Original Research Article
Effects of Continuous Deep Fat Frying on the Physicochemical Properties of Assorted Brands of Edible Cooking Oils Sold in Greater Metropolitan Kampala

ABSTRACT

Deep-fat frying is not novel, but a classical antiquity culinary technique preferred chiefly for its swiftness, amenity, conferment of a crispy 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 reported the effects of continuous deep fat frying of white (Irish) potatoes (*Solanum tuberosum*) on the physical and chemical attributes of ten brands of edible cooking oils: Fortune Butto, Roki, Tamu, Best Fry, Mukwano, Golden Fry (hard oils); Sunseed, Sunny, Sunvita and Sunlite (soft oils) used in Kampala Metropolis, Uganda. Three oil samples from three randomly selected Local Irish potato fryers were collected and comparatively investigated. 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 frying cycles using Irish potato chips were determined. Maximum number of reuses of an oil was estimated from the frying round before its POV or AnV surpassed the maximum permissible statutory or Codex Alimentarius limit for edible oils. For fresh oils, the statistical parameter ranges were: CV (0.4R 3.4Y-7.7R 70Y), FFA (0.0430±0.30-0.1508±0.30), POV (0.5951±0.03-6.6134±0.23 $meqO_2$/Kg), AnV (0.90±0.01-4.30±0.19) and IV (57.62 ±0.17-128.35±0.02gI_2/100g). By the 10th fry, the ranges were CV (3.0R 23Y-20.4R 70Y), FFA (0.2286±0.01-0.4817±0.01), POV (11.1138±0.01-15.7525±0.01$meqO_2$/Kg), AnV (10.31±0.03-22.16±0.01) and IV (53.66±0.01-126.03±0.02 gI_2/100g). Considering oxidizability as TOTOX values, frying stability of the selected oil brands during the ten continuous frying cycles followed the order: Roki > Fortune Butto > Sunvita > Sunny > Sunlite > Mukwano > Tamu > Best Fry > Golden Fry > Sunseed. Reuse of the oils for continuous frying of Irish potatoes on the same day can be done only up to 7 times on average for hard oils and 6 times for soft oils with the oils still regarded as safe for human consumption. Hard oils should be preferred to soft oils for deep frying of Irish potato chips.

Keywords: color index, free fatty acids, iodine absorption value, paraanisidine value, peroxide index

1. INTRODUCTION

Kampala, the central business district and the capital city of Uganda is an area of population with over 1.53 million metropolitans surviving on a vast array of quick foods such as ready-to-drink milk, tossed salads, snacks [1] and unique Ugandan deep-fried delicacies: fried

dough (*mandazi*), sweet plantain (*gonja*), edible grasshoppers (*nsenene*), banana pancakes (*kabalagala*), Nile perch fish (*emputa*), chapatti (*kikomando*), sausages, chicken nuggets (*enkoko*), meat (*enyama*), Irish potatoes and cassava chips. The fries are prepared in repeatedly used oils and sometimes fresh oil is added to the used oils. In either case, recycling of oil enhances the innocuous contamination and interaction of moisture and air (oxygen) with the oil [2-5].

1.1 Deep Frying

Deep 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 at or in excess of 180^{o}C [7-9]. The heat, augmented by moisture, oxygen and air culminate in food dehydration, further potentiating a complex cascade of physicochemical 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].

1.2 Stability of Deep-Frying Oils

The stability of frying oil is governed primarily by two inherent factors: the presence of antioxidants and precursors such as butylatedhydroxyanisole (BHA), *tert*-butylhydroquinone (TBHQ), butylated hydroxytoluene (BHT), propyl gallate (PG) and tocopherols [15] and the fatty acid composition. 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]. In terms of saturation, an ideal frying oil should 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]. Breakdown reactions occurring in frying oils often yield harmful polymers [19-21]. Thus, oils used repeatedly for deep frying has raised global health-related 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 for example, 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 a fourfold increase in yellow units was recorded after 2 hours of frying while darkening occurred beyond 2 hours. Physicochemical properties and oxidative degradation of the rice bran oil during the initial 2 hours of heating registered a steep increment in POV from 0.2 to 6.3meqO_2/kg, AnV from 5.04 to 19.4 and total polar components from 1 to 4.1% [23].

Free fatty acid content of frying oils on the other hand has been reported to rise with the number of fryings [24] and frying time [25]. The formed FFA, glycerol, di- and mono-acylglycerols have been further 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 [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 accretion of polar compounds 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^{o}C 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 hydrolytic degradation of oils 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 only slightly for oil A and sharply for oils B and C.

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, Iodine Value (IV), Peroxide value (POV), Anisidine value (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 45.36gI_2/100 g and 65.40 to 55.29 gI_2/100g were registered in palm 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 *et al* [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 and 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].

This research, in addition to assessing the effects of continuous deep-fat frying on the physicochemical parameters of edible oils in Metropolitan Kampala reveals the maximum

number of times the 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 concerted investigation were all of analytical grade. The conventional volumetric ware employed were sterilized 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 (6) 1L samples of hard oil brands (Fortune Butto, Roki, Tamu, Golden fry, Mukwano and Best fry) and soft oil brands (Sunny, Sunvita, Sunlite and Sunseed) of approximate manufacturing dates were procured from Mega Standard Supermarket, Yusuf Lule road, Greater Metropolitan Kampala (**Figure 1**). The brands were chosen based on their common use in deep frying according to a prestudy tour and were majorly brands from two giant oil refining companies: Bidco Uganda Limited (BUL)-Jinja and Mukwano Industries Limited-Kampala. Hence exactly sixty (60) samples of edible 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 frying cycles from Makindye division of greater Metropolitan Kampala were collected at intervals from three randomly selected local traders deep frying of Irish potatoes. 10kg of fresh white (Irish) potatoes (*Solanum tuberosum*) were purchased from Nakasero market, Nakasero Hill, Market square road, Kampala. The potatoes were 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 Metropolis 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

The physicochemical parameters of the oils were analyzed prior to deep fat frying.

2.4 Frying method

Exactly 400g of Irish potato slices were submersed in 1500mL of oil maintained at 140°C for 6 mins in Skyline VT5424 4L Electric Deep Fryer (Skyline, New Dehli, India) (**Figure 2** and **Figure 3**) with detachable oil tank and slotted spoon. A frying time of 10 mins was used with 800g of the Irish fried in 20 mins. The physicochemical properties of the oils after deep frying were determined after cooling the oils (**Figure 4**).

Figure 1. Location of the area under study-Greater Metropolitan Kampala

Figure 2. Mukwano cooking oil during deep frying

Figure 3. Sunseed during deep fat frying

Figure 4. Samples of Mukwano cooling prior to physicochemical analysis

2.5 Determination of Colour Index

Color value (color index) of the oil samples free from moisture and insoluble impurities were measured 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. A measured 60ml of neutralized ethanol was added and then boiled. The solution was titrated with standardized 0.025M Sodium hydroxide using phenolphthalein indicator until the solution just turned pink. FFA was expressed as a percentage of oleic acid in the sample [42].

2.7 Determination of Iodine Absorption Value

Iodine absorption value was determined according to ISO 3961: 2009 iodometric procedure [43]. 0.2g of the oil sample was weighed into a quick fit flask and dissolved in 20ml of chloroform. 25mL of Hanus Iodine solution was added. Three drops of Potassium Iodide were put on the mouth of the flask and kept in the dark for 30 minutes. The sample was then removed and 10mls of 15% Potassium Iodide solution was added followed by 100ml of freshly distilled water. The solution was subsequently titrated with a standard 0.1N Sodium thiosulphate solution while stirring until a 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 the edible cooking oil.

2.9 Determination of Paraanisidine Value

Paraanisidine value is a measure of the carbonyl content of the edible oils. It is based on the reactiveness of the aldehyde carbonyl bond on the *p*-anisidine amine group, leading to the formation of a Schiff base that absorbs at 350 nm. Paraanisidine value was determined using the AOCS Official Method Cd 18-90 [45] and expressed in anisidine numbers.

2.10 Estimation of Total Oxidation Value

TOTOX value was computed from Equation 1 employed in other studies [40,46, 47].

$$\mathrm{TOTOX} = 2\mathrm{POV} + \mathrm{AnV} \qquad (1)$$

3. RESULTS

3.1 Statistical Analysis of Results

Each determination was done in triplicate and results recorded as averages or

means±standard deviations. Data was compared by ANOVA and Tukey test with statistical significance at $p<0.05$ using Statgraphics software (Statpoint Technologies, Virginia, USA). The frying stability of the oils during frying and the average number of times the oils could be re-used for continuous deep frying were statistically computed.

