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Full Length Research Paper

Development and evaluation of a multi-heat source deep fat fryer

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Abstract

Deep fat frying constitutes a reasonable percentage in cottage food preparation across the globe. The need to upgrade the local deep fat frying process to be more user friendly, efficient and versatile is the basis of the development of an appropriate portable, low-cost and affordable multi-heat source deep fryer. The machine was evaluated using wheat flour dough to produce *chin-chin*, a local fried wheat product. Performance of groundnut, corn and soya oils under different heat sources; gas, electricity and charcoal energy were considered. The average capacity of the machine was found to be 7.69 kg/h when using electric energy, 8.52 kg/h when using gas energy and 6.00 kg/h when using charcoal energy. Heat requirement of the machine was 1428 W. The fat uptake of the *chin-chin* fried with groundnut oil was 0.51, 0.49 and 0.67 g for gas, electric and charcoal energy respectively; for soya oil 0.47, 0.43 and 0.63 g respectively; and for corn oil 0.46, 0.41 and 0.57 g respectively. Vitamin A retention in soya, groundnut and corn oil was 13515, 18485 and 34242 IU/kg respectively when using gas energy; 14727, 22243 and 38182 IU/kg respectively when using charcoal energy; 20606, 27273 and 41030 IU/kg respectively when using electric energy. Thus, corn oil gave the least fat uptake when using electric energy; it also gave the highest vitamin A retention, given the mandatory vitamin A level of 30000 IU/kg in flour and 20000 IU/kg in vegetable oils under the National Food Fortification Programme in Nigeria.

Keywords: design, frying, experiment, fat uptake, vitamin A, *chin-chin*

INTRODUCTION

The Latin and Greek words for ‘frying’ originate from word ‘roasting’, suggesting that frying may have developed from roasting (Dogan *et al*., 2005). The simplest deep-fat frying process is conducted in a kettle of oil heated on a stove or over an open fire in which small batches of food are immersed in hot oil and removed when fried as determined by the experience of the cook. The first real technological advance in frying was the introduction of continuous cooking which involves the immersion of food in hot oil or fat for a given period of time, draining, cooling, and further processing or consumption (Garayo and Moreira, 2002). As the food fries, the internal cells become dehydrated and the evaporated water is partially replaced by frying oil. Frying is extremely popular kitchen appliances and is used in about 85% of food service establishments. It is designed to cook chicken, fish, breaded vegetables, specialized pastries, French-fried potatoes and other foods.

The cooking medium during frying is hot oil, also known as shortening, frying compound or fat. The quality of the final food product largely depends on the quality of the oil. Pintus *et al.,* (1995) indicated that as the product fries, the inner moisture is converted to steam, creating a pressure gradient. The surface dries out causing the oil to adhere to the product surface and enter the surface of the damaged area. A wide spectrum of factors has been reported to affect oil absorption in fried food. This includes oil quality and composition, frying temperature and time, product composition, moisture content, shape, porosity, pre-frying treatment, surface treatment, initial interface tension, and crust size (Ballard and Mallikarjunan, 2006).

Frying fat influences many qualities of the finished product such as flavour, texture, shelf life and nutritional attributes. The oils that are exposed to a high temperature when left in open air are subject to thermolytic and oxidative reactions (Teye *et al*., 2006). These result in their partial conversion to volatile chain-scission products, non-volatile oxidative derivatives and dimeric, polymeric or cyclic substances. The quality of fried foods must depend not only on the type of food and frying condition, but also on the oil used for frying. Thus, the selection of stable frying oils of good quality is of great importance to maintain a low deterioration during frying and consequently a high quality of fried foods (Mellema, 2003). When the oil is heated, it enables heat transfer due to conduction and convection, the latter being caused by free water boiling at the surface upon immersion of the moist food in hot oil. The moisture vaporizes out, and creates a path known as capillary pore, through which hot oil enters the food. The reaction occurs by the influence of oil uptake, crust formation, shrinkage and swelling, thus inducing macro- and micro-structural changes (Garayo and Moreira, 2002). This influences the vapour and liquid diffusion, safety assurance, and yield final products with the taste and textural characteristics expected by the consumer. Thus, most foods with capillary porous matrices are found hygroscopic (Yamsaengsung and Moreira, 2002).

