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Effect of Temperature on the Chemical Characteristics of Vegetable Oils Consumed in Ibadan, Nigeria

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Abstract: The effect of changing temperature on various chemical characteristics of vegetable oils sold in Bodija Market, Oyo State, Nigeria was studied. The chemical characteristics were investigated within a temperature range of 25-300°C. The paper also investigated the rate of change of the various chemical parameters with increasing temperature, as suggested by the slope of linear graph of each cooking oil. The peroxide values (6.01-7.02 Meq/kg) were highest in palm kernel oil (PKO), followed by olive oil (OO) (5.20-6.10 Meq/kg) but were lowest in palm oil (PO) (1.80-2.31 Meq/kg). The iodine values were highest (60.0-70.0 g/100 g of sample) in sunflower oil (SFO), followed by soybean oil with values of 58.75-60.0 g/100 g of sample and were lowest (19.2-20.2 g/100 g of sample) in PO. Olive oil (OO) had the highest acid values from 6.01-7.40 mg KOH/g, followed by PKO (3.01-3.99) and the lowest values were recorded for soybean oil (2.80-3.81 mg KOH/g). For the free fatty acid, the highest values (2.49-3.50%) were observed for PO, followed by OO (2.61-3.05%) and the least values were found in SO. The rate of change in PV, as demonstrated by the positive slope ranged from 0.001 Meq/kg/°C in PO to 0.05 Meq/kg/°C in both SO and SFO. The highest rate of change in AV (0.007 mg KOH/g/°C) was obtained for PO, while the lowest value (0.003 mg KOH/g/°C) was recorded for SO, OO and SFO. The rate of change in the free fatty acid value with changing temperature was 0.003, 0.001, 0.002, 0.001 and 0.001%/°C for PO, SO, OO, PKO and SFO oil respectively. However, negative rates were recorded for the iodine values as evidenced by the reduction in the value of this characteristic with increasing temperature. The respective rates of change for PO, SO, OO, PKO and SFO were -0.003, -0.004, -0.013, -0.011 and -0.009 g/100 g of sample/°C. Although our research shows the change in the chemical characteristics with increase in temperature is low, the rate of change must be monitored because of the likely deterioration of the overall quality of the oil at elevated temperatures.

Key words: Vegetable oil, temperature, palm kernel oil, olive oil

INTRODUCTION

Vegetable oils are an indispensable part of everyday meal in most parts of the world. From time immemorial, vegetable oils have been used in cooking and for medicinal purpose. Cooking oil manufacturers are important employers of labor in many parts of the world and are an important part of national revenue. For instance, PO was the highest export commodity in Indonesia and Malaysia with a combined output of 46.5 Mt/y towards the end of the year 2012 (Index Mundi, 2013). Olive plants, peanut (*Arachis hypogaea*), soybean, palm tree are few examples of plants whose seeds and fruits can be processed to obtain edible oils. These plants are cultivated in different parts of the world (Wilfred *et al*., 2010; Adubofuor *et al*., 2013; Fontanel, 2013). Oils have always been an important component of human foods, being essential for health (Atinafu and Bedemo, 2011; Olorunfemi *et al*., 2014). Oils serve as a source of fat-soluble vitamins and essential fatty acids. Hormone-like substances, such as prostaglandins and leukotrienes that have a number of regulatory functions including immune and inflammation response are synthesized from these essential fatty acids (Babalola and Apata, 2011; Ahmad *et al*., 2014). Also, they play important roles in the development of different areas of chemical products, pharmaceuticals, biofuels, cosmetics, paints and most importantly, food production, all of which are important industrial processes (Atef, 2010; Iha *et al*., 2014; de Melo *et al*., 2014). In the food industry, oils are used in frying, salad dressing, shortening of pastries; margarine, cooking and ice cream manufacture (Aboki *et al*., 2012). Current research suggests that vegetable oils are suitable replacements for mineral oils in the production of environmentally friendly lubricants (Farooq *et al*., 2011) and they can be used as alternative energy sources in fish meals (Kamalam *et al*., 2013; Liland *et al*., 2013; Murray *et al*., 2014). When used properly, these oils nourish the body with their natural ingredients.