3.2 Physicochemical Changes in the Edible Oils

The investigated properties of the oils are given in Table 1, Table 2 and Table 3.

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

Oil Brand	Oil Sample	Color Value	FFA	POV ($meqO_2/Kg$)	AnV	IV ($I_2/100g$)	TOTOX
Fortune Butto	Fresh	4.8R 70Y	0.0977±0.01	1.6924±0.01	2.50±0.04	57.67±0.06	5.8848
	1st fry	6.0R 70Y	0.1305±0.02	3.0157±0.02	3.50±0.01	57.56±0.03	9.5314
	2nd fry	6.3R 70Y	0.1420±0.07	3.0481±0.01	3.90±0.02	56.46±0.01	9.9962
	3rd fry	7.1R 70Y	0.1428±0.05	3.2682±0.04	4.20±0.02	56.42±0.05	10.736
	4th fry	7.3R 70Y	0.1522±0.03	3.6635±0.02	4.80±0.01	56.14±0.01	12.127
	5th fry	7.5R 70Y	0.1779±0.01	6.0672±0.02	5.24±0.11	55.57±0.02	**17.374**
	6th fry	8.0R 70Y	0.2544±0.02	8.3062±0.04	7.73±0.03	55.21±0.01	24.342
	7th fry	8.2R 70Y	0.2613±0.09	9.3708±0.02	**8.94±0.06**	54.80±0.01	27.682
	8th fry	8.5R 70Y	0.3269±0.01	9.9978±0.02	10.14±0.01	54.65±0.01	30.136
	9th fry	9.0R 70Y	0.3513±0.02	10.4800±0.02	10.35±0.01	54.12±0.20	31.310
	10th fry	9.9R 70Y	0.3776±0.02	12.2809±0.02	11.84±0.01	53.66±0.01	36.401
Roki	Fresh	4.6R 70Y	0.1099±0.05	0.7848±0.001	1.80±0.09	60.06±0.01	3.3696

	1st fry	6.1R 70Y	0.1305±0.02	1.9309±0.03	2.50±0.05	59.31±0.01	6.3618
	2nd fry	6.1R 70Y	0.1356±0.01	2.8011±0.02	2.80±0.16	59.15±0.04	8.4022
	3rd fry	6.5R 70Y	0.1449±0.02	3.0712±0.01	3.40±0.08	58.92±0.07	9.5424
	4th fry	7.2R 70Y	0.1527±0.02	3.2109±0.01	4.00±0.02	58.92±0.11	10.4218
	5th fry	7.5R 70Y	0.1541±0.03	5.3638±0.01	4.85±0.01	58.51±0.03	15.5776
	6th fry	8.2R 70Y	0.1702±0.03	5.7558±0.02	5.38±0.04	57.77±0.06	16.8916
	7th fry	8.4R 70Y	0.1865±0.01	6.9578±0.03	5.83±0.19	57.77±0.02	**19.7456**
	8th fry	9.5R 70Y	0.2098±0.04	9.7719±0.02	6.44±0.01	57.60±0.01	25.9838
	9th fry	10.0R 70Y	0.2472±0.01	9.9846±0.02	**7.47±0.04**	57.27±0.05	27.4392
	10th fry	10.8R 70Y	0.2844±0.01	11.1138±0.01	10.31±0.03	57.05±0.01	32.5376
	Fresh	5.0R 70Y	0.0987±0.04	0.7137±0.01	2.30±0.20	58.88±0.09	3.7274
	1st fry	6.3R 70Y	0.1365±0.01	2.0110±0.02	3.80±0.01	58.34±0.07	7.8220
	2nd fry	6.6R 70Y	0.1443±0.02	4.5741±0.02	4.20±0.11	58.29±0.07	13.3482
Tamu	3rd fry	6.9R 70Y	0.1527±0.02	5.5595±0.02	5.30±0.06	58.05±0.04	**16.4190**
	4th fry	7.3R 70Y	0.1812±0.01	7.6355±0.02	6.90±0.01	57.50±0.02	22.1710
	5th fry	8.5R 70Y	0.1993±0.03	10.0566±0.02	8.94±0.01	57.34±0.01	29.0532
	6th fry	8.7R 70Y	0.2939±0.02	**10.566±0.02**	**9.70±0.05**	57.01±0.03	30.8332

Golden Fry	7th fry	9.8R 70Y	0.3079±0.04	11.0939±0.01	11.24±0.01	56.96±0.01	33.4278
	8th fry	10.0R 70Y	0.3053±0.02	11.2413±0.02	11.39±0.11	56.47±0.05	33.8726
	9th fry	10.8R 70Y	0.3305±0.03	12.5219±0.03	11.59±0.03	56.26±0.21	36.6338
	10th fry	12.0R 70Y	0.3833±0.03	13.0047±0.04	14.73±0.01	55.51±0.10	40.7394
	Fresh	5.4R 70Y	0.1247±0.02	1.7272±0.11	2.60±0.01	57.62±0.17	6.0544
	1st fry	6.5R 70Y	0.1462±0.02	4.0312±0.13	3.40±0.31	57.62±0.02	11.4624
	2nd fry	6.9R 70Y	0.1825±0.06	4.5876±0.01	4.80±0.08	57.57±0.06	13.9752
	3rd fry	7.2R 70Y	0.2017±0.07	6.0430±0.03	6.20±0.05	57.66±0.03	**18.2860**
	4th fry	7.8R 70Y	0.2668±0.12	7.2802±0.02	7.50±0.07	57.40±0.01	22.0604
	5th fry	8.4R 70Y	0.3029±0.08	8.0133±0.01	**8.40±0.03**	57.06±0.05	24.4266
	6th fry	9.1R 70Y	0.3428±0.02	9.3237±0.01	10.80±0.01	56.90±0.01	29.4474
	7th fry	10.0R 70Y	0.3374±0.06	10.0599±0.06	11.40±0.01	56.45±0.40	31.5198
	8th fry	11.0R 70Y	0.3874±0.01	10.6783±0.08	11.80±0.02	56.42±0.02	33.1566
	9th fry	11.8R 70Y	0.4441±0.01	10.9245±0.04	12.40±0.01	56.47±0.06	34.2490
	10th fry	12.4R 70Y	0.4817±0.01	11.7157±0.12	12.80±0.01	56.15±0.01	36.2314
Mukwano	Fresh	4.5R 70Y	0.0576±0.02	0.7119±0.30	0.90±0.01	61.59 ±0.03	2.3238
	1st fry	5.8R 70Y	0.1429±0.22	3.9388±0.22	2.90±0.01	61.18±0.04	10.7776

	2nd fry	6.2R 70Y	0.1581±0.02	4.1649±0.10	3.40±0.01	60.57±0.13	11.7298
	3rd fry	6.5R 70Y	0.1665±0.02	4.6978±0.12	4.50±0.01	60.20±0.44	13.8956
	4th fry	6.4R 70Y	0.1755±0.03	6.1839±0.02	6.20±0.01	60.31±0.20	**18.5678**
	5th fry	7.0R 70Y	0.2275±0.03	7.4132±0.10	6.80±0.01	59.92±0.01	21.6264
	6th fry	7.4R 70Y	0.2372±0.02	7.4361±0.02	7.90±0.26	59.22±0.39	22.7722
	7th fry	8.3R 70Y	0.2534±0.01	9.7599±0.01	**8.70±0.03**	59.06±0.21	28.2198
	8th fry	8.9R 70Y	0.2785±0.02	9.9139±0.02	10.20±0.01	58.71±0.01	30.0278
	9th fry	9.5R 70Y	0.3216±0.01	11.009±0.21	12.69±0.03	58.34±0.04	34.7080
	10th fry	10.9R 70Y	0.3310±0.03	11.820±0.09	14.73±0.03	58.13±0.04	38.3700
	Fresh	5.2R 70Y	0.1376±0.01	2.3542±0.02	3.40±0.03	58.34±0.09	8.1084
	1st fry	7.4 70Y	0.1927±0.01	3.1264±0.07	4.90±0.20	58.16±0.01	11.1528
	2nd fry	7.9R 70Y	0.2528±0.04	4.2248±0.01	5.80±0.19	57.94±0.01	14.2496
Best fry	3rd fry	8.3R 70Y	0.2655±0.01	4.5703±0.10	7.70±0.26	57.25±0.01	**16.8406**
	4th fry	8.8R 70Y	0.2829±0.02	5.8642±0.02	8.40±0.38	57.29±0.08	20.1284
	5th fry	9.7R 70Y	0.2854±0.12	6.1624±0.13	**9.11±0.10**	57.13±0.04	21.4348
	6th fry	10.5R 70Y	0.2978±0.17	6.9323±0.01	12.63±0.01	57.03±0.01	26.4946
	7th fry	12.0R 70Y	0.2989±0.03	8.8926±0.14	14.21±0.01	57.04±0.01	31.9952

