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Review Paper

Deep Fat Frying of Fruits, Vegetables and Tuber Crops: A Review

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ABSTRACT

The most significant traditional method used in food preparation and preservation through dehydration is frying. In this case, the water content is very important for extending the food's shelf-life. Food shelf life can be increased by decreasing the amount of water in the food. The objective of this review paper is to provide readers with information about the whole frying process, heat and mass transfer during frying, and what changes occur in food components, i.e., moisture content, texture, fat content, protein content, carbohydrates, vitamins, minerals, and color after frying. Also, the types of frying, various kinds of oils used, and various products made from fruits, vegetables, and tuber crops that are preserved for a long time by frying. The shelf-life of the product increases, and it can be easily available in off-season. A classic culinary technique is deep-fat frying, which involves cooking food in an oil or fat bath until it becomes crispy and golden brown. The amount of oil used in 1000 cm^3 of frying. Deep fat frying coats the surface of the food by retaining the taste and fluids through the formation of a crust and crisp that makes chewing and digesting easier while the food is submerged in an oil bath. There is a 120°C to 200°C temperature range for frying.

Keywords: Food preparation, preservation, crops, shelf-life, deep-fat frying, fat bath, vegetables

In our daily consumption of food, according to the FDA, vegetables and fruits should be eaten at least five times per day, but the fruits and vegetables's shelf life is very short. So, to improve it's shelf life and for long-term fulfillment of fruits, vegetables, vegetable's, and some tubers required to store (Setyawan *et al.* 2013), It could be done by frying or making chips. (Pandey *et al.* 2020) According to NHB, the total production of fruits in India is 99069 thousand metric tons, and 191769 thousand metric tons of vegetables. For complete utilization of these productions and to maintain the availability of products throughout the year, it is necessary to develop value-added products from fruits, vegetables, and tubers (Pandey *et al.* 2020). There are various preservation techniques for fruits, vegetables, and tubers, like pickling, drying, canning, freezing, jellying, vacuum packaging, and water bathing (Dwivedi *et al.* 2017).

Frying is the most important age-old practice carried out in food processing and preservation through dehydration. Here, the water content plays a crucial role in improving the shelf life of the food. By reducing the water content in food, the shelf life of food is extended.

The most important cooking method is frying, which is also the most economical way to preserve

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food and create both conventional and novel items like high-quality processed snacks (Mujumdar and Devahastin, 2008).

PROCESS AND MECHANISM OF FRYING

Frying is a multifaceted process that involves simultaneous heat, mass transfer, and other chemical reactions. (Gupta, 2005) This procedure involves the transfer of heat, oil, and moisture in the form of vapor inside the food and heating medium. (Ok *et al.* 2018). The thing or product that is being fried in this procedure receives heat from heated oil. Heat causes the food products' interior moisture to evaporate as water vapor. The product exterior allows the water vapor to exist. This explains the bubbles that form around the frying food. When the food is placed in heated oil, it begins vigorously and ends when the moisture content reaches a certain point. The food product becomes dehydrated due to the loss of moisture in the controlled atmospheric conditions. (Gupta, 2005). Fig. 1 shows the Process of Frying process (a) Frying Pan; (b) Frying process.

1. Frying types

There are four types of frying. (1) Pan frying (2) Saute/stir-fry (3) shallow-frying (4) deep-frying. Panfrying is nothing but cooking on a flat surface, in a frying pan, or on a lightly oiled, hot griddle that has been preheated with a tiny amount of oil or fat. Saute or stir frying is nothing but frying in a pan or