Uses of vegetable oils: The use of oils from plant origin cuts across many industries including but not limited to

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food (both human and animal), cosmetics, energy and manufacturing industries e.t.c. Some of their uses are explained below.

Fuel production: Vegetable oils are becoming attractive choices in the production of bio-fuels due to the high energy density of the triacylglycerol. Other attractive characteristics of biodiesel include non-toxicity, low emission of CO, particulate matter, unburned hydrocarbons high biodegradability, high flash point, improved cetane number and reduced exhaust emission (Abbaszaadeh *et al.*, 2012; Balat, 2010; Fazal *et al.*, 2013). However, vegetable oils cannot be used directly as bio-fuels and are often subjected to different modifications prior to use as bio-fuels. Some of the treatments used include dilution, thermal cracking (pyrolysis), transesterification and microemulsification. However, trans-esterification is the best method for producing higher quality biodiesel (Balat, 2010; Lian *et al.*, 2012). The costs of vegetable oils are increasing because of their high demand from food and energy industries. Also, the high viscosity, low volatility and cold folw greatly reduce the application of vegetable oils in the production of bio-fuels. However, the use of waste cooking oils (WCO) in recent applications has been reported to give 35-60% reduction in the production cost. Furthermore, other steps, such as reduction in reaction time, amount of alcohol, catalyst and temperature have been taken to make the production of bio-fuels from WCO to be cost effective (Talebian-Kiakalaieh *et al.*, 2013). According to the authors, the problem inherent in the conventional trans-esterification process is another challenge the limit the utilization of vegetable oils in the production of bio-fuels. The most widely used alkali-based method has difficulty during the separation process due to the presence of free fatty acid (FFA) and moisture in the raw material, while the acid-catalysed procedure is very slow. In addition, the enzymatic procedure is prohibitively expensive. To overcome these challenges, scientists have investigated the role of various heterogeneous catalysts in the production of bio-fuels from vegetable oils since these catalysts can be re-used over a number of production cycles (Liu *et al.*, 2014).

Liu *et al.* (2014) investigated the production of bio-diesel from WCO, using NKC-9 ion-exchange resin and H- beta zeolite as heterogeneous catalysts. Based on orthogonal experiments, the authors demonstrated that the NKC-9 ion-exchange resin had higher activity and yield compared to H-beta zeolite under the same experimental conditions. The NKC-9 catalyst was effective, as revealed by high activity over 5 runs. Temperature was shown to affect the final conversion of the WCO to bio-diesel. Other factors include the mole ratio of alcohol to oil, reaction time, catalyst dose and the FFA content of the oil. Dehkordi and Ghasemi (2012) also investigated the trans-esterification of WCO to biodiesel fuel using C and Zr mixed oxides as heterogeneous catalyst. While the activity of the synthesized catalyst increases with increasing Ca-to-Zr molar ratio, the stability of the catalyst was found to decrease at the same time. Under optimal conditions, a yield of 92.1% was achieved. According to the authors, the synthesized catalyst demonstrated the ability of been reused for further reaction. Apart from WCO, non-edible oils have also been used in the production of bio-diesel. It is believed that the use of non-edible oil for this purpose will reduce the demand pressure for edible oils in the future production of biodiesels, with the consequent effect of reducing the cost of production and increasing food security for humans.