	8th fry	15.0R 70Y	0.3595±0.12	10.422±0.04	16.12±0.03	56.87±0.01	36.9640
	9th fry	16.0R 70Y	0.3591±0.02	11.017±0.10	17.03±0.05	56.71±0.01	39.0640
	10th fry	17.5R 70Y	0.3591±0.03	11.952±0.08	17.77±0.20	56.66±0.17	41.6740

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

Oil Brand	Oil Sample	Color Value	FFA	POV ($meqO_2/Kg$)	AnV	IV (I_2/100g)	TOTOX
Sunseed	Fresh	0.4R 3.4Y	0.1508±0.03	6.6134±0.23	4.30±0.19	58.30±0.02	**17.5268**
	1st fry	1.0R 4.7Y	0.1567±0.07	7.8224±0.32	5.70±0.01	58.02±0.02	21.3448
	2nd fry	1.1R 5.4Y	0.1693±0.01	8.8646±0.08	6.60±0.20	58.08±0.07	24.3292
	3rd fry	1.2R 6.3Y	0.1829±0.02	9.2997±0.30	7.40±0.03	57.88±0.01	25.9994
	4th fry	1.3R 7.2Y	0.1932±0.22	10.2907±0.01	**9.50±0.08**	57.87±0.42	30.0814
	5th fry	2.0R 8.5Y	0.2099±0.01	10.8085±0.29	10.90±0.10	57.83±0.37	32.5170
	6th fry	2.1R 9.9Y	0.2152±0.33	10.9622±0.10	13.80±0.19	57.71±0.22	35.7244
	7th fry	2.1R 11Y	0.2201±0.01	10.9920±0.23	16.70±0.02	57.72±0.19	38.6840
	8th fry	2.4R 13Y	0.2715±0.01	12.2302±0.02	17.90±0.56	57.57±0.01	42.3604
	9th fry	2.9R 14Y	0.2769±0.02	13.4418±0.12	19.50±0.49	57.45±0.02	46.3836
	10th fry	2.6R 22Y	0.2908±0.02	13.6042±0.02	20.20±0.30	57.40±0.08	47.4084

Sunny	Fresh	0.8R 4.9Y	0.0884±0.31	1.4980±0.06	2.50±0.06	128.35±0.02	5.4960
	1st fry	1.6R 14Y	0.1163±0.50	2.1135±0.07	3.70±0.01	127.13±0.05	7.9270
	2nd fry	1.9R 15Y	0.1407±0.09	3.0874±0.02	4.00±0.02	126.94±0.07	10.1748
	3rd fry	2.1R 19Y	0.1571±0.04	4.3946±0.01	4.90±0.10	126.88±0.10	13.6892
	4th fry	2.7R 16Y	0.1766±0.06	5.0359±0.06	6.20±0.10	126.70±0.43	**16.2718**
	5th fry	2.9R 19Y	0.1875±0.06	6.7514±0.01	7.60±0.01	126.69±0.01	21.1028
	6th fry	3.0R 23Y	0.1917±0.10	7.9430±0.02	**9.40±0.11**	126.33±0.56	25.2860
	7th fry	3.0R 24Y	0.2173±0.01	9.0678±0.02	10.40±0.08	126.27±0.34	28.5356
	8th fry	3.3R 24Y	0.2435±0.09	10.3814±0.17	12.80±0.04	126.24±0.01	33.5628
	9th fry	3.5R 27Y	0.2477±0.04	10.8668±0.10	15.50±0.02	126.08±0.31	34.5336
	10th fry	3.6R 27Y	0.2540±0.11	11.7032±0.04	17.50±0.01	126.03±0.02	40.9064
Sunvita	Fresh	0.9R 5.1Y	0.0430±0.30	1.4714±0.01	2.80±0.05	126.96±0.11	5.7428
	1st fry	0.9R 6.7Y	0.0892±0.04	3.3087±0.01	3.50±0.02	126.10±0.28	10.1174
	2nd fry	0.9R 7.5Y	0.1503±0.08	3.8037±0.01	4.70±0.09	123.03±0.21	12.3074
	3rd fry	1R 9.1Y	0.1666±0.01	4.9809±0.08	5.70±0.12	124.88±0.52	15.6618
	4th fry	1.1R 11Y	0.1937±0.14	5.2830±0.11	6.80±0.03	123.96±0.06	17.3660
	5th fry	1.3R 11Y	0.1991±0.01	5.9740±0.05	**7.75±0.02**	123.27±0.11	**19.6980**

Sunlite	6th fry	1.7R 14Y	0.2136±0.03	8.2301±0.02	10.46±0.19	122.59±0.42	26.9202
	7th fry	2.1R 15Y	0.2576±0.07	10.110±0.03	14.89±0.01	121.81±0.01	35.1100
	8th fry	2.4R 20Y	0.3081±0.02	11.530±0.20	15.78±0.02	121.48±0.05	38.8400
	9th fry	2.8R 22Y	0.3078±0.05	14.680±0.16	16.49±0.02	121.48±0.04	45.8500
	10th fry	3.0R 23Y	0.3396±0.02	15.370±0.31	18.66±0.02	120.28±0.01	49.4000
	Fresh	0.7R 5Y	0.0963±0.01	1.2723±0.01	2.60±0.01	126.80±0.22	5.1446
	1st fry	0.7R 5.5Y	0.1098±0.06	2.0882±0.12	2.92±0.15	126.46±0.15	7.0964
	2nd fry	0.8R 5.8Y	0.1319±0.01	3.9624±0.04	3.50±0.01	125.98±0.02	11.4248
	3rd fry	1.0R 6.0Y	0.1458±0.03	4.4835±0.20	4.30±0.01	125.79±0.20	13.2670
	4th fry	1.3R 6.8Y	0.1603±0.01	5.9978±0.01	5.80±0.06	125.73±0.40	**17.7956**
	5th fry	1.5R 6.8Y	0.1720±0.01	7.5574±0.01	6.90±0.11	125.47±0.25	22.0148
	6th fry	1.8R 7.2Y	0.2001±0.05	9.0822±0.03	8.30±0.20	125.29±0.09	26.4644
	7th fry	2.0R 7.5Y	0.2159±0.06	10.5798±0.16	**10.0±0.01**	124.89±0.04	31.1596
	8th fry	2.4R 13.0Y	0.2599±0.02	11.2972±0.08	12.72±0.04	124.57±0.21	35.3144
	9th fry	2.56R 13Y	0.2828±0.02	11.9001±0.20	14.68±0.02	124.55±0.13	38.4802
	10th fry	2.9R14.5Y	0.3202±0.03	12.7721±0.10	16.02±0.02	124.21±0.25	41.5642

