average number of times the hard oils and soft oils could be re-used for continuous deep-fat frying were statistically calculated using Microsoft Excel 2016. The analysis gave an average of 7.0 times for hard oils and 6.25 times (approximately 6 times) for soft oils.

5. Conclusions

Prior to deep-fat frying, all the selected brands of edible cooking oils met the National and thus Codex specifications in terms of the assessed physicochemical properties. Oil from the third outside chips fryer however, failed to meet the color specification. After successive deep fat fryings, the physicochemical properties of the edible oils increased significantly between fryings and some oils went out of specifications of the Codex standards before the tenth fry. Iodine adsorption values decreased only slightly for the ten fryings. The results of the study showed that changes in the physical and chemical parameters increases with increase in the number of fries of the potato chips. Repeated re-use of oils for consecutive deep frying of potato chips on the same day can be done only up to a maximum of 7 times on average for hard oils and 6 times for soft oils with the oils still regarded as safe for frying potato chips for human consumption. Thus, hard oils should be preferred to soft oils for deep frying of Irish potato chips.

There is a continuous need to subtly carry out research on every new edible cooking oil brand on the Ugandan market as most companies tend to package a blend of oils. Further comprehensive research should be done to elucidate the variation of physicochemical properties of other edible cooking oil brands on the Ugandan market such as Nile, Fortune, Kimbo, Cow boy and Ufuta. Further research should be done with other food samples such as fish, cassava, chicken, plantain, dough, meat and edible grasshoppers as the nature of the food sample influences the quality of the oil after deep frying. The organoleptic test of smell should not be used physiognomically in making conclusions about the suitability of cooking oils after deep fat frying as it is hard to clearly deduce since individual sensoriums vary widely and thus judgement is made so indifferently. Other physicochemical properties of the investigated edible cooking oils such as smoke point, viscosity, moisture content, volatile matter content, total polar components and saponification value should be determined.

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