The production of biodiesel from *Jathropa curcas* oil in the presence of synthetic hydrotalcite heterogeneous catalyst has been reported (Helwani *et al.*, 2013). The highest conversion of Jathropa oil to biodiesel (75.2%) was achieved at 65°C with a methanol: Jathropa oil molar ratio of 12:1, the optimal reaction time and catalyst loading being 6 h and 4 wt.%, respectively. The calcination of the catalyst at 850°C proved to favour the reaction due to increased basicity of the catalyst's surface (Helwani *et al.*, 2013). It is worth noting that the catalyst was rich in Al and Mg, causing the potential contamination of the final product by these metals. It is therefore necessary to determine the level of metals in the product. Step should then be taken to reduce the metals if they exceed particular values in order to prevent adverse effects during the eventual use of the product. Furthermore, the esterification-based conversion of Jathropa oil to biodiesel in the presence of mixed-oxide catalysts of Ca and La has been evaluated (Taufiq-Yap *et al.*, 2014). The highest conversion of Jathropa oil to biodiesel (86.51%) was achieved at 65°C with a methanol:Jathropa oil molar ratio of 24:1, the optimal catalyst dose being wt. 4%. Beside Jathropa oil, other non-edible vegetable oil used in the production of biodiesel include *Sterculia foetida, Ceiba pentandra, Pongamia glabra, Madhuca indica*, Karanga, linseed, rubber seed oils, among others (No, 2011).

Polyurethane production: The use of vegetable oils raw materials in the production of polyurethane has been widely reported (Palaskar *et al.*, 2012; Pan and Webster, 2012; More *et al.*, 2013). Polyurethane is a vital starting material in many industrial products that give us comfort. From time to time, enormous amount of energy is lost from homes. With polyurethane insulation, the heat is conserved within the home during the winter, while it is released during summer, meaning less energy bills and reduced carbon footprint. It is also used as insulator in refrigerators, which allows the preservation of food and other products. The use of polyurethane polymer in the manufacture of wears used in extreme environment has been reported (Wolfrum *et al*., 2014). It is an important component of spacesuit, which prevents astronauts from the extreme conditions of the outer space. It is also used in swimsuit and it has been argued that the incorporation of the chemical into swimsuit gave some athletes advantage over their competitors (Wolfrum *et al*., 2014). Moreover, products made of polyurethane are found almost in every environment. The polymer is an important of furniture and mattresses, products which give us the physical comfort that we desire. In automobiles, it is used in shock absorbers and bumpers to ensure the safety of the users. Furthermore, it shields noise from the engine, which helps the driver to operate in a relaxed environment. Polyurethane also makes vehicles lighter, thereby improving the fuel economy and reducing atmospheric pollution. The increasing interest in the use of bio-based raw materials for the production of most industrial products is due to the depletion of world's fossil resources and environmental concerns (Palaskar *et al*., 2012). Unlike petroleum products, bio-based materials are more easily biodegradable and they generate lesser amount of greenhouse gases. In a recent study, Palaskar *et al*. (2012) investigated the synthesis of a series of novel diols from sunflower and ricin oils using optimized chemical conditions and purification. The formation of polyurethane was reported to proceed via a number of reactions including transesterification, epoxidation, ring opening of epoxides and thiol-ene additions depending on the type of oil or the diols involved. According to the authors, the thermal and rheological properties of the polymer were affected by its molecular structure and purity. Pan *et al*. (2012) reported the preparation of high-functionality polyols by epoxide ring-opening reaction of epoxidized sucrose esters of soybean oil. In this reaction, secondary hydroxyl groups were generated from the epoxides of the fatty acid chains. The product-sucrose soyate polyol- was demonstrated to exhibit the desired hardness and a range of cross-linked density to polyurethane thermosets because of the well-defined compact structures with a rigid sucrose core coupled with high hydroxyl group functionality.