Deep-fat frying is typically conducted in a temperature range of 120 to 180°C (Shyu *et al*., 2005). Deep-fat frying is a complex process that involves simultaneous heat and mass transfer. The process induces a variety of physicochemical changes in both the food and the frying medium. The principles underlying the mechanisms of water evaporation and oil absorption are intimately related (Hussain *et al.,* 2002). Investigation reveals that several prototype deep fat fryers have been developed. These include: open fryers which may either be single heat source or double heat sources; as well as pressure fryers designed to keep vapour inside the fryer while cooling. The frying vessel captures steam from cooked food, increasing the pressure inside the unit until no more moisture is released from the food. The pressure ranges from 34473.80–82737.12 N/m^2 (Innawong *et al.,* 2006). This research is therefore aimed at designing and evaluating the performance of a multi-heat source deep fat fryer using charcoal, gas and the electricity as sources of energy in different frying oils, namely groundnut, soya and corn oil. Heat transfer mechanism and the effect of this on nutritional value of the product were also investigated.

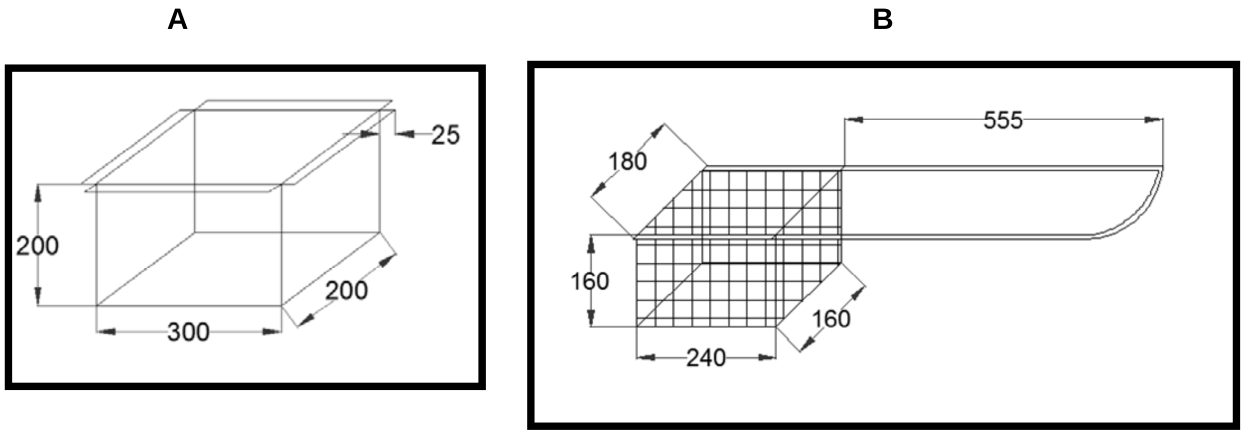
MATERIALS AND METHODS

Description of the multi-heat source deep fat fryer

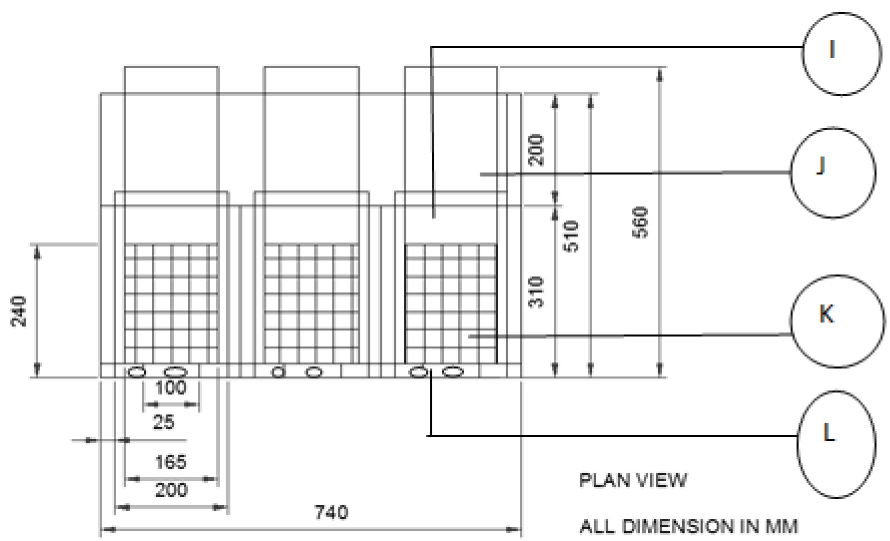
The multi-heat source deep fat fryer was designed to have multiple energy sources; charcoal, gas and the electricity. The components include the stainless steel basket, the stainless steel pot, and the exterior components such as fan switch, thermostat, electric hot plate, fan, gas burner, gas control, gas pipe, hinges, basket lifter, and charcoal compartment. The design, fabrication and performance evaluation of the machine was done