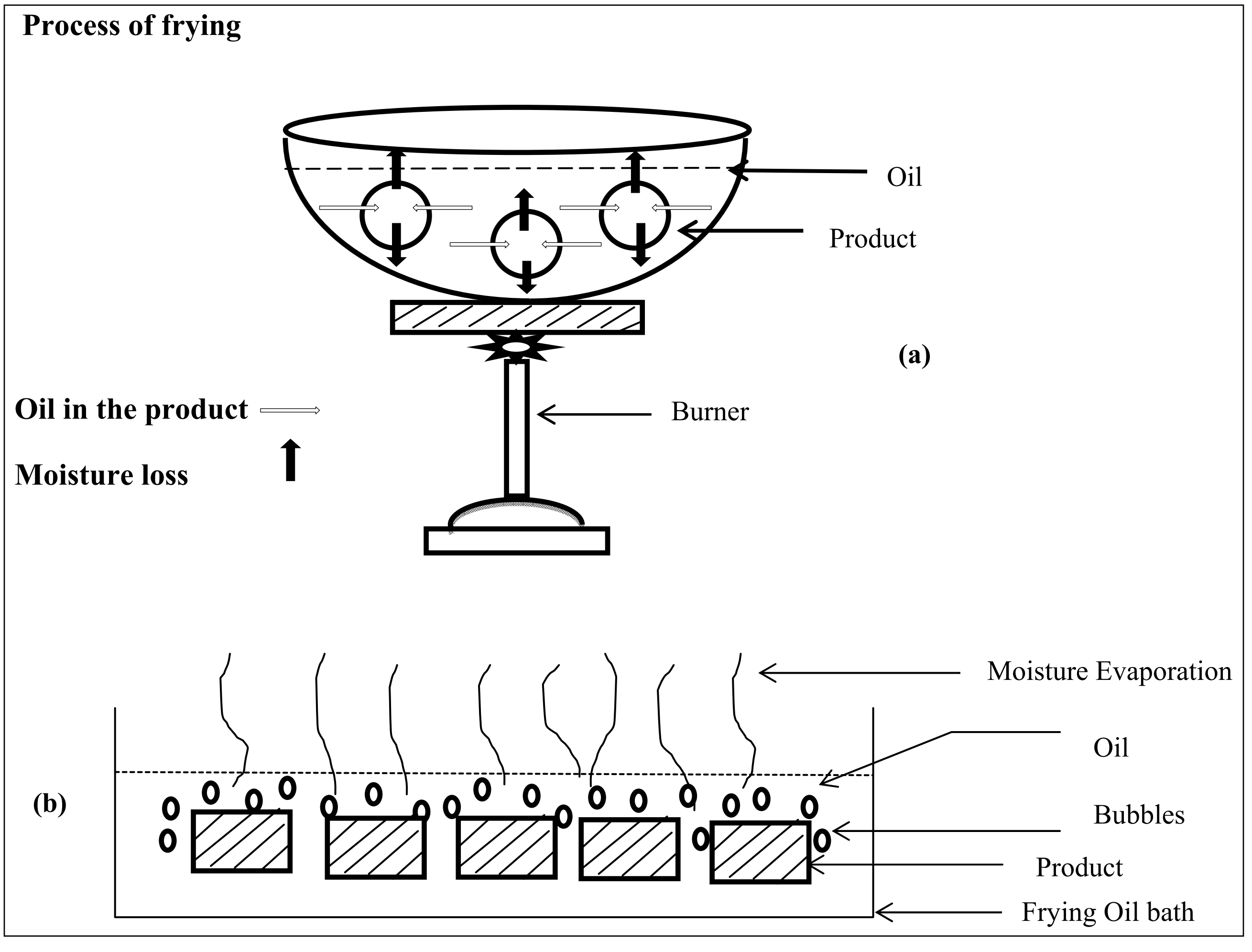

Fig. 1: Process of Frying process **(a)** Frying Pan; **(b)** Frying process

fast frying, an example of cooking in a small amount of heated fat or oil. Shallow frying is also involved; frying in a small pan causes the product to brown. Deep-fat frying is a traditional method of cooking food in a deep-fat or oil bath until it gets crispy and golden brown. The volume of oil required to carry out each frying is 15 cm^3, 15 cm^3, 500 cm^3, and 1000 cm^3, respectively (Devi *et al.* 2021). Traditional atmospheric frying and vacuum frying are two types of deep-fat frying methods (Alvis *et al.* 2008; Garayo and Moreira, 2002).

Protein, carbs, and minerals were almost entirely preserved when potatoes, vegetables, and breaded chicken, fish, and poultry were fried; in contrast, boiling and steaming decreased the protein content by 5–10% and the mineral content by 25–50%. Fish, poultry, and beef that have been deep-fried with breading often absorb less fat than those that have been shallow-fried. Deep-frying and shallow-frying, as opposed to boiling, steaming, and stewing, often maintained more of the vitamins B_1,B_2,B_6, and C (Bognar, 1998).

1.1 Frying mechanism in deep fat frying

One of the earliest cooking techniques is deep-fat frying, which most likely originated in the Mediterranean (Varela and Ruiz-Rosso, 1998). By integrating convection in the heating medium, i.e., oil, with conduction inside the product, deep fat frying is a simultaneous heat and mass transfer method that results in a variety of physical, chemical, and organoleptic changes (Devi *et al.* 2021; Alvis *et al.* 2009). While submerging the food in an oil bath, deep fat frying seals the surface of the meal by keeping flavor and juices through the creation of a crust that facilitates chewing and digestion (Oke *et al.* 2018). The frying temperature ranges from 120 °C to 200 °C. Where the oil usually reaches up to 175 °C (Oke *et al.* 2018; Bordin *et al.* 2013; Pedrosi and Zuniga, 2009; Orthoefer and List, 2007; Bouchon, P., 2009). Either bathing or continuous frying can be done. Usually, smaller batch fryers are mainly utilized in catering services. Continuous fryer, which is employed by big businesses (Bordin *et al.* 2013; Bouchon, P. 2009).

1.2 Heat Transfer

Food is composed of pore spaces or vacant spaces between the cells that are filled with water and juices. Whenever frying in a deep-fat fryer, the product needs to have a fine oil coating and be fully submerged in oil, at least 2 cm thick (Granda and Moreira, 2005).