Role in human nutrition and health: Most vegetable oils are rich in antioxidant, such as carotenoids, tocotrienols and tocopherols among others (Swaminathan and Jicha, 2014). These compounds are essential for human health as they help to maintain the integrity of the brain, heart and other vital components of the human system. For example, tocotrienols have cardio-protective potentials that prevent the heart vessels from adverse effects. These compounds also help to prevent cell membrane and DNA from damage by free radicals. Furthermore, they serve many functions in the immune system, blood vessels and the eyes. Vitamin E in the form tocotrienols is beneficial for the flow of blood to the brain and the ketones they contain may serve as an alternate burning fuel to glucose, which could be an effective treatment for Alzheimer's (Swaminathan and Jicha, 2014; de la Monte and Tong, 2014; Zhang *et al*., 2013). Tocotrienols may also help in the treatment of patients with dementia, Parkinson disease, diabetes since these diseases are associated with insulin resistance, which is the main cause of Alzheimer disease (de la Monte and Tong, 2014; Zhang *et al*., 2013). Most vegetable oils contain medium chain triacylglycerides (MCTs) and have been reported to be essential for normal neurological and hormonal functioning (Swaminathan and Jicha, 2014). MCTs are good fat as they are easily digested, converted to energy and any excess is easily released through the elimination channels. People aiming at reducing their weight may use vegetable oils as an alternative to other oils since the MCTs in vegetable oils are not stored as fats. In addition, recent studies have suggested the effectiveness of PO in improving the vitamin A status among population at risk of vitamin A deficiency (Rice and Burns, 2010).

On the contrary, saturated fats from meat, eggs and dairy products contain long chain fatty acids. Numerous heart and other health issues can occur if these food products are consumed in excess and on a continuous basis. Apart from the use of vegetable oils in human nutrition, they have also found application in soap and cosmetic industries.

Effect of temperature on oil quality: Temperature has been recognized as one of the factors that reduce oil quality (Ulu, 2004; Jabeur *et al*., 2015; Santos *et al*., 2013). It has been established that heating oil at frying temperature of 185°C for up to 6 hours gradually increases the formation of polar lipophylic aldehydes (Seppanen and Csallany, 2006; Zhang *et al*., 2013). Reuse of frying oils is known to be associated with various health problems but it is known that discarding these oils after 2-3 cycles of frying is not economically viable (Vankar and Sahu, 2011).

Frying oil at high temperature has been implicated in elevated levels of low density lipoproteins, also known as bad cholesterols (Ramadan, 2013; Kiralan *et al*., 2014). Elevated temperature is a factor that causes increased acid value in oils (Atinafu and Bedemo, 2011). High acid value indicates high free fatty acid, which causes oil to become rancid (Tamzid *et al*., 2007) and ingestion of free fatty acids, especially trans-fatty acids appears to increase blood cholesterol, in particular the ratio of low-density lipoproteins to high-density lipoproteins (Matsumori *et al*., 2013). High levels of low density lipoproteins in the blood have been linked to arterosclerosis, a disease of the heart that can cause stroke, heart attack and serious health problems. Almost every adult at present time develop some degree of this disease (Atinafu and Bedemo, 2011). Low density lipoproteins have also been reported to be associated with increased risk of hypertension. In Nigeria, the prevalence of hypertension ranged from a minimum of 12.4% to maximum of 34.8%. The increase in the number of hypertension cases is not peculiar to Nigeria, as similar increase has been observed in other African (Ekwunife and Aguwa, 2011). Due to increasing awareness on the health implications of bad cholesterols in diet, most people now prefer to purchase vegetable oils with low density lipoproteins (Attarde *et al*., 2010).

It has been demonstrated that elevated free fatty acids, change of colour, low smoke point, low iodine values, elevated total polar materials, high peroxide values, high foaming properties and increased viscosity are indicators of poor oil quality (Loh *et al*., 2006; Turan and Yalcuk, 2013).