with necessary modification in the Department of Food Science and Technology, Bells University of Technology, Ota, Nigeria in collaboration with an Industrial Engineering outfit, Addis Engineering Ltd at Abimbola Street along Isolo road, Lagos. The frame was divided into three rectangular but equal sections. This facilitates a standing support to the pot that was constructed and the hinges fabricated to the frame in connection with the frying pot for easy swing movement. The fry-pot was constructed to be rectangular, made of a stainless steel and constructed to sit on the frame. It was also constructed to be easily removable for easy accessibility to cleaning. The fry basket was also constructed to be rectangular, made of stainless steel and constructed to be smaller than the fry-pot for free movement when hinged. This also allows for free movement of heat by convection. The gas burner was welded to the frame constructed to support the electric radiation plate; the electric plate has a power of 1500 watt with a sensor wired into it to detect changes in temperature. Thus, when the heat gets to the set temperature, it cuts off automatically and then when below the set temperature, the temperature rises again and vice versa. The charcoal compartment was constructed on the basis of 2 kg of charcoal required for heating the fryer.

Machine drawings

These include major components of the machine such as stainless steel frying pot and stainless steel frying basket as shown in Figure 1, plain view of the machine as shown in Figure 2, front view of the machine as shown in



A- Stainless steel frying pot, and B- Stainless steel frying basket
Figure 1. Major components of the machine.



I- Stainless steel pot, J- Basket lifter, K- Stainless steel basket, and L- Hinges
Figure 2. Plain view of the machine.