Heat transfer involves the energy transferred from one location to another. Here, both the convection and conduction heat transfer phenomena occur. Heat transfer occurs between food and frying oil, with convective heat transfer from the frying medium to the product's surface and conduction heat transferred within the food (Bouchon, 2009; Asokapandian *et al.* 2020). Fig. 2 shows the simultaneous heat and mass transfer in frying of foods.

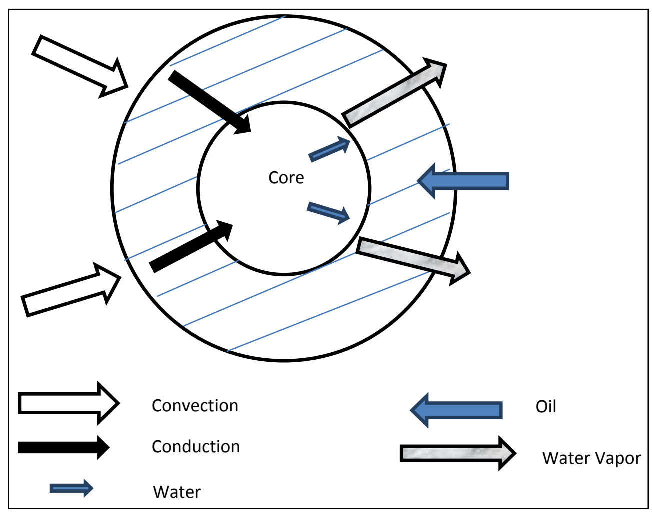

Fig. 2: Simultaneous heat and mass transfer in frying of foods (Bouchon, 2009)

The impact of frying oil and water on heat transfer is noteworthy since oil transfers heat more effectively in the direction of the food, while water transfers heat more effectively within the food (Orthoefer and List, 2007). When a product is placed in hot oil, water escapes from the product quickly during the first few minutes of frying and reaches the surface. This water condenses as bubbles in oil, which affects the heat transfer coefficient and creates turbulence. After first heating, water starts to evaporate at the product's surface and rises to the interstitial liquid's boiling point, which is somewhat higher than the boiling point of water. Once the water is lost, it leaves quickly, causing forced convection because of the turbulence that results from nucleate boiling (Bouchon, P., 2009; Asokapandian *et al.* 2020; Orthoefer and List, 2007).

Bubbling increases the oil-to-air contact area; as a result, the rate at which heat is transferred from the oil to the air rises, hastening the oil's oxidative deterioration. As the oil cools, the bubbling becomes a little lower, and moisture that evaporates vapor creates a protective layer above the oil surface, limiting headspace air flow and providing shielding from oxidation by limiting air contact (Dana *et al.* 2003; Costa *et al.* 1999).

Generally frying procedure is divided into four stages by Farkas *et al.* 1996.

1. Initial heating
2. Surface heating
3. Falling Rate
4. Bubble end point

Stage first

Food immersed in oil is heated throughout the frying process to the boiling point of water by natural convection, preventing water from evaporating from the food's surface. In the final moment of frying, right before moisture evaporation starts, the product temperature reaches the boiling point. This quick step ensures a uniform cooking procedure because there is less water lost. Fig. 3 (a) shows the first stage of frying process.

Stage second

Due to turbulence in the oil, water on the food surface evaporates, changing the process of heat transfer from natural to forced convection. This raises the surface heat transfer coefficient of the snack by causing a crust to grow on its surface. Slight crust formation starts. Fig. 3(b) shows the surface heating of the product in an oil bath

Stage third

Food undergoes physicochemical changes such as gelation and protein denaturation when its internal temperature rises as a result of increased internal humidity. The food's center transfers moisture to the outer layer during this phase, which is the longest phase. This causes internal cooking starch gelatinization, denaturation of proteins, and thickening of the crust. Fig. 3(c) shows the Internal heating of the product in oil bath.

When it comes to finished fried commercial French fries, Aguilera and Gloria (1997) identified three distinct microstructures. The evaporation front is reached via an intermediate layer of shrunken, intact cells. The thin outer layer is composed of fragments of cells' cell walls. The core is made up of fully hydrated, undamaged cells that have gelatinized starch inside,.

Stage Four

The last phase of frying produces no more water vapor bubbles on the outside of the food due to a drop in moisture removal rates. The stability of the pectic compounds in cell walls and middle lamellae, as well as starch swelling and gelatinization, are frequently correlated with firmness. Fig. 3(d) shows the fried product with a crust formed.

According to Pedreschi and Aguilera (2002), at a 20x magnification, there was no evidence of cell wall breaking despite the intense forces the cell walls were subjected to during frying. It has been suggested that the walls of the cells in the crust shrink and become wrinkled and twisted around dried-gelled starch without breaking.

Heat transfer plays an important role in frying. The development of a product's sensory qualities is greatly influenced by the heat transfer coefficient during the boiling phase, which also causes browning and caramelization reactions that distribute essential flavor, color, and texture characteristics (Alvis *et al.* 2009). The sample-to-oil heat energy balance was used to evaluate the heat transfer coefficient. This equation, which represents the total heat transmitted by convection from oil to product, is equal to the product's heating energy in addition to water evaporation energy.