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

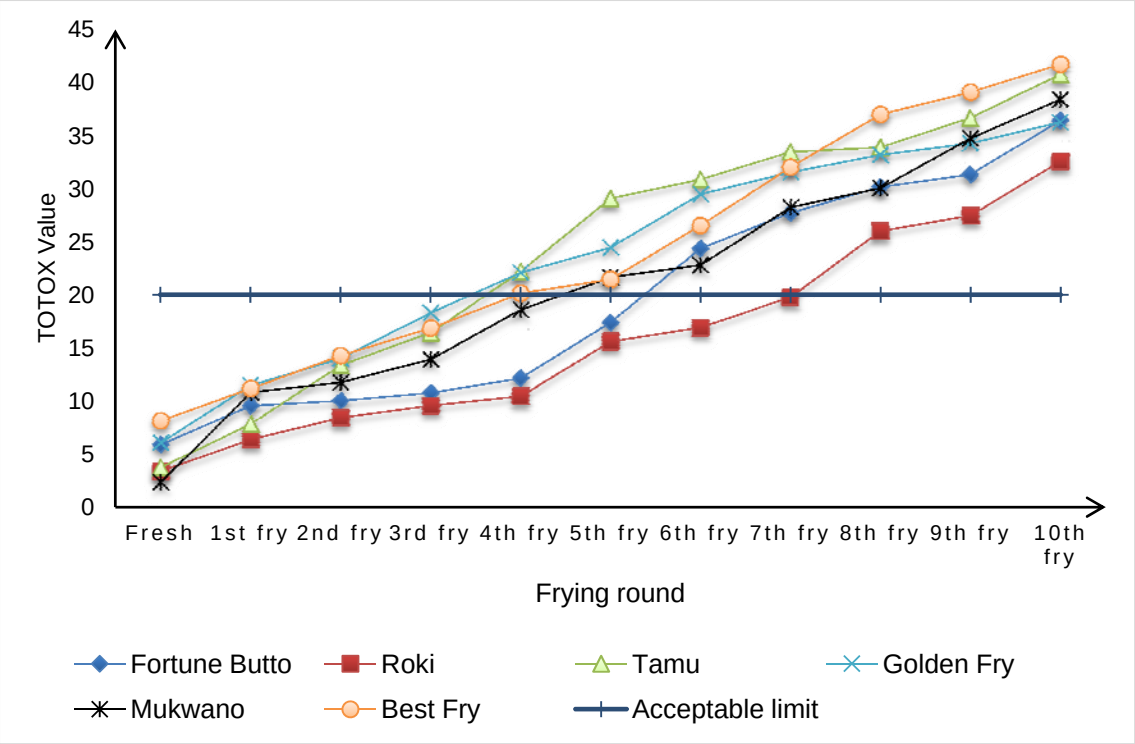
Oil Brand	Oil Sample	Color Value	FFA	POV ($meqO_2/Kg$)	AnV	IV ($I_2/100g$)	TOTOX
First Local Fryer	Fresh	6.8R 70Y	0.1399±0.02	3.1037±0.10	4.30±0.01	58.42±0.22	10.5074
	1st fry	7.4R 70Y	0.1499±0.04	3.5849±0.06	5.10±0.11	58.42±0.92	12.2698
	2nd fry	7.9R 70Y	0.1556±0.01	4.4937±0.01	6.80±0.02	58.38±0.34	15.7874
	3rd fry	8.1R 70Y	0.1698±0.02	5.8645±0.01	7.50±0.02	58.30±0.01	**19.2290**
	4th fry	8.9R 70Y	0.2013±0.07	8.6028±0.04	7.90±0.02	58.34±0.20	25.1056
	5th fry	9.7R 70Y	0.2432±0.01	9.0689±0.01	**9.00±0.02**	58.15±0.05	27.1378
	6th fry	10.7R 70Y	0.2449±0.01	10.738±0.11	10.40±0.06	57.67±0.02	31.876
	7th fry	12.0R 70Y	0.2466±0.03	11.0264±0.01	14.20±0.04	57.66±0.31	36.2528
	8th fry	12.9R 70Y	0.2635±0.06	12.2278±0.01	16.50±0.01	57.55±0.02	40.9556
	9th fry	14.8R 70Y	0.3094±0.01	14.6568±0.03	17.50±0.03	57.55±0.01	46.8136
	10th fry	15.2R 70Y	0.3334±0.03	**15.7525±0.01**	19.90±0.01	57.35±0.02	51.405
Second Local Fryer	Fresh	4.5R 70Y	0.1007±0.01	0.5951±0.03	2.80±0.01	59.43±0.17	3.9902
	1st fry	6.0R 70Y	0.1282±0.01	0.9021±0.02	3.40±0.02	59.23±0.07	5.2042
	2nd fry	6.0R 70Y	0.1300±0.05	1.5840±0.01	3.80±0.01	58.90±0.01	6.9680
	3rd fry	6.2R 70Y	0.1354±0.01	2.2182±0.02	4.50±0.03	58.97±0.32	8.9364

	4th fry	7.1R 70Y	0.1398±0.02	2.9961±0.01	5.10±0.02	58.55±0.21	11.0922
	5th fry	7.3R 70Y	0.1403±0.03	3.3954±0.01	6.30±0.06	58.37±0.40	13.0908
	6th fry	7.8R 70Y	0.1625±0.01	4.4962±0.01	6.50±0.01	58.27±0.07	15.4924
	7th fry	8.2R 70Y	0.1687±0.03	5.1984±0.05	7.40±0.01	58.15±0.03	**17.7968**
	8th fry	8.7R 70Y	0.1812±0.04	6.5811±0.01	8.50±0.04	58.10±0.01	21.6622
	9th fry	9.0R 70Y	0.2014±0.01	6.9981±0.02	**9.10±0.01**	58.10±0.63	23.0962
	10th fry	9.5R 70Y	0.2286±0.01	7.995±0.12	10.70±0.22	58.12±0.18	26.6900
Third Local Fryer	Fresh	7.7R 70Y	0.0496±0.01	1.1957±0.01	2.70±0.04	128.16±0.22	5.0914
	1st fry	9.0R 70Y	0.1362±0.02	1.6099±0.01	3.60±0.01	127.18±0.01	6.8198
	2nd fry	10.1R 70Y	0.1535±0.01	1.7636±0.01	3.90±0.02	126.33±0.21	7.4272
	3rd fry	10.9R 70Y	0.1634±0.01	2.0909±0.01	4.80±0.02	124.79±0.17	8.9818
	4th fry	12.5R 70Y	0.1697±0.03	2.5227±0.01	5.90±0.07	124.22±0.01	10.9454
	5th fry	14.3R 70Y	0.2030±0.01	2.4450±0.02	7.46±0.01	123.30±0.03	12.3500
	6th fry	16.0R 70Y	0.2980±0.02	2.9739±0.06	**8.65±0.02**	121.40±0.04	**14.5978**
	7th fry	17.0R 70Y	0.3235±0.04	6.0875±0.01	14.20±0.02	120.13±0.11	26.3750
	8th fry	18.8R 70Y	0.3874±0.01	6.3546±0.03	17.98±0.16	118.77±0.05	30.6892
	9th fry	19.2R 70Y	0.4165±0.01	7.1760±0.01	20.70±0.03	119.00±0.01	35.0520

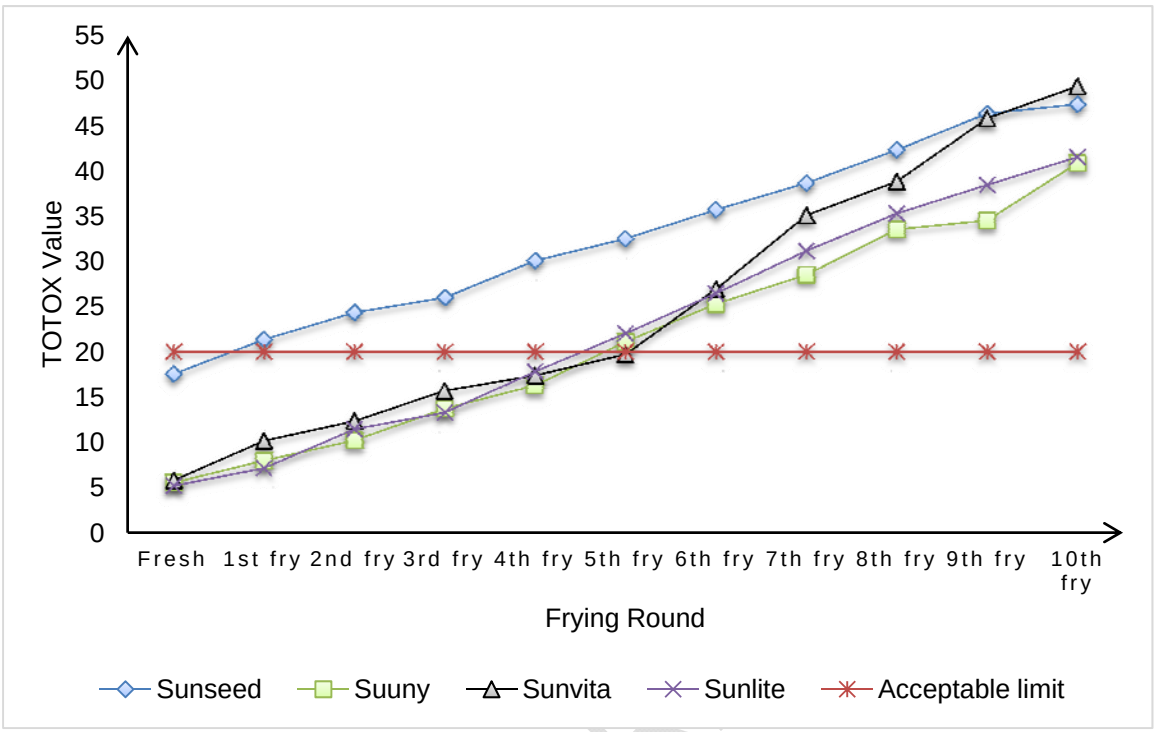
10th fry	20.4R 70Y	0.4748±0.06	8.5800±0.04	22.16±0.01	119.14±0.02	39.3200