Indicators of oil quality-chemical characteristics

Peroxide value: Peroxide value is a measure of oxidation or rancidity (Nordin and Wannahari, 2012). The peroxide value is a useful indicator of the early stages of rancidity occurring under mild conditions and it is a measure of primary lipid oxidation products (Atinafu and Bedemo, 2011). Peroxidation of oils leads to by-products that negatively affect the palatability and health benefits of the diets (Fontagne *et al*., 2006) and polyunsaturated fatty acids are especially susceptible to this type of oxidation (Fernandes *et al*., 2012). This leads to reduction in oil quality (Babalola and Apata, 2011). Factors that accelerate oxidation of oils include exposure to oxygen, heat and light (Ulu, 2004; Liu, 2014). In a similar experiment, Shahina *et al*. (2004) demonstrated that off-flavors, nutritional loses and other deteriorative changes in oils can occur through oxidation or hydrolysis, especially when the reaction is catalyzed by lipases from food and microorganisms. Due to their nutritional benefits, edible oils are widely consumed in different parts of Nigeria. This has continuously attracted scientists' interest to monitor the chemical indicators that determine the quality of the cooking oils consumed in the country. Onyeike and Acheru (2002) reported the peroxide value of castor, coconut, diakanut, groundnut, melon, bean and palm kernel seed oils to be 22.7, 40.0, 40.0, 20.0, 21.3, 23.3 and 20.0 mg/g of sample respectively. These values were generally higher than those reported by Okogeri and Okoro (2014), who reported the ranges of peroxide values of unadulterated palm kernel oil and adulterated palm kernel oil to be 3.35-16.00 and 2.07-6.80 meq/kg, respectively. They are also higher than the values reported for groundnut oil (Yusuf *et al*., 2014). Abiodun *et al*. (2014) determined the PV of 11.0 mg/g for *Thaumatococcus danielli*, which in a typical fruit plant. The difference in the value must have resulted from the different methods used for determination as well as variation in the species.

Iodine value: Iodine value is the number of grams of iodine absorbed by 100 g of fat (Babalola and Apata, 2011). It is an important indicator of the degree of saturation and unsaturation of fats and oils. Saturated fats and oils have low iodine values and unsaturated fats and oils have high iodine values. Iodine value depends directly on the number of double bonds present in oils (Aberounmand, 2010; Sanli *et al*., 2014). Onyeike and Acheru (2002) reported the iodine value of castor, coconut, diakanut, groundnut, melon, bean and palm kernel seed oils, which are commonly consumed in Nigeria, to be 20.0, 17.6, 21.5, 11.2, 19.2, 18.7 and 33.3 g/100 g of sample, respectively.

Acid and free fatty acid values: Acid value gives an indication of the suitability of oil for direct consumption and industrial use (Al-Bachir, 2015). Acid value is the measure of free fatty acids in oils. Fatty acids are normally found in the form of triglycerides but they may break down into free fatty acids during processing (Atinafu and Bedemo, 2011). Increase in acid value may be caused by elevated temperature, moisture in oil and most importantly, lipases coming from the source or contaminating microorganisms (Atinafu and Bedemo, 2011). High acid value indicates high free fatty acid, which causes the oil to become rancid (Tamzid *et al*., 2007). Elevated fatty acids in diets should be avoided, as this can impair the ability of liver to store sugar (Jacome-Sosa and Parks, 2014). In a study to investigate the storage stability and sensory attribute of contaminated palm oil in Nigeria, it was discovered that the free fatty acid values of unadulterated palm oil and the adulterated one were 2.28-2.8 and 1.32-1.9%, respectively (Okogeri and Okoro, 2014).

Although, literature is replete with works on the effect of temperature on the chemical characteristics of edible oils, there is need to examine those that are sold in Bodija market, one of the largest markets in Oyo State. To the best of our knowledge, no work has been done on the rate of change of the chemical characteristics of vegetable oils with changing temperature. This work aims to determine the rate of change of various quality parameters of vegetable oils with temperature.

MATERIALS AND METHODS

Olive oil (OO), palm kernel oil (PKO), peanut oil (PO), sunflower oil (SFO) and soybean oil (SO) were purchased at Bodija market in Oyo State, Southwest Nigeria located on latitude 7°25'35"N and longitude 3°54'39"E. The samples were later analyzed in the laboratory. The results are means of three determinations.

The results are reported as mean±standard deviation.

During analysis, the samples were prevented from the effects of moisture, light and oxygen according to (Vaclavik *et al*., 2013), which are the factors that might influence the outcome of the determinations.