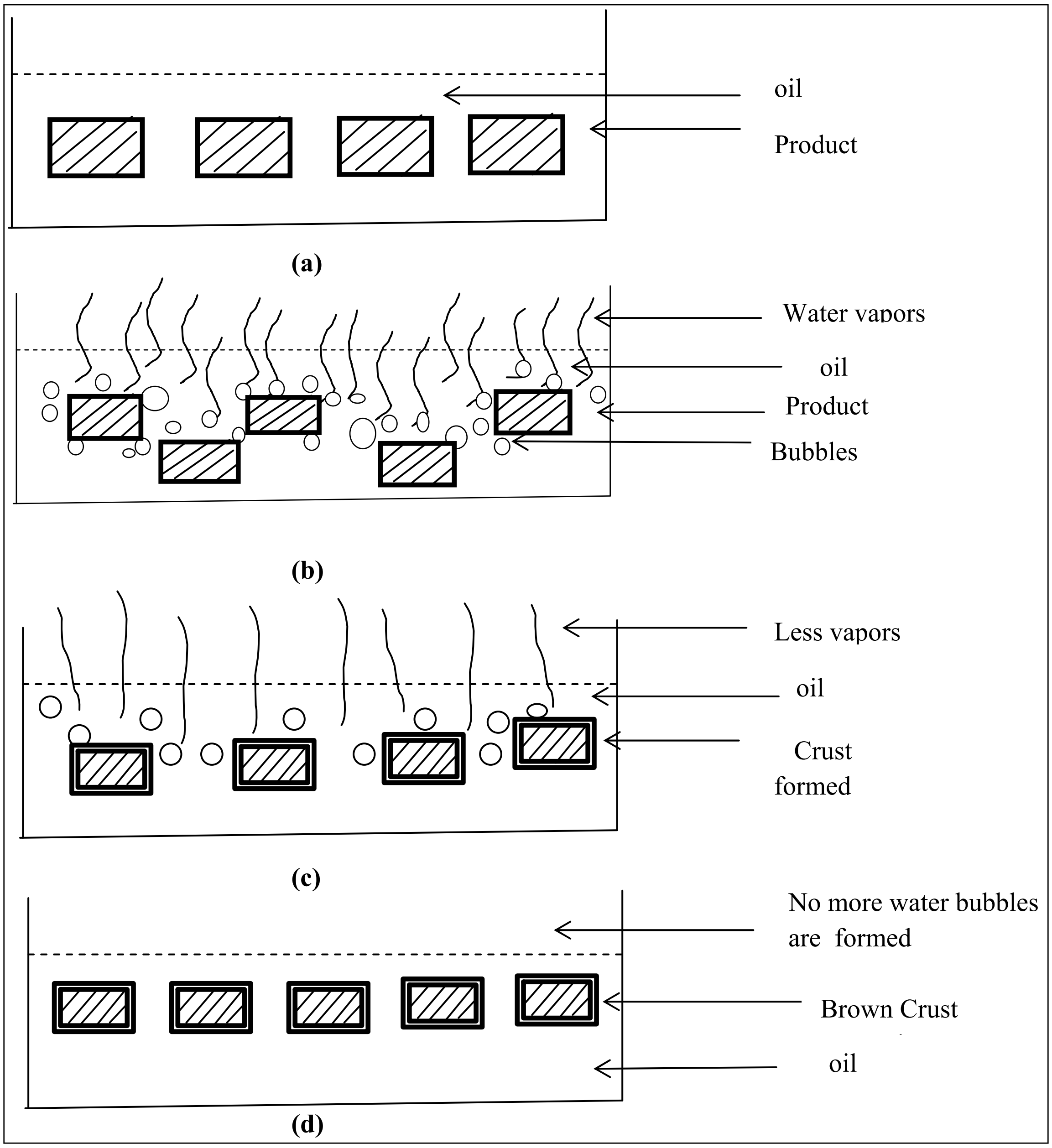

Fig. 3: (a) Heating of the product in oil bath; **(b)** Surface heating of the product in oil bath; **(c)** Internal heating of the product in oil bath; **(d)** Fried product with crust formed

$$hA(T_\infty - T_s) = MC_p \frac{dT}{dt} + L_v \frac{dW}{dt} \quad \ldots(1)$$

Where,

h = Heat Transfer coefficient of product

dT = Difference between volume Avg. temperature

dt = time interval

(T_∞ – T_s) = oil temperature – sample surface temperature

i.e. frying progression ΔT (Farinu and Baik, 2007)

Heat transfer coefficient quantitatively measured by various methods that all are as:

1. Steady- state measurement of surface temperature.
2. Transient measurement of temperature.
3. Heat flux measurement of surface temperature (Alvis *et al.* 2009).