3.3 Frying Stability of the Edible Cooking Oils

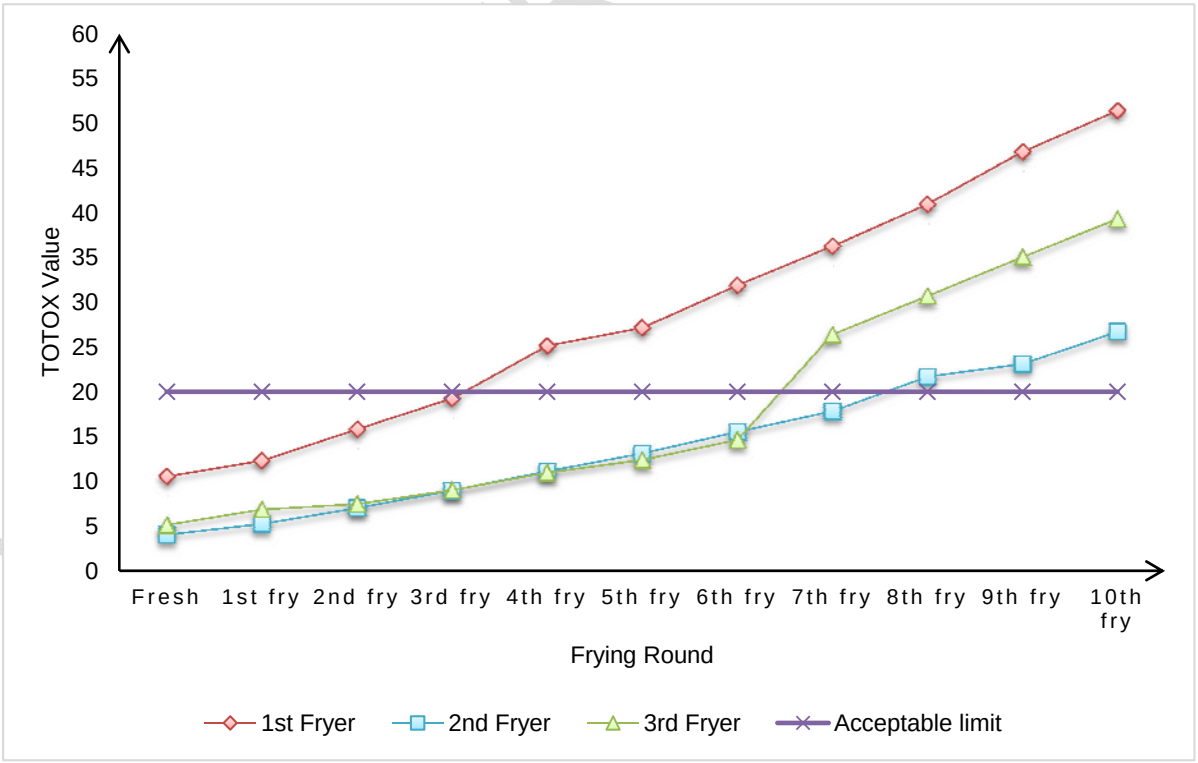
Frying stability of the oils were monitored using TOTOX values (Table 1, Table 2, Table 3).



(a)



(b)



(c)

Figure 5. Changes in TOTOX values of the frying oils (a) hard oils; (b) soft oils; (c) oils from Local fryers.

4. DISCUSSION

4.1. Colour Index

There is no standard specification for color as per Uganda National Bureau of Standards (UNBS) for fresh edible oils. However, most Ugandan edible oil refining companies have internal color specifications of 7.5R 70Y maximum. Of the fresh oil samples, oil from the third Local chips fryer had the highest color reading of 7.7R 70Y (Table 3) while the lowest color reading (0.4R 3.4Y) was recorded in Sunseed (Table 2). Sunseed, Sunvita, Sunlite and Sunny cooking oils was still within color index specifications even after the 10th fry (Table 2). Mukwano after the 6th fry, Fortune Butto, Roki and Best fry after the 5th fry, Tamu after the 4th fry and Golden fry after the 3rd fry fell out of specification (Table 1). Oil from the first and second local fryers fell out of color index specification after a fry while oil from the third fryer did not meet the color specification (Table 3). The color values increased significantly (P = .05). By the 9th fry, the color recitation for oil from the Third Local fryer could hardly be determined experimentally (Table 3) and by the 10th fry, the oil from the second local fryer had become reasonably dark. Generally, by the 10th fry, all the oils had changed the color of the fried food product. It is worth noting that the yellow units of the color index of all the hard oils did not change during the ten continuous frying cycles.

The physical change in the color value of oils is a rather intuitive and swift visual index implicatory of a trend of oil deterioration. 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 [48-50]. Another close cause of the observed color regression could be due to the dispersion of Millard pigments generated *in situ* augmented by traces of carotenoids from the fries [51]. 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 [52]. 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 [53]. More so, the Maillard reaction is accompanied by loss of nutrients and the ensuing browning intensity it impacts on the fries is proportionate to the proteinaceous loss of amino acids: lysine, histidine and methionine. The results obtained in this investigation are in complete agreement with the diagnostic statement of Orthoefer and Cooper [54] that assorted frying oils and the foods fried darken oils to varying degrees during deep frying.

4.2 Free Fatty Acids

The chief composition of oils is fatty acids and the degree of unsaturation is the very first factor influencing the oxidative stability of frying oils despite other oil intrinsic and extrinsic factors [30]. In this study, the lowest FFA of 0.0430±0.30 was recorded in Sunvita (Table 2) while the highest recorded FFA of 0.1508±0.30 was in Sunseed (Table 2). Roki, Best fry, Sunvita and oil from the Second Local fryer were still within the maximum permissible FFA of 0.30 for edible oils even after the 10th fry (Table 1, Table 2, Table 3). Sunlite after the 9th fry, Mukwano after the 8th fry, Fortune Butto, Sunny and oil from the First Local fryer after the 7th fry had FFA greater than the permissible limit (Table 1, Table 2, Table 3). Tamu, Sunseed and oil from the Third Local fryer after the 6th fry and Golden fry after the 4th fry had FFA greater than the specification of 0.30 (Table 1, Table 2, Table 3).

The differences observed in the FFA values of the fresh edible oils could be attributed to blending of several edible oils by the refining companies. Blending of edible oils is known to alter their fatty acid profiles [55, 56] and can steeply retard oxidation of oils during deep-fat frying. The increase in FFA values of oils during the frying cycles can be attributed to the breakdown of long carbon chains into shorter chains due to thermal and oxidative decomposition. 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 [57-59]. FFA is preferred frequently by food processors for indication of oil acidity and oil authenticity verification [14,60]. Filtration of frying oils have been reported to reduce FFA content of oils and improve their frying stability.

The results of this collaborative study is concordant with that of Stevenson *et al* [61] who reported that edible oils with FFA values less than 0.05 and POV of 1.0meqO_2/kg or less are best suited for deep frying. It also agrees well with other studies that the FFA content of oils increases with the number of frying cycles [24] as well as the frying time [25].

4.3 Peroxide Value

For fresh samples, oil from the Second Local fryer had the lowest POV of 0.5951 ±0.03meqO_2/Kg (Table 3) while the highest POV of 6.6134±0.23 meqO_2/Kg was observed in Sunseed (Table 2). Aside from the nature of the oil, oils to be utilized in deep frying should have a Codex regulatory maximum POV of 15meqO_2/K [62]. In this concerted study, POVs increased significantly (P = .05) during the ten successive fries (Table 1, Table 2, Table 3). However, up to the 10th fry, the POVs of all the oils were still concordant with the maximum Codex standard POV for vegetable oils except for Sunvita and Oil from the First Local Fryer that were above the maximum Codex standard after the 9th fry (Table 2 and Table 3.

The increase in the POVs of edible oils following frying is because of the 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 AnV shoot up as they decompose further to secondary oxidative compounds which constitute the paraanisidine components. POV is implicative of incipient oxidation which directly translates into 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 [63].