Statistical analysis: Statistical analysis was carried out using SAS software. One-way ANOVA was performed to evaluate significance of individual differences between the means of each chemical characteristic, as related to the selected oils, with a probability threshold of 0.05. This was followed by a Post-Hoc Duncan test. However, the effect of temperature variation was evaluated by a non-parametric test.

Determination of parameters: The following parameters were determined to examine the effect of varying temperature on the nutritional values of various vegetable oils. They include; (1) peroxide value as recommended AOCS (1997a), (2) iodine value as recommended by AOCS, (1997b) (3) free fatty acid as recommended by AOCS (1997c) (4) acid value as recommended by AOCS (1997a).

RESULTS AND DISCUSSION

PV: The peroxide values of the selected vegetable oils were presented in Table 1. Amongst the oils analyzed, the ranges of the peroxide values of PO, SO, SFO, OO and PKO are 1.80-2.31, 2.01-3.60, 2.30-3.82, 5.20-6.10 and 6.01-7.02 Meq/kg respectively. Generally, the PVs were observed to increase with temperature. The highest PV was obtained for PKO, while the lowest value was observed in PO at any given temperature. The linear plot of the PVs versus temperature revealed that the rate of change of the PV gives a positive slope. This is demonstrated by the gradient values of 0.001, 0.005, 0.003, 0.003 and 0.005 for PO, SO, OO, PKO and SFO respectively. From the One-way ANOVA of the mean PVs for the different vegetable oils, there was no statistically significant difference between the PVs of SFO and SO. However, there was a significant difference in the PVs of PKO, OO and OO at 95% confidence level (CL). Though the PV of each vegetable oil increased with increase in temperature, there was no significant difference at 95% Confidence level in the values as revealed by Kruskal-Wallis test, which was the non-parametric test that was used to determine the effect of temperature on the measured chemical characteristics. The lack of significant difference in the chemical characteristics of the selected oils with change in temperature may be due to the breakdown of primary oxidation products including hydroperoxide into smaller stable fragments, such as carbonyl compounds, alcohols and hydrocarbons (Bhatti *et al*., 2013).

Despite the increase in the PV at high temperatures, the value did not exceed the maximum level of 10 Meq/kg set by the Codex Alimentarius Commission (CAC, 1993). The increase in PV is, however, not acceptable since this is a reflection of deteriorating oil quality (Fontagne *et al*., 2006). Apart from harmful effect to human health, peroxide value also has effect on the quality of biodiesel derived from vegetable oils. While the PV is not specified in the current biodiesel fuel standards, it has a significant effect on the cetane number (CN), a parameter that is specified in the fuel standard (Bouaid *et al*., 2007). Although increasing PV indicates increasing CN, which may reduce ignition delay (Bouaid *et al*., 2007), it does have impact negative effects, such as non-compatibility with certain plastics and elastomers (Dunn, 2005; Fernandes *et al*., 2012).

IV: As shown in Table 2, there was a decrease in the IV as the temperature increased at a 95% CL. The ranges of iodine values of PO, SO, SFO, OO and PKO are 20.20-19.20, 60.00-58.75, 70.00-66.59, 39.86-36.85, 23.52-21.01 g/100 g of sample respectively. Generally, the IVs were observed to decrease with temperature. The highest IV was observed with SFO and the lowest was found in PO at any given temperature. The linear plot of the IVs versus temperature showed that the rate of change of IV with temperature is negative. This is demonstrated by the gradient values of -0.003, -0.004, -0.013, -0.011 and -0.009 g/100 g of sample/°C for PO, SO, OO, PKO and SFO, respectively. The decrease in the IVs at higher temperatures may be due to the saturation of the double bonds of given oil as the temperature increased (Al-Bachir, 2004). From the One-way ANOVA of the mean IVs for the different vegetable oils, there was no statistically significant difference between the IV values of all the selected oils at 95% confidence level (CL). Though the IV of each vegetable oil decreased with increase in temperature, there was no significant difference at 95% Confidence level in the values as revealed by Kruskal-Wallis test, which was the non-parametric test that was used to determine the effect of temperature on the measured chemical characteristics.