1.3 Mass Transfer

Two forms of mass transfer are involved in frying: oil and moisture. It includes leaching, liquid extraction, distillation, and dehydration. Steam causes dehydration, food odors are produced by distillation, and food components are extracted and leached into the oil. The mobility of water and oil is a characteristic of mass transfer (Orthoefer and List, 2007; Asokapandian *et al.* 2020).

When frying food comes into contact with hot oil, the fluid found on the surface evaporates. This permits the liquid contained in food to migrate outward; this process is known as pumping, which is the movement of water from inside to outside (Lydersen, A., 1985).

2. Effect of various paramaters of frying on the product quality

1. Water loss

Liquid movement represents the moisture transfer that takes place at low frying oil temperatures. The water vapor phase is faster than the liquid phase (Mallikarjunan, Ngadi, and Chinon 2009).

Fick's second law of diffusion can be used to explain the product's moisture loss, which is thought to be a diffusion-controlled process. The diffusion gradient between the product wet and dry layers, as well as the pressure gradient brought about by the evaporation of internal moisture, serve as the driving force for moisture transfer (Asokapandian *et al.* 2020). The first-order kinetic model is used to describe the mass transfer phenomenon. According to Krokida *et al.* (2000), the assumptions are:

1. The oil temperature is constant during frying.
2. Initial water cocn. in the product is uniform.
3. The two flows (water from product into the oil and oil into the product) were considered to be independent of each other.

Kinetic model for moisture;

$$\frac{d(x)}{d(t)} = -K_x\left(X - X_e\right) \quad \ldots(2)$$

Kinetic model for oil;

$$\frac{d(y)}{d(t)} = -K_y\left(Y - Y_e\right) \quad \ldots(3)$$

Where,

X_e is the moisture content of an infinite process time (kg/kg db),

K_x the rate constant of moisture loss (min^{-1}),

Y_e the oil content at infinite process time (kg/kg db)

K_y is the rate constant of oil uptake (min^{-1})

Mathematical model for moisture content

Exponential model-

$$\frac{\left(X - X_e\right)}{X_o - X_e} = \exp\left(-K_x t\right) \quad \ldots(4)$$

Transport properties model

$$K_x = K_{ox}\left[\frac{T}{170}\right]^{K_T}\left[\frac{d}{10}\right]^{K_d}\left[\frac{1}{2}+\frac{C}{100}\right]^{K_C} \quad \ldots(5)$$

$$X_e = X_{oe}\left[\frac{T}{170}\right]^{X_T}\left[\frac{d}{10}\right]^{X_d}\left[\frac{1}{2}+\frac{C}{100}\right]^{X_C} \quad \ldots(6)$$

Mathematical model for oil content

Exponential model

$$Y = Y_e\left[1 - exp\left(-K_y t\right)\right] \quad \ldots(7)$$

Transport Properties Model

$$K_Y = K_{OY}\left[\frac{T}{170}\right]^{K_{YT}}\left[\frac{d}{10}\right]^{K_{Xd}}\left[\frac{1}{2}+\frac{C}{100}\right]^{K_{XC}} \quad \ldots(8)$$

$$Y_e = Y_{oe}\left[\frac{T}{170}\right]^{Y_T}\left[\frac{d}{10}\right]^{Y_d}\left[\frac{1}{2}+\frac{C}{100}\right]^{Y_C} \quad \ldots(9)$$

Where,

T is oil temperature (°C),

d cross section thickness of the sample (mm),

C is the conc.(%) of oil in total oil,

X and Y process model,

K_X and K_y transport properties model for kinetic rate constant,

X_e and X_e transport properties model for equilibrium value.

The amount of moisture loss increases during the first sixty seconds of frying, then gradually decreases and eventually approaches a constant level at the completion of frying (Lalam *et al.* 2013). Constant moisture loss is a sign that the food's internal pressure is higher than the fryer's.

2. Oil Uptake

Oil uptake is an important phenomenon in the frying of food. The surface moisture content, product structure, pressure, frying time, oil absorption, and surface area all have a major impact on oil uptake, which is not affected by the temperature at which it is fried (Innawong, 2001; Álvarez *et al.* 2000; Gamble *et al.* 1987).

Food cannot absorb oil while frying because of high pressure and the evaporation of steam. But as it cools down after removal, oil sticks to the surface and seeps into pores. Oil penetration is driven by a decline in steam condensation pressure and capillary pressure (Moreira and Barrufet, 1998; Bouchon and Pyle, 2005; Moreira *et al.* 1997; Ufheil and Escher, 1996). Water condenses inside the product as it cools, starting to absorb oil as soon as it happens at a temperature that is roughly 10 °C above the boiling point of free water (Christian Gertz, 2014). The product's moisture loss is closely related to the amount of oil absorbed (Asokapandian *et al.* 2020). Fried potatoes' oil content is positively impacted by oil temperature. The oil content rises with cooking time and the temperature of the food (Krokida *et al.* 1999). The effect of temperature on the oil content of fried potatoes was given by Krokida *et al.* (1999) and showed that at temperatures of 150°C, 170°C, and 190°C, oil absorption starts at the initial phase of frying time and maximum oil absorption occurs at the 20-minute frying process, which is about 0.35 kg/kg db.