The observed increase in POV during heating of oils have been reported by other authors [14, 40, 64, 65]. Furthermore, polyunsaturated oils exhibit readily depressed stability at elevated temperatures because the unsaturated fatty acids are readily oxidized to peroxides [65, 66]. Empirical data also point that POVs of fresh oils may be higher than the Codex standard primarily owing to improper storage and/or packaging that triggers degradation via photo-oxidation. Auto-oxidation of oils may supposedly occur in storage due to chemical interaction with air, peculiarly oxygen [67]. However, such oils with high POVs are typically unstable and becomes rancid easily [68].

4.4 Paraanisidine Value

Oxidative degradation of frying oils is innocuously deleterious as it impacts sensorial and organoleptic attributes of fries [69]. Primary oxidation quantifies the amount of hydroperoxides as 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 AnV of 0.90±0.01 was observed in Mukwano (Table 1) while the highest recorded AnV were 4.30±0.01 and 4.30±0.19 in Sunseed and oil from the First Local fryer (Table 2 and Table 3) respectively. Sunseed after the 4th fry, Golden fry, Best fry, Oil from the First Local Fryer and Sunvita after the 5th fry were above the maximum permissible limit of 10 [70]. Tamu, Sunny and Oil from the Third Local fryer after the 6th fry were out of specifications. Sunlite, Fortune Butto and Mukwano were out of specifications after the 7th fry whereas Roki and oil from the Second Local fryer after the 9th fry recorded AnV above the maximum acceptable limit.

Secondary oxidation products are principally non-volatile aldehydes, principally 2,4-dienals and 2-alkenals [71, 72] which AnV is a quantitative measure. The AnV was observed to increase insignificantly ($P = .05$) between the successive fries. Initial stages of heating resulted in faster increase in AnV followed by a more gradual increment (Table 1, Table 2 and Table 3). This could be due to further decomposition of the carbonyls and polymerization reactions. The observed trend is due to the fact that the less stable primary oxidative products (hydroperoxides) decompose further to form aldehydic compounds. These compounds are not easily decomposed, thus the test to determine the AnV is more meaningful than that to determine the POV. Similar results have been reported by Xu *et al* [40] in their comparison of oxidative stability of edible oils under continuous deep frying conditions.

4.5 Iodine Absorption Value

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 [73]. Iodine index, is a frequently considered vital analytical measure of the unsaturation of oils [74] and any significant differences in IV can be translated into increased oxidation rate.

At fresh conditions, the maximum IV observed was in Sunny (128.35±0.02gI_2/100g) (Table 2) and the least IV of 57.62±0.17gI_2/100g was recorded in Golden fry (Table 1). It was observed in this investigation that there were no significant differences ($P = .05$) in IV during the frying cycles. The observed decrement in the Iodine indices is concordant with the decrement in double bonds attributed to oxidation and thermal decomposition and has been reported by other authors [40]. However, this decrement implies there was little oxidation because significant changes in iodine values can only be appreciated during deep frying when there is excessive deterioration of the oil [49].

4.6 Frying Stability of the Edible Oils

The average number of times the hard oils and soft oils could be re-used for continuous deep-fat frying were statistically calculated. Possible reuse of the oils were estimated from the frying round when a quality criterion (POV or AnV) surpassed UNBS or Codex Alimentarius specification. The analysis gave an average of 6.5 times (≈7 times for hard oils and 5.5 times (≈ 6 times) for soft oils.

The stability (oxidizability) of the oils were reflected by the changes in their TOTOX values during the frying cycles. The TOTOX values of frying oils take into consideration the actual state of the oils (using POV) as well as the history of the oil (employing the AnV). Thus, the

significance of TOTOX value is much stronger than the individual Peroxide and Anisidine values. A 2006 position paper for the German Society for fat sciences (cited in [75]) recommended a TOTOX value of less than 20 for refined and virgin vegetable oils. In this study, a maximum TOTOX value of 20 was considered acceptable for deep frying.

Among the hard oil brands investigated, Roki was the most stable followed by Fortune Butto, Mukwano, Tamu, Best fry and lastly Golden fry (Table 1; Figure 5(a)). For soft oils, Sunseed was the most unstable as it could only be used for frying once (Table 2; Figure 5(b)). It was followed by Sunny, Sunlite and lastly Sunvita (Table 2; Figure 5(b)). Oils from the Local fryers followed the order: Oil from the Second Fryer > Oil from the Third Fryer > Oil from the First Local Fryer. Overall, the stability of the oils investigated followed the order: Oil from the Second Local Fryer > Roki > Oil from the Third Local fryer >Fortune Butto > Sunvita > Sunny > Sunlite > Mukwano > Tamu > Best Fry > Golden Fry > Oil from the First Local Fryer > Sunseed.

5. CONCLUSIONS AND RECOMMENDATIONS

Prior to deep frying, all the selected brands of edible oils sold in Kampala metropolis met the Uganda National Bureau of Standards and thus Codex Alimentarius specifications in terms of the assessed physicochemical properties except oil from the Third Local fryer which failed to meet the color index specification. After ten successive deep fryings, the physicochemical properties of the edible oils increased between fryings and some oils went out of specifications of before the 10^{th} fry. Iodine adsorption values decreased only slightly during the ten continuous frying cycles. Changes in the physical and chemical parameters of frying oils increases with increase in the number of frying cycles of the Irish potato chips. Repeated re-use of oils for consecutive deep frying of Irish potato chips on the same day can be done only up to a maximum of 7 times on average for the investigated hard oils and 6 times for the 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. Waste oils not recommended for further use for deep frying of Irish potatoes could be harnessed for biodiesel production.

Further comprehensive research should elucidate the variation of physicochemical properties of other edible cooking oil brands on the Ugandan market such as Nile, Fortune, Kimbo, Star Fry, Cow boy and Ufuta. Further research should be done with other food samples such as fish, cassava, chicken, sweet plantain, dough, meat and edible grasshoppers as the nature of the food sample influences the quality of an oil utilized for 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 sensorium 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.

DISCLAIMER:

Authors have declared that no competing interests exist. The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by

the producing company rather it was funded by personal efforts of the authors.

REFERENCES

1. Omara T, Nnankabirwa R, Nassazi W, Nakabuye BV, Musau B. Spectroscopic Screening of Assorted Pigmented Vegetables and Fruits Common in Metropolitan Kampala Culinary Recipes for Anthocyanins. Int J Food Sci Nutr. 2018; 3(6):285-290. http://www.foodsciencejournal.com/download/506/3-6-62-643.pdf.
2. Peers KE and Swoboda PAT. Deterioration of Sunflower Seed Oil Under Simulated Frying Conditions and During Small-Scale Frying of Potato Chips. J Sci Food Agric. 1982;33:389–95. https://doi.org/10.1002/jsfa.2740330414.
3. Cuesta C, Sanchez-Muniz FJ, Garrido-Polonio C, Lopez-Varela S and Arroyo R. Thermooxidative and Hydrolytic Changes in Sunflower Oil Used in Frying With a Fast Turnover of Fresh Oil. J Amer Oil Chem Soc. 1993; 70:1069–73.
4. Sanchez-Muniz FJ, Cuesta C, Lopez-Varela MC, Garrido-Polonio MC and Arroyo R. Evaluation of the Thermal Oxidation Rate of Sunflower Oil Using Various Frying Methods. In: Applewhite TH, editor. Proceedings of World Conference on Oilseed and Technology and Utilization. Champaign, Ill: American Oil Chemists Society, 1993.
5. Houhoula DP, Oreopoulou V, Tzia C. The Effect of Process Time and Temperature on the Accumulation of Polar Compounds in Cottonseed Oil During Deep-Fat Frying. J Sci Food Agric. 2003;83 (4), 314–19. https://doi.org/10.1002/jsfa.1314.
6. Aladedunye FA. Curbing Thermo-Oxidative Degradation of Frying Oils: Current Knowledge and Challenges. European J Lipid Sci Tech. 2015; 117 (11):1867-81. https://doi.org/10.1002/ejlt.201500047.
7. Kita A. The Influence of Potato Chemical Composition on Crisp Texture. Food Chem. 2002;76 (2):173–79. https://doi.org/10.1016/S0308-8146(01)00260-6.
8. Choe E and Min DB. Chemistry of Deep-Fat Frying Oils and Fats. J Food Sci. 2007; 72(5):77–86. https://doi.org/10.1111/j.1750-3841.2007.00352.x
9. Weisshaar R. Quality Control of Used Deep-Frying Oils. European J Lipid Sci Tech. 2014; 116 (6):716–22. https://doi.org/10.1002/ejlt.201300269
10. Yoon SH, Kim SK, Kim KH, Kwon TW and Teah YK. Evaluation of Physicochemical Changes in Cooking Oil During Heating. J Amer Oil Chem Soc. 1987;64(6);870–73. https://doi.org/10.1007/BF02641496
11. Mariod A, Omer N, Al E and Mokhtar M. Chemical Reactions Taken Place During Deep-Fat Frying and Their Products: A Review. SUST J Natur Medic Sci. Suppl Issue. 2014; 09:01-17.
12. Dana D and Saguy IS. The Protective Role of Water Injection on Oil Quality in Deep Fat Frying Conditions. Eur Food Res Tech. 2003:217:104-109. https://doi.org/10.1007/s00217-003-0744-x
13. Pokorny J. Flavor Chemistry of Deep Fat Frying in Oil. In: Min DB, Smouse TH, Editors. Flavor Chemistry of Lipid Foods. Champaign, Ill., USA: American Oil Chemists Society, 1989.
14. Park J and Kim J. Monitoring of Used Frying Oils and Frying Times for Frying Chicken Nuggets Using POV and Acid Value. Korean J Food Sci Ani. 2016;5(36):612–16. https://dx.doi.org/10.5851%2Fkosfa.2016.36.5.612.
15. Rohman A and Che Man YB. Authentication of Extra Virgin Olive Oil from Sesame Oil Using FTIR Spectroscopy and Gas Chromatography. Int J Food Prop. 2015;15:1309–18. https://doi.org/10.1080/10942912.2010.521607
16. Boskou D. Stability of Frying Oils. In: Frying of Food: Principles, Changes, New Approaches. VCH Publishers: New York. 1998, pp. 174-82.
17. Choe E and Lee J. Thermooxidative Stability of Soybean Oil, Beef Tallow and Palm Oil During Frying of Steamed Noodles. Korean J Food Sci Tech. 1998; 30:288–92.