AV and FFA: The suitability of a vegetable oil for any direct consumption or industrial application depends on its acid value (Al-Bachir, 2015). Over the tested temperature range (25-300°C), the minimum (2.80) and maximum (6.01 mg KOH/g) acid values were recorded for SO and OO respectively. These values were in generally higher than those obtained by Al-Bachir (2015), who obtained an acid value of 1.78 mg KOH/g for peanut oil extracted from non-irradiated peanut seeds. According to the author, the acid value of the oil, however, rose to 3.44 mg KOH/g during storage. In connection with the fatty acid values, the acid values were observed to be correlated with the free fatty acid content for all the vegetable oils tested. This suggests that hydrolytic and lipolytic activities became increasingly high as the operating temperature was raised. Increasing acid value is therefore an indication of deteriorating vegetable oil, as demonstrated by the increase in degradation of chemical bonds in the oils at higher temperatures. The one-way ANOVA indicates that there was no statistical significant difference between

Table 1: Trend in PV of the different vegetable oils

	PV (Meq/kg)				
T (°C)	PO	SO	SFO	OO	PKO
25	1.80±0.05	2.01±0.02	2.30±0.02	5.20±0.02	6.01±0.02
50	1.91±0.04	2.39±0.03	2.59±0.04	5.39±0.02	6.19±0.04
100	2.01±0.01	2.81±0.02	2.91±0.04	5.60±0.03	6.40±0.04
150	2.10±0.02	3.18±0.03	3.20±0.02	5.72±0.01	6.61±0.01
200	2.19±0.04	3.40±0.04	3.49±0.03	5.89±0.03	6.79±0.02
250	2.31±0.02	3.59±0.02	3.81±0.03	6.10±0.02	7.01±0.03
300	2.31±0.03	3.60±0.02	3.82±0.03	6.10±0.03	7.02±0.05

T: Temperature

Table 2: Trend in IV of the different vegetable oils

	IV (g/100 g of sample)				
Temperature (°C)	PO	SO	SFO	OO	PKO
25	20.20±0.03	60.00±0.02	70.00±0.02	39.86±0.02	23.52±0.02
50	19.97±0.03	59.75±0.05	69.39±0.02	39.21±0.04	23.01±0.03
100	19.80±0.02	59.51±0.05	68.81±0.01	38.63±0.04	22.52±0.02
150	19.61±0.01	59.24±0.03	68.19±0.02	38.01±0.02	22.05±0.01
200	19.39±0.02	58.99±0.04	67.60±0.02	37.44±0.03	21.53±0.04
250	19.20±0.02	58.75±0.02	66.00±0.01	36.85±0.01	21.00±0.03
300	19.20±0.01	58.75±0.01	66.59±0.04	36.85±0.03	21.01±0.01

Table 3: Trend in AV of the different vegetable oils

	AV (mg KOH/g)				
Temperature (°C)	PO	SO	SFO	OO	PKO
25	5.00±0.02	2.80±0.02	3.00±0.01	6.01±0.01	3.01±0.03
50	5.38±0.01	2.99±0.03	3.19±0.01	6.32±0.01	3.18±0.02
100	5.81±0.04	3.22±0.03	3.41±0.04	6.59±0.03	3.39±0.03
150	6.20±0.04	3.40±0.02	3.60±0.04	6.90±0.02	3.60±0.01
200	6.59±0.03	3.58±0.02	3.79±0.02	7.19±0.02	3.81±0.01
250	7.01±0.02	3.81±0.01	4.02±0.02	7.40±0.04	4.00±0.03
300	7.00±0.02	3.81±0.03	4.02±0.01	7.40±0.03	3.99±0.03