Due to strong water escape during the immersion phase, oil absorption is restricted; as a result, the majority of oil is absorbed after the potato cylinders are withdrawn at the end of the cooking process. Oil is found either on the chip's surface or drawn into the product's crust microstructure after cooling (Ouchen *et al.* 2003). Ouchen *et al.* (2003) studied that after cooling, maximum oil absorption occurs in fries at temperatures of 155°C, 170°C, and 185°C, with a time period of 4 minutes after frying. The maximum oil absorbed at the time of 4 minutes was 20% db. Table 1 shows the different kinds of oils are used for frying and its properties.

According to the physical relationship between porosity and oil absorption established by Moreira *et al.* (1999), capillary forces may be the cause of the oil uptake mechanism. It's true that when a fluid displacement like oil absorption takes place in tiny openings called crust pores (Moreira *et al.* 1999),.

Capillarity is the upward movement of liquid due to stronger adhesive intermolecular forces between a liquid and a solid, resulting in a concave meniscus and a pressure difference as per Laplace law.

$$P_1 - P_2 = \frac{2\gamma\cos\theta}{r} \qquad \ldots(10)$$

Where,

P_i = pressure at point i (Pa)

γ = Surface tension of oil (N/m)

θ = wetting angle between oil and solid (rad)

r = Pore radius

$$P_2 - P_3 = \rho g h \qquad \ldots(11)$$

according to hydrostatic pressure difference.

Where,

ρ = the oil density (Kg/m^3)

g = acceleration due to gravity

h = the height of capillary motion (m)

Therefore, the pressure difference ΔP at two points 1 and 3 of pore,

$$\Delta P = P_1 - P_3 = \frac{2\gamma\cos\theta}{r} - \rho gh \qquad \ldots(12)$$

The pore radius determines how much oil is absorbed. Higher capillary pressure results from small pores, which raises the oil content. Furthermore, the adhesion forces and oil uptake are higher the smaller the contact angle between the oil and product surface. Ultimately, the liquid's surface tension determines how much oil it can absorb (Moreira *et al.* 1997).

Changes Occurs in oil While frying

During frying process the most important flavor development in oil occurs with certain chemical reactions—

1. Hydrolysis

Where the water molecules react with triglycerides and breakdown the bonds within triglycerides, they hydrolyze to FFA and glycerol, monoacylglycerol, and diacylglycerol (Warner, 2002; Chung *et al.* 2004). Fig.4 shows the hydrolysis reaction of triglycerides. The combination of three groups of unsaturated or saturated fatty acids with varying carbon numbers and one glycerol is known as triacylglycerol, which is what makes makeup oil and fat (Stevenson *et al.*1984). Deep-fat frying is less acceptable when using oil that contains free fatty acids and their oxidized components, as they give off a bad taste. Hydrolyzing the glycerol that remains in the oil after it evaporates at 150 °C encourages the synthesis of free fatty acids (Naz *et al.* 2005). Fry oil has a maximum FFA content and concentration of 0.05–0.08% (Stevenson *et al.* 1984).

2. Oxidation

Molecular oxygen can destroy edible fats that include unsaturated molecules. Lipid oxidation