18. Chen JF, Tai CY, Chen YC and Chen BH. Effects of Conjugated Linoleic Acid on the Oxidation Stability of Model Lipids During Heating and Illumination. Food Chem. 2001; 72:199–206. https://doi.org/10.1016/S0308-8146(00)00219-3
19. Gertz C and Klostermann SH. Analysis of Acylamide and Mechanisms of its Formation in Deep-Fried Products. Eur J Lipid Sci Tech. 2002;104:762–71. https://doi.org/10.1002/1438-9312(200211)104:11%3C762::AID-EJLT762%3E3.0.CO;2-R
20. Debnath NK, Rastogi NK, Gopal Krishna AG and Lokesh BR. Oil Partitioning Between Surface and Structure of Potato Slices-A Kinetic Study. Food Sci Tech. 2009;42:1054–58.
21. Ghidurus M, Turtoi M, Boskou G, Niculita P and Stan S. Nutritional and Health Aspects Related to Frying (I). Roman Biotech Letts. 2010;15:5675–82.
https://www.rombio.eu/rbl5vol16/1%20Ghidurus%20Mihaela.pdf
22. Dhaka V, Gulia N, Ahlawat K and Khatkar B. Trans Fats–Sources, Health Risks and Alternative Approach – A Review. J Food Sci Tech. 2011;48:534-41.
https://dx.doi.org/10.1007%2Fs13197-010-0225-8
23. Baby Latha R and Nasirullah. Physico-chemical Changes in Rice Bran Oil During Heating at Frying Temperature. J Food Sci Tech. 2014; 51:335-40. https://doi.org/10.1007/s13197-011-0495-9
24. Chung J, Lee J and Choe E. Oxidative Stability of Soybean and Sesame Oil Mixture During Frying of Flour Dough. J Food Sci. 2004; 69:574-78. https://doi.org/10.1111/j.1365-2621.2004.tb13652.x
25. Mazza G and Qi H. Effect of After-Cooking Darkening Inhibitors on Stability of Frying Oil and Quality of French Fries. J Amer Oil Chem Soc. 1992; 69:847–53. https://doi.org/10.1007/BF02636331
26. Frega N, Mozzon M and Lecker G. Effects of Free Fatty Acids on Oxidative Stability of Vegetable Oil. J Amer Oil Chem Soc. 1999; 76:325–29. https://doi.org/10.1007/s11746-999-0239-4
27. Miyashita K and Takagi T. Study on the Oxidative Rate and Prooxidant Activity of Free Fatty Acids. J Amer Oil Chem Soc. 1986; 63:1380–84. https://doi.org/10.1007/BF02679607
28. Mistry BS and Min DB. Effects of Fatty Acids on the Oxidative Stability of Soybean Oil. J Food Sci; 1987:52(3):831-32. https://doi.org/10.1111/j.1365-2621.1987.tb06741.x
29. Karakaya S and Simsek S. Changes in Total Polar Compounds, POV, Total Phenols and Antioxidant Activity of Various Oils Used in Deep Fat Frying. J Amer Oil Chem Soc. 2011; 88:1361–66. https://doi.org/10.1007/s11746-011-1788-x
30. Casal S, Malheiro R, Sendas A, Oliveira BPP and Pereira JA. Olive Oil Stability Under Deep-Frying Conditions. Food Chem Toxicol. 2010; 48:2972–79. https://doi.org/10.1016/j.fct.2010.07.036
31. Romero A, Cuesta C and Sanchez-Muniz FJ. Effect of Oil Replenishment During Deepfat Frying of Frozen Foods in Sunflower Oil and High-Oleic Acid Sunflower Oil. J Amer Oil Chem Soc. 1998;75:161–67. https://doi.org/10.1007/s11746-998-0028-5
32. Xu X, Tran VH, Palmer M, White K and Salisbury P. Chemical and Physical Analyses and Sensory Evaluation of Six Deep-Frying Oils. J Amer Oil Chem Soc. 1999; 76:1091–99. https://doi.org/10.1007/s11746-999-0209-x
33. Gordon MH and Kourimska L. The Effects of Antioxidants on Changes in Oils During Heating and Deep Frying. J Sci Food Agric. 1998;68:347–53. https://doi.org/10.1002/jsfa.2740680314
34. Tompkins C and Perkins EG. Frying Performance of Low-Linolenic Acid Soybean Oil. J Amer Oil Chem Soc. 2000; 77:223–29. https://doi.org/10.1007/s11746-000-0036-2
35. Warner K, Orr P and Glynn M. Effect of Fatty Acid Composition of Oils on Flavor and Stability of Fried Foods. J Amer Oil Chem Soc. 1997;74:347–56.
https://doi.org/10.1007/s11746-997-0090-4
36. Romero A, Cuesta C and Sa´nchez-Muniz FJ. Trans Fatty Acid Production in Deep Fat Frying of Frozen Foods with Different Oils and Frying Modalities. Nutr Res. 2000; 20(4):599–608. https://doi.org/10.1016/S0271-5317(00)00150-0