Table 4: Trend in FFA value of the different vegetable oils

	FFA (%)				
Temperature (°C)	PO	SO	SFO	OO	PKO
25	2.49±0.03	1.42±0.05	1.51±0.02	2.61±0.01	1.49±0.03
100	2.90±0.03	1.60±0.03	1.70±0.04	2.81±0.03	1.69±0.04
150	3.01±0.01	1.69±0.02	1.79±0.03	2.90±0.01	1.81±0.02
200	3.29±0.02	1.81±0.02	1.90±0.05	2.99±0.04	1.90±0.01
250	3.50±0.04	1.90±0.02	2.10±0.02	2.10±0.02	1.99±0.03
300	3.50±0.03	1.90±0.01	2.10±0.03	3.05±0.04	1.99±0.01

Table 5: R2 values and slope from linear curves (95% CL)

	R2 value					Slope				
Parameter	PO	SO	OO	PKO	SFO	PO	SO	OO	PKO	SFO
PV	0.965	0.915	0.961	0.970	0.967	0.001	0.005	0.003	0.003	0.005
IV	0.961	0.963	0.928	0.960	0.965	-0.003	-0.004	-0.013	-0.011	-0.009
AV	0.964	0.965	0.967	0.950	0.962	0.007	0.003	0.003	0.005	0.003
FFA	0.967	0.968	0.976	0.942	0.957	0.003	0.001	0.002	0.001	0.001

the acid values of PKO, SO and SFO, while significant difference did occur between the values for PO and SFO at 95% CL. The Kruskal-Wallis non-parametric test suggests that the acid value for given oil did not differ significant with change in temperature at 95% CL (Table 3), though there was an increase in value as the temperature was raised. The AV for PO was observed to increase from 5.00 at 25°C to 7.01 mg KOH/g at 250°C. However, a slight decrease of 0.01 mg KOH/g was observed as the temperature rose to 300°C. In a similar way, the minimum AV of 2.80 mg KOH/g was obtained for SO at 25°C but the value increased to 3.81 mg KOH/g at 250 and 300°C. Generally, the same trend was observed for the other oils. Despite the increase in AV value at higher temperatures, the values obtained in this work lie within the codex of 0.6 and 10 mg KOH/g for virgin and non-virgin edible oils respectively (CAC, 1999). From the linear curve, the rate of change of acid value was positive, as revealed by the gradient values of 0.007, 0.003, 0.003, 0.005 and 0.003 mg KOH/g/°Cfor PO, SO, OO, PKO and SFO respectively (Table 5). Furthermore, the FFA was found to increase with temperature. The values for PO ranged from 2.49 at 25°C to 3.5% at 250 and 300°C. For SO, FFA of 1.42 and 1.90% were recorded at 25 and 300°C, respectively. Generally, the same trend was observed for the other oils.

However, there was a decrease in the FFA (2.99%) at 200°C to 2.10% at 250°C during the investigation involving OO. The reason for this reversal was not understood. As already stated, the FFA value increases in proportion to the AV. According to Atsu Barku *et al.* (2012), high AV normally results from high FFA content in oils and is usually indicative of spoilage. Elevated FFA can trigger various adverse health effects (Jacome-Sosa and Parks, 2014). The FFA values are given in Table 4. High levels of FFA also have negative effects on alkaline-catalysed trans-esterification of vegetable oils, which is one of the most effective methods for the production of bio-diesel from vegetable oils (Leung *et al.*, 2010). In a review conducted in Vyas *et al.* (2010) concluded that alkali-catalysed trans-esterification can be inhibited by a level of FFA greater than 3%, due to the consumption of alkali catalyst by FFAs. The results of our study were in agreement with Chen *et al.* (2011), who observed a spike in in FFA from a negligible level to 70.3% with increasing storage temperatures.

Conclusions: The results of this study revealed that the PVs, AVs and FFAs increased as the temperature increased, while the IVs decreased as the temperature increased. Generally, the chemical characteristics remained below the maximum desirable limits set by Codex.

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