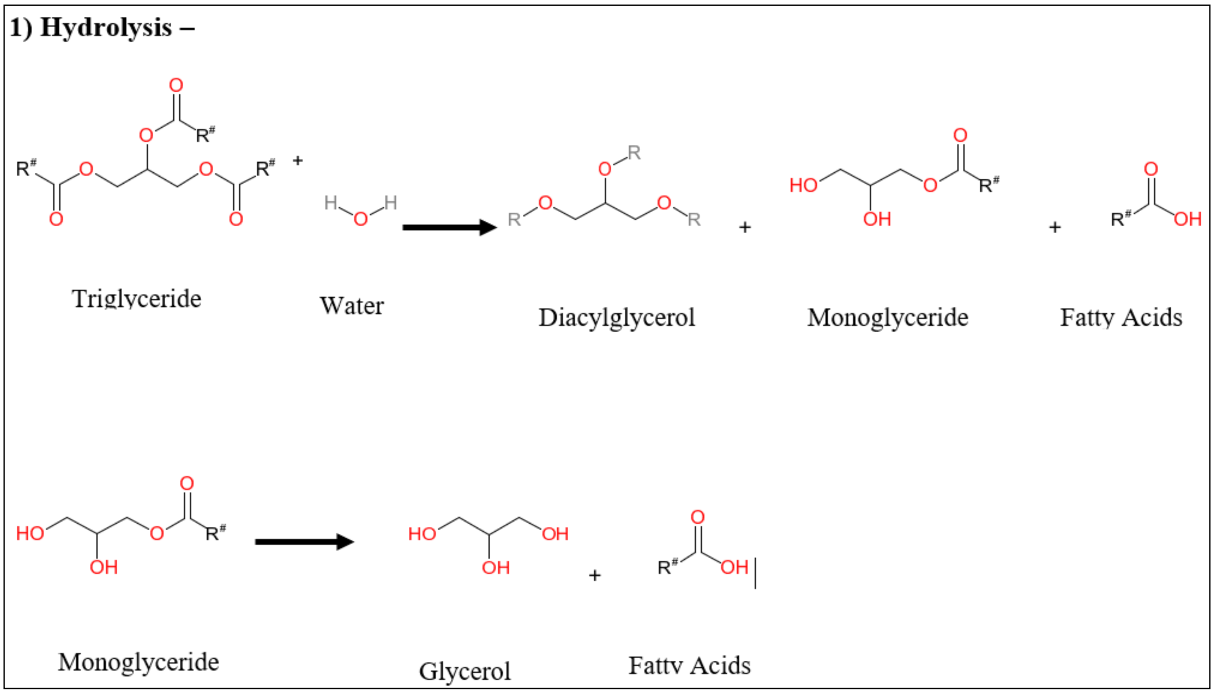

Fig. 4: Hydrolysis reaction of triglycerides

Table 1: Different kinds of oils are used for frying

Sl. No.	Oil Name	Melting Point °C	Iodine Value (I.V.)	Saponification value (S.V.)	Free Fatty Acid (FFA%)	Unsaponifiables %	Refractive Index (R.I.) ND	Density	Flash Point	Smoke Point	References
1	Ground Nut	0 – 3	82 – 106	188 – 195	0.02 – 0.6	0.3 – 0.7%	1.46 – 1.47(@ 20 °C)	0.910	458°C	258.8 ± 0.050 °C	Williams 1966, cobb/johnson 1973 Das *et al.* 2013; Bello, E.I. and Agge, M., 2012
2	Mustard Hear oil	– 80	87 – 120	170 – 200	60	0.750 – 1.20	1.469 – 1.485(@ 30°C)	904 kg/m^3 at 30°C	278 – 282	226 – 234	Sonntag 1979 Kumari *et al.* 2015; Brahmachari, B.B., 1935
	Canola Oil	– 10	110 – 126	188 – 192	—	0.5 – 1.2	1.465 – 1.467 (@ 30°C)	—	275 – 290	220 – 230	Shenolikar 1985
3	Safflower oil	– 17	136 – 146	186 – 195	0.15 – 0.01	0.3 – 1.3%	1.473 – 1.476 (@25°C)	921.03 kg/m^3 at 15°C	– 30 to 300°	212 ± 4°C	Vibhakar *et al.* 1981; Eryilmaz, T. and Yesilyurt, M.K., 2016, Katragadda *et al.* 2010
4	Sunflower oil	– 18 ± 0.6	101.4 – 135.0	193 – 200	1.10	0.20 – 1.93	1.4636 – 1.4681 (@40°C)	0.92 g/cm^3	292	240	Kamath *et al.* 1979 pal *et al.* 2015; Al-Janabi, A.M.A.A., 2021, Devi, A. and Khatkar, B.S., 2017
5	Sesame	– 6	103.6 – 112.8	188.6 – 191.2	1 – 3	1.4 – 2.5	1.4760 – 1.4770 (@25°C)	0.915 – 0.924 at 20 °C	312 ± 1.50 – 326 ± 1.30	206 ± 2.10 – 210 ± 1.10	Tyagi and Vasistha 1983; Hwang, L.S., 2005; Arawande, J.O. and Alademeyin, J.O., 2018
6	Soybean	– 16	118 – 132	188 – 196	0.57 – 1.06	0.72 – 1.46%	1.436 – 1.471 (@25°C)	0.919 – 0.925	304 – 316	192 – 209	Celik *et al.* 2001; Agwu *et al.* 2015; Detwiler Jr, S.B. and Markley, K.S., 1940
7	Niger 1)	– 8 to – 20	138.2	190.8	3.12	0.2 – 1.7	1.4715	901 kg/m^3	95	—	Nasirullah *et al.* 1987; Osman, A., 2020; Ramesh Babu, and Dr Sharanappa Godiganur 2018; Ranganatha *et al.* 2016; Bhavsar *et al.* 2017; Ofodile *et al.* 2018
8	Linseed	20 – 24°C	182 – 203	187 – 195	0.1 – 2.0	01 – 1.7%	1.475 – 1.476 (@20°C	0.925 – 0.935	120 – 135	163	Jameson 1943 Detwiler Jr 1940.
9	Palm oil	27 – 50	46 – 60	196 – 209 (mgKOH/g)	0.65 ± 0.09	0.3 – 1.0%	1.453 – 1.459 (@40°C)	0.891	314	220	Carnelius1977; Tan *et al.* 2009; Ismail, R., 2005; Azman *et al.* 2020
10	Rice Bran	70	90 – 105	180 – 195	0.1	3.0 – 5.0%	1.4600 – 1.4700 (@40°C)	0.891 – 0.899	250	257 ± 4	Nagaraj,G., 2009; Jennings, B.H. and Akoh, C.C., 2009; Dijkstra, A.J. and Van Duijn, G., 2016