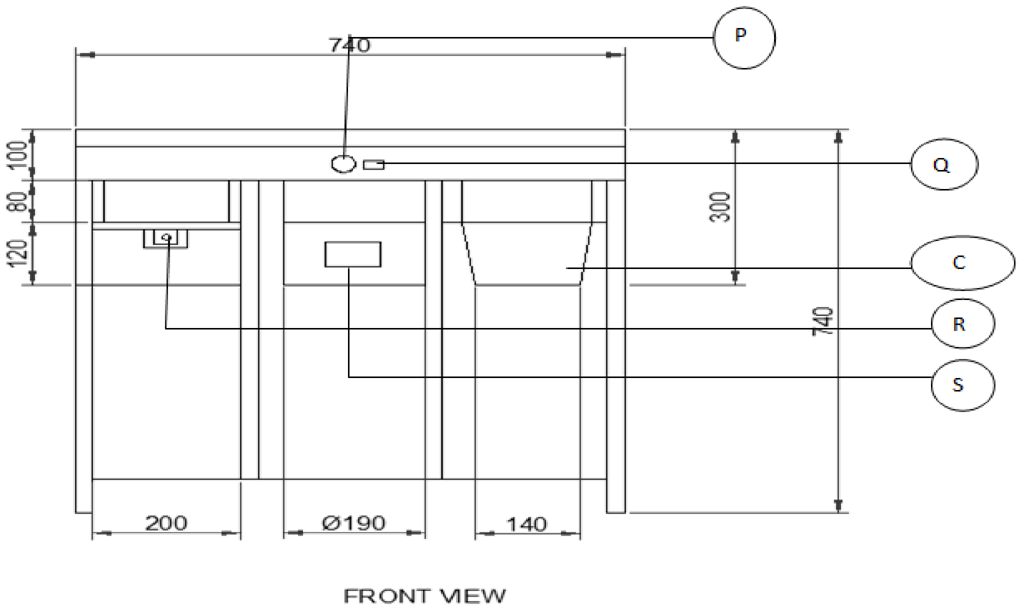
Figure 3 and pictorial representation of the multi-heat source deep fat fryer (MSDFF) as shown in Figure 4.

Design considerations

The machine was developed with the following considerations:
i. locally available materials at low cost was used in the fabrication of the machine. Overall cost of the machine is N50,000 only.
ii. stainless steel was used for all contact surfaces to enable easy cleaning and to prevent corrosion and contamination.
iii. the machine allows easy assembling, dismantling, adjustiments and operation.
iv. the power requirement was designed to be minimal and efficient for processing of any type of food material using good quality oil. The power requirement is 1.43 Kw.
vi. The machine was designed to handle various deep fat fried products such as *chin-chin,* plantain chips, bean flour, yam chips and wheat flour balls.
vii. the positioning of machine component parts is to enhance safety of the operator.

Design calculations

Selected materials in the development of the machine include:
i. Frying basket: stainless steel mesh (1.5 mm thickness) (240 mm x 160 x 160 mm)



P- Thermostat, Q- Fan switch, C- Chacoal compartment, R- Gas control, and S- Electric hot plate
Figure 3. Front view of the machine.

Figure 4. pictorial representation of the multi-heat source deep fat fryer (MSDFF).

ii. Frying pot: stainless steel material (2 mm thickness) (300 mm x 200 mm x 200 mm)
iii. Frame: 745 mm x 500 mm x 710 mm,
Frame sections for three compartments: 500 mm x 260 mm each
Bended hinges: 100 mm x 35 mm x 10 mm
Hot plate: 1500 watts
Gas burner: ϕ75 mm by 150 mm by 50 mm
Fan: 75 mm by 75 mm

iv. Determination of Heat Transfer rate: When a temperature gradient exists in a body during frying, experience has shown that there is an energy transfer from the high-temperature region to a low-temperature region. The energy transferred across the frying pot is by conduction and that the heat-transfer rate per unit area is proportional to the normal temperature gradient (Jimoh, 2014):

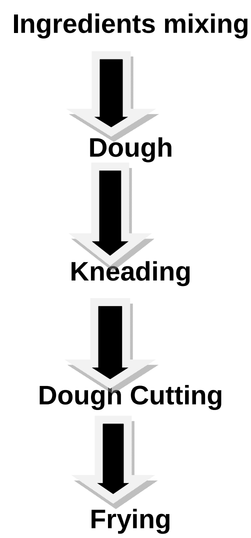


Figure 5- Flow chart for the production of *chin-chin.*
Source: (Greg and others 2008)

$$\frac{q}{A} = \frac{\partial T}{\partial x} \quad (1)$$

When proportionality constant is introduced,

$$q = -KA\frac{\partial T}{\partial x} \quad (2)$$

Where q is heat transferred by conduction, K is thermal conductivity of the stainless steel pot and minus sign indicated shows that it obeys second law of thermodynamics, A is cross sectional area of 2 mm thickness steel through which heat flow to the oil, $\partial T/\partial x$ is temperature gradient in the direction of heat flow.
Thus, heat conducted through the pot is transmitted to the oil by convection within the hot oil and conducted to the interior of the food. Part of it also escapes to the atmosphere by radiation since the process is in an open system. The relationship between the three medium of heat transfer is expressed in equation 2 and 4.