37. Naz S, Siddiqi R and Sayeed SA. Effect of Flavonoids on the Oxidative Stability of Corn Oil During Deep Frying. Int J Food Sci Tech. 2005;43(10):1850-54. https://doi.org/10.1111/j.1365-2621.2008.01731.x
38. Diop A, Ndao S, Cissé M, Baldé M, Ndiaye B and Diop YM. Effect of Deep-Fat Frying on Chemical Properties of Edible Vegetable Oils Used by Senegalese Households. Afr J Food Agric Nutr Dev. 2014;14(6):9418-9438. https://www.ajol.info/index.php/ajfand/article/view/109767/99516
39. Juárez MD, Osawa CC, Acuña ME, Sammán N and Gonçalves LAG. Degradation in Soybean Oil, Sunflower Oil and Partially Hydrogenated Fats After Food Frying, Monitored by Conventional and Unconventional Methods. Food Control. 2010;22:1920–27. https://doi.org/10.1016/j.foodcont.2011.05.004
40. Xu T, Li J, Fan Y, Zheng T and Deng Z. Comparison of Oxidative Stability Among Edible Oils Under Continuous Frying Conditions. Int J Food Prop. 2015; 18:1478–90. https://www.tandfonline.com/doi/ci-edby/10.1080/10942912.2014.913181?scroll=top&needAccess=true
41. Abdulkarim SM, Long K, Lai OM, Muhammad SKS and Ghazali HM. Frying Quality and Stability of High-Oleic *Moringa oleifera* Seed Oil in Comparison with other Vegetable Oils. Food Chem. 2007;105:1382–89. https://doi.org/10.1016/j.foodchem.2007.05.013
42. AOCS. AOCS-Official Methods And Recommended Practices of the American Oil Chemists' Society. 2004, Champaign, IL, USA.
43. ISO. Animal and Vegetable Fats and Oils- Determination of Iodine Value. ISO 3961: 2009. 4th edn. 2009, Geneva, Switzerland.
44. ISO. Animal and Vegetable Fats and Oils-Determination of Peroxide Value. ISO 3960: 2007. 2007, Geneva, Switzerland.
45. AOCS. AOCS. p-Anisidine value. In: AOCS Official Method Cd 18-90: Official Methods and Recommended Practices of the American Oil Chemists' Society. 1998, Champaign, IL, USA.
46. Shahidi F, Wanasundara UN. Methods for Measuring Oxidative Rancidity in Fats and Oils. In: Food Lipids: Chemistry, Nutrition, and Biotechnology; Akoh, C.C.; Min, D.B.; Eds.; Marcel Dekker Inc.: New York, NY, 2002:465–482.
47. Pereira de Abreu DA, Paseiro Losada P, Maroto J, Cruz JM. Evaluation of the Effectiveness of a New Active Packaging Film Containing Natural Antioxidants (From Barley Husks) That Retard Lipid Damage in Frozen Atlantic Salmon (Salmo salar L.). Food Res Int. 2010; 43(5):1277–82. http://dx.doi.org/10.1016/j.foodres.2010.03.019
48. Gutierrez R, Gonzalez-Quijano J and Dobermans MC. Analytical Procedures for the Evaluation of Used Frying Fats. In: Varela G, Bender AE and Morton ID (Eds.), Frying of Food: Principles, Changes, New Approaches. England: VCH-Ellis Horwood Ltd, pp. 141-154
49. Augustin MA and Berry SK. Efficacy of the Antioxidants BHA and BHT in Palm Olein During Heating and Frying. J Amer Oil Chem Soc. 1983;60:1520-23.
50. Farhoosh R, Kenari RE and Pooazrang R. Frying Stability of Canola Oil Blended With Palm Olein, Olive and Corn Oils. J Amer Oil Chem Soc. 2009;86(1):71-76. https://doi.org/10.1007/s11746-008-1315-x
51. Lalas S, Gortzi O and Tsankanis J. Frying Stability of *Moringa stenopetala* Seed Oil. Plant Foods Hum Nutr. 2006; 61(2): 99-108. https://doi.org/10.1007/s11130-006-0022-8
52. Che Man, Y.B. and Tan, C.P. Effects of Natural Antioxidants on Changes in Refined, Bleached and Deodorized Palm Olein during Deep-Fat Frying of Potato Chips. J Amer Oil Chem Soc. 1999;76:331-39. https://doi.org/10.1007/s11746-999-0240-y
53. Reda SY. Comparative Study of Vegetable Oils Subjected to Thermal Stress. Masters Dissertation, Universidade Estadual de Ponta Grossa, 2000.
54. Orthoefer ET and Cooper DS. Evaluation of Used Frying Oil. *In*: Perkins, EG Erickson, MD. Deep Frying: Chemistry, Nutrition and Practical Applications. AOAC Press: Champaign.1996;285-296.

55. Shiota M, Konishi H and Tatsumi K. Oxidative Stability of Fish Oil Blended with Butter. J Dairy Sci. 1999;82:1877–81. https://doi.org/10.3168/jds.S0022-0302(99)75421-4
56. Mamat H, Aini IN, Said M and Jamaludin R. Physicochemical Characteristics of Palm Oil and Sunflower Oil Blends Fractionated at Different Temperatures. Food Chem. 2005;91:731–36. https://doi.org/10.1016/j.foodchem.2004.06.045
57. Baby Latha R and Nasirullah. Effect of Heat on Physico-Chemical and Thermo-Oxidative Stability of Repeatedly Heated Rice Bran Oil (RBO). Int J Food Nutr Sci. 2016; 5:49-60. https://www.ijfans.com/ijfansadmin/upload/ijfans_572329985c27f.pdf
58. Faridah DN, Lioe HN, Palupi NS and Kahfi J. Detection of FFA and Peroxide Values using FTIR for Quality Measurement in Palm Oil Frying Activities. J Oil Palm Res. 2015; 27(2):156-67. https://inis.iaea.org/search/search.aspx?orig_q=RN:48005572
59. Lalas S. Quality of frying oil. Advances in Deep-fat Frying of Foods. New York, USA: CRC Press, 2009.
60. Ahmad-Tarmizi AH and Siew WL. Quality Assessment of Palm Products Upon Prolonged Heat Treatment. J Oleo Sci, 2008;57(12):639-48. https://doi.org/10.5650/jos.57.639
61. Stevenson SG, Vaisey-Genser M and Eskin NAM. Quality Control in the Use of Deep Frying Oils. J Amer Oil Chem Soc. 1984; 61:1102–08. https://doi.org/10.1007/BF02636232
62. Codex Alimentarius. Codex Standard for Named Vegetable Oils, CODEX STAN 210-1999. Amended in 2005 and 2011. Rome, Italy, 1999.
63. Atinafu DG and Bedemo B. Estimation of Total Free Fatty Acid and Cholesterol Content in Some Commercial Edible Oils in Ethiopia, Bahir DAR. J Cereals Oilseeds. 2001;2:71-76. http://www.academicjournals.org/JCO
64. Sulthana SN and Sen DP. Studies on Deep Fat Frying: Changes During Heating of Oil. J Food Sci Tech. 1979;16:208.
65. Serjouie A, Tan CP, Mirhosseini H and CheMan YB. Effect of Vegetable-Based Oil Blends on Physicochemical Properties of Oils During Deep-Fat Frying. Amer J Food Tech. 2010; 5(5):310-23. http://dx.doi.org/10.3923/ajft.2010.310.323
66. Che-Man YB and Wan-Hussin WR. Comparison of the Frying Performance of Refined, Bleached and Deodorized Palm Olein and Coconut Oil. J Food Lipids. 1998; 5:197–210. https://doi.org/10.1111/j.1745-4522.1998.tb00120.x
67. Ojeh O. Effects of Refining on the Physical and Chemical Properties of Cashew Kernel Oil. J Fats Oils Tech. 1981; 16(5):513–17. https://doi.org/10.1111/j.1365-2621.1981.tb01844.x
68. Susheelamma NS, Asha MR, Ravi R and Kumar AKV. Comparative Studies on Physical Properties of Vegetable Oils and their Blends After Frying. J Food Lipids. 2002; 9:259–76. https://doi.org/10.1111/j.1745-4522.2002.tb00225.x
69. Dana D and Saguy IS. Frying of Nutritious Foods: Obstacles and Feasibility. Food Sci Tech Res. 2001;7(4):265-79. https://doi.org/10.3136/fstr.7.265
70. Rossell JB. Measurement in Rancidity. In: Allen JC, Hamilton RJ (eds) Rancidity in Food. Elsevier, London, 1989, pp. 22–51.
71. Sulieman MR, Makhzangy AE and Ramadan MF. Antiradical Performance and Physicochemical Characteristics of Vegetable Oils Upon Frying of French Fries: A Preliminary Comparative Study. J Food Lipids. 2006; 13(3):259-76. https://doi.org/10.1111/j.1745-4522.2006.00050.x
72. Bou R, Navas JA, Tres A, Codony R, Guardiola F. Quality Assessment of Frying Fats and Fried Snacks During Continuous Deep-Fat Frying at Different Large-Scale Producers. Food Control. 2012; 27(1):254–67. https://doi.org/10.1111/j.1745-4522.2006.00050.x
73. Tomkins PC and Perkins EG. The Evaluation of Frying Oils with the P-Anisidine Value. J Amer Oil Chem Soc, 1999, 76 (8), 945-947. https://doi.org/10.1007/s11746-999-0111-6.
74. Otunola, A.G., Adebayo, G.B. and Olufemi, O.G. Evaluation of Some Physicochemical Parameters of Selected Brands of Vegetable Oils Sold in Ilorin Metropolis. Int J Phys Sci. 2009; 4 (5):327-29.

75. Marthias B. *In*: Oxidation in Foods and Beverages and Antioxidant Applications: Management in Different Industry Sectors, 2010.