11	Corn oil	– 12 to – 10	103 – 128	187 – 193	0.1	2%	1.470 – 1.474 (@25°C)	0.917 – 0.925	294	178	Nagaraj,G., 2009; Barrera-Arellano *et al.* 2019; Noureddini, *et al*. 2009 Detwiler Jr, S.B. and Markley, K.S., 1940.
12	Cotton-seed oil	10 – 15	103 – 116	190 – 198	0.05	0.5 – 0.7	1.46 at 55°C	0.918 – 0.926	293	220	Nagaraj,G., 2009; Riazet al .,2023; O'Brien, R.D., 2002
13	Coconut oil	23 – 26	7.5 – 10.5	250 – 264	0.61 ± 0.59	0.5%	1.448 – 1.450 (@40°C)	0.908 – 0.921	274.33 ± 3.51	230.67 ± 2.52	Sanntag 1979; Kumar, P.P. and Krishna, A.G., 2015; Nwadinobi, C.P. and Ikeme, P.C., 2021
14	Olive oil	0	80 – 88	188 – 196	0.1 – 2.1	1.8	1.4680 – 1.4705 (@20°C)	0.913 – 0.916	321	199	Sanntag 1979; Detwiler Jr, S.B. and Markley, K.S., 1940.; Bertrant *et al*. 1999
15	Mahua	23 – 31	55 – 63	187 – 196	2 – 9%	1.0 – 3.0%	1.4520 – 1.45620	920	212	184	Bhattacharya,1988; Acharya *et al.* 2017; Kapilan, N. and Reddy, R.P., 2008; Malavi Tagore, M., 1989.
16	Kokum	39.4 – 43	25 – 36	187 – 191.7	5.64	1.2 – 2.3%	1.4565 – 1.4575	1380 – 1209kg/m3	250	150 – 200	Lakshmikantan,1978; Parthasarathy *et al*. 2014

is the term for this process, which can result in unfavorable volatile flavor compounds, possibly harmful oxidation products, products, and an overall decline in fat quality (Stevenson *et al.* 1984**).** Unwanted oxidized (rancid) flavor is mostly caused by volatile degradation products, which are typically saturated and monounsaturated:: hydroxyl, aldehyde, keto and dicarboxylic acids, hydrocarbons, alcohols, aldehydes, ketones, ketones, and aromatic compounds (Warner, 2002).

The autoxidation and thermal oxidation mechanisms share a similar chemical mechanism. The autoxidation rate is slower than the thermal oxidation rate. Initiation, propagation, and termination are all components of the thermal oxidation process (Choe and Min, 2007).

An unsaturated fatty acid exposed to oxygen in the presence of a metal initiator (iron, nickel, or copper) will produce a free radical in the oil, which will start the process of autoxidation of the unsaturated fatty acid. It takes radical oxygen and radical oil for oil to oxidize. If oil is in a radical state and reacts with radical oxygen, an oil oxidation process will start. The weakest hydrogen atom in an oil will be destroyed first in order for it to become radical (Gupta, 2006). By taking electrons away from the carbon-hydrogen bond at carbon 11, the double bonds at carbon 9 and carbon 12 weaken it. Oleic acid's double bond is represented by the α carbon-hydrogen bond on carbon 8 or 11. Linoleic acid's carbon-11 carbon-hydrogen bond is the weakest, and it will be broken first, releasing a radical at that position. Conjugated penta dienyl radical at carbon 9 or carbon 13 with a trans double bond will be formed by rearranging the radical at carbon 11 (Choe and Min, 2007).

The elimination of hydrogen creates an alkyl radical, which starts the oil oxidation process. By reducing oil-air interaction, phospholipids, monacylglycerol, and diacylglycerol encourage autoxidation. The formation of soaps by calcium and magnesium raises the level of autoxidation in fryer oil (Choe and Min, 2007; Gupta, 2006). The peroxy radical takes a hydrogen atom from another oil molecule to produce a new hydroperoxide and an extra alkyl radical. The term "free radical chain reaction" describes this chain reaction in the food and propagation stages. A peroxy (alkoxy) radical is created when the free radical combines with an oxygen molecule. The presence of oxygen is vitally required. For this reason, whether oil is nitrogen-saturated or vacuum-stored, it does not oxidize. The interaction of free alkyl and peroxy radicals speeds up heat-induced oil oxidation. As seen in the figure, the formation of nonradical, volatile, and nonvolatile compounds takes place toward the end of oxidation and is referred to as the termination phase. Interactions between free radicals are possible. When the system is either completely depleted of unsaturated fatty acids or completely oxygenated (Choe and Min, 2007). Fig: 5 shows the Chemical Reactions taken place during oxidation.