$$Q_{cond} = (Q_{conv} + Q_{cond}) + Q_{rad} \quad (3)$$

$$-KA\frac{\partial T}{\partial x} = \left[hA(t_s - t_f) + (-K_F A\frac{\partial T}{\partial x})\right] + Q_{rad} \quad (4)$$

Given that convective heat transfer coefficient, h of fat at 160°C is 580 W/m^2 °C (Seruga and Budzaki, 2005), thermal conductivity of fat, K_F is 27 W/m °C, thermal conductivity of carbon steel, K is 45 W/m °C, (Holman, 1999). The fat is assumed to be at average room temperature, t_f of 32 °C before heating. During experimentation, surface temperature of the pot, t_s is taken to be 160 °C and the pot is assumed to be maintained at a level two-third filled with fat. Applying the above conditions, the rate of heat transfer by conduction, convection and radiation during frying are found to be as given below.

1428 = 1392 + Q_{rad}

Q_{rad} = 36 W

Concept of moisture migration and fat uptake

Moisture content plays a significant role in pore formation (Hussain *et al.,* 2002). Fat absorption is dependent on the initial moisture content of the food product being fried. Foods are hygroscopic materials and carry significant quantities of bound water in their porous matrix. As a result, as water diffuses from the matrix during frying, pathways usually referred to as 'capillary pores' are created. The formation of capillary pores enhances oil absorption. Thermal processing of food causes physicochemical reactions that affect food structure. As food fries, the food moisture is converted to steam and releases under pressure. The type of process and the intensity of heating, coupled with the initial moisture content of the food product influence the final pore structure (Hussain *et al.,* 2002). Many researchers have reported that the relationship between moisture loss and fat absorption is proportional and linear (Kassama and Ngadi, 2001); (Krokida *et al.,* 2000).

The diffusion rate of the moisture into the fat and that of the fat through the capillary pores depend on temperature gradient across the heating medium. Since the two are proportional to one another, the basic equation giving the mass flux is expressed as (Ibarz and Barbosa-Canovas, 2003):

A B

Figure 6.A (gradual changes during frying operation, B (*chin-chin* production ready for packaging).

$$-\left(\frac{D_F}{L}\right)(C-C_i)=-\left(\frac{D_M}{L}\right)(C-C_i) \qquad 5$$

Where D_F and D_M are diffusivity of fat and moisture respectively, L is the thickness of the respective liquid film through which diffusion takes place, and C_i and C are the concentrations at the interface and within the liquid respectively.

The mass flux through the liquid mass becomes:

$$K_F(C_i-C)=K_M(C_i-C) \qquad 6$$

Hence the diffusivity of fat *(D_F)* and diffusivity of moisture *(D_M)* are related as follows:

$$K_F=\frac{D_F}{L}, K_M=\frac{D_M}{L} \qquad 7$$

Where K_F is the thermal conductivity of fat and K_M is the thermal conductivity of moisture. Hence D_F has been determined under various heat sources in this study as the fat uptake.

Performance evaluation of the machine

The performance of the multi-heat source deep fryer was tested using wheat flour which was made into dough fried with different oils to produce *chin-chin*, namely Groundnut, Soya and Corn oils. Each of these oils was tested with different heat energy sources in the multi-source fryer i.e. Charcoal, Gas and Electricity.

Procedure

Materials used for the production of *chin-chin* are flour, sugar, eggs, baking powder, salt and margarine. 2 kg of wheat flour was weighed into a container, four pieces of egg, 200 g of flour, four tea spoon of baking powder, one table spoon of salt, 200 g of margarine and 150 ml of water. Figure 5 shows flow chart for the production of *chin-chin*.

Experimentation

Determination of fat uptake in the chin-chin

Material used for this experimentation includes Petroleum ether, 2 g of *chin-chin* sample, soxhlet extractor, running tap. The cups were dried in the oven at a temperature of 105 ^oC for one hour, it was cooled inside the desiccators and weighed. 2 g of the grounded samples was wrapped using tissue paper, each of the samples was then put inside a thimble. The soxhlet extractor was switch on and allowed to reach the set temperature (135 ^oC) (Greg *et al.,* 2008). The thimble was placed in a soxhlet extraction chamber and 80 ml of petroleum ether was measured in the weighed cup. The cups containing the petroleum either were put in the soxhlet extractor using the cup rack. The running tap was opened to allow for easy extraction. The soxhlet extractor was then set to boil for about 30 minutes and the solvent evaporated for another 30 minutes and moves up into the condenser stage for about 10 minutes where it was converted into liquid that trickles into the extraction chamber containing the

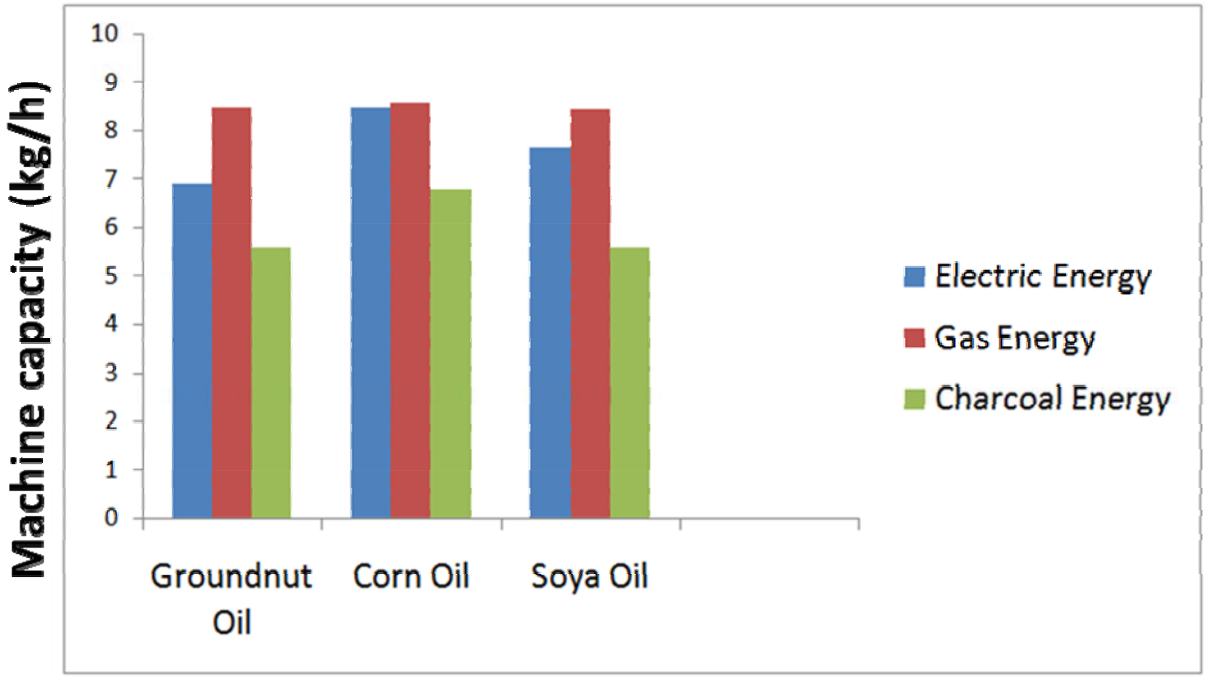


Figure 7. Machine capacity (kg/h) using different oils and different heat sources.

sample. At the end of the extraction process, it finally goes into the rinsing stage for about 5 minutes and the cup containing the lipid was removed (Greg *et al.,* 2008). The cups were dried in the oven for about 10 minutes at a temperature of 60 ^{o}C. The cups were weighed and the readings were recorded.

Determination of vitamin A in the production of *chin-chin*

The *chin-chin* fried from different oil sources and from different heat sources was grounded separately in to small pieces using mortar and pestle. 5 g of each grounded sample was dissolved in 50 ml of distilled water and then left for one hour. 0.5 ml of each of the dissolved solution containing the samples was injected into the Val using needle and syringe. They were left for five minutes to settle and were put inside the I-check, Bio Analyt, quantitative equipment for vitamin A determination. The readings were taken appropriately.

RESULTS AND DISCUSSION

Deep-fat frying is a complex process that involves simultaneous heat and mass transfer. The process induces a variety of physicochemical changes in both the dough and the frying medium. The mechanisms of water evaporation and oil absorption are intimately related. When the dough is immersed in hot oil, the initial fat absorption takes place through surface wetting, depending on the surface structure and by capillary action. As the product heats up, moisture is converted to steam, migrates to the surface and eventually into the frying medium due to a pressure differential. The vapour being release from the dough surface impedes fat intrusion into the product during surface boiling. Thus, the colour of the dough gradually changes to brown as shown in Figure 6A. Heat conducted by the frying pot during production of *chin-chin* as shown in Figure 6B is transferred by combination of convection within the hot oil, conduction to the interior of the food and radiation heat losses.

The capacity of the machine as shown in Figure 7 using Groundnut, Corn and Soya oils (GCS) was found to be 6.90, 8.50 and 7.68 kg/h respectively for electric energy source; 8.50, 8.60 and 8.46 kg/h respectively for gas energy source; and 5.60, 6.80 and 5.60 kg/h respectively for charcoal energy source. From the experimental results, conductive heat transfer or heat requirement of the machine was found to be 1428 W, with heat required for effective frying as 1392 W and heat losses by radiation as 36 W.

The fat uptake of the *chin-chin* fried with GCS using electric, gas and charcoal energy sources shows appreciable result. The fat uptake of the *chin-chin* fried with GCS oils using electricity as heat source was found to be 0.49, 0.41 and 0.43 respectively as shown in Table 1. Thus the *chin-chin* fried with corn oil gave the least fat uptake followed by the soya oil when using electricity. The fat uptake of the *chin-chin* fried with GCS oils using gas as heat source was 0.51, 0.46, and 0.47 respectively as shown in Table 2. Thus the *chin-chin* fried with corn oil

Table 1. Fat uptake of *chin-chin* after frying using electricity.

Oil	Groundnut	Corn	Soya
weight of cup (g)	44.95	44.95	43.56
weight of samples (g)	2	2	2
weight after extraction (g)	45.44	45.36	43.99
weight of oil (g)	0.49	0.41	0.43

Table 2. Fat uptake of *chin-chin* after frying using gas.

Oil	Groundnut	Corn	Soya
weight of cup (g)	44.43	44.71	44.83
weight of samples (g)	2	2	2
weight after extraction (g)	44.94	45.17	45.30
weight of oil (g)	0.51	0.46	0.47

Table 3. Fat uptake of *chin-chin* after frying using charcoal

Oil	Groundnut	Corn	Soya
weight of cup (g)	44.82	44.96	44.83
weight of samples (g)	2	2	2
weight after extraction (g)	45.49	45.53	45.46
weight of oil (g)	0.67	0.57	0.63

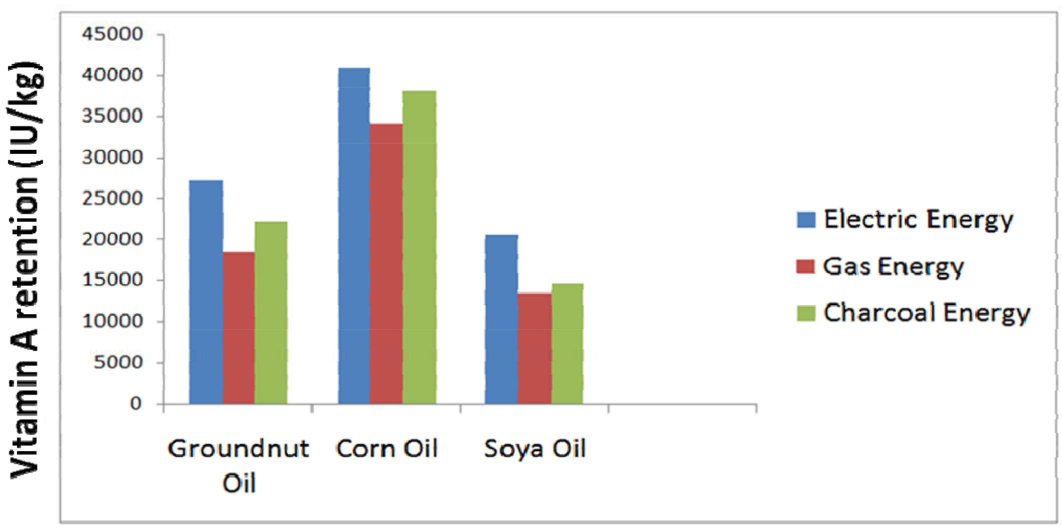


Figure 8. Vitamin A retention in *chin-chin* during frying using different heat sources.

gave the least fat uptake followed by the soya oil when using gas. The fat uptake of the *chin-chin* fried with GCS oils using charcoal as heat source was 0.67, 0.57 and 0.63 respectively as shown in Table 3. Thus the *chin-chin* fried with corn oil gave the least fat uptake followed by the soya oil when using charcoal. The fat uptake of the *chi-chi* fried with groundnut oil was found to be on the high side in all the heat sources which may likely be due to the presence of unsaturated double bonds.

Figure 8 illustrates the relationship between the effects of degradation of vitamin A in *chin-chin* production using different heat sources. This is used to estimate which heat source and under what oil gives a low retention of Vitamin A. The trend of degradation of vitamin A level shows that gas and charcoal energy sources degrades vitamin A level faster with vitamin A retention 13515 IU/kg and 14727 IU/kg respectively using soya oil as frying medium. When using groundnut oil as frying medium, gas and charcoal also degrades vitamin A faster with vitamin A retention 18485 IU/kg and 22242 IU/kg respectively. When using corn oil as frying medium, gas and charcoal equally degrades vitamin A faster with vitamin A retention 34242 IU/kg and 38182 IU/kg respectively. Gas and charcoal degrades vitamin A faster with low retention in all frying medium. This is likely to be as a result of incomplete combustion in both the gas and charcoal. The gas produced yellow flame instead of the blue flame because the space constructed for the oxygen inflow was too wide. The charcoal produced smoke when lighted up. These contain carbon monoxide which is poisonous to the health. However, vitamin A degradation using electric energy is slow with high vitamin A retention 20606 IU/kg, 27273 IU/kg and 41030 IU/kg in soya, groundnut and corn oil respectively.

CONCLUSION

In the production of *chin-chin*, conductive heat transfer is equal to the combination of convective heat transfer within the hot oil, conductive heat transfer to the interior of the food and heat losses as a result of radiation. *Chin-chin* fried with corn oil gave the least fat uptake followed by soya oil. However, these are recommendable in accordance to the conviction that high fat intake in human system causes cardiovascular diseases (Hoffman *et al.,* 2006). Electric energy has high vitamin A retention in all frying medium and the machine capacity ranges from 5.60 – 8.60 kgh^{-1} depending on heat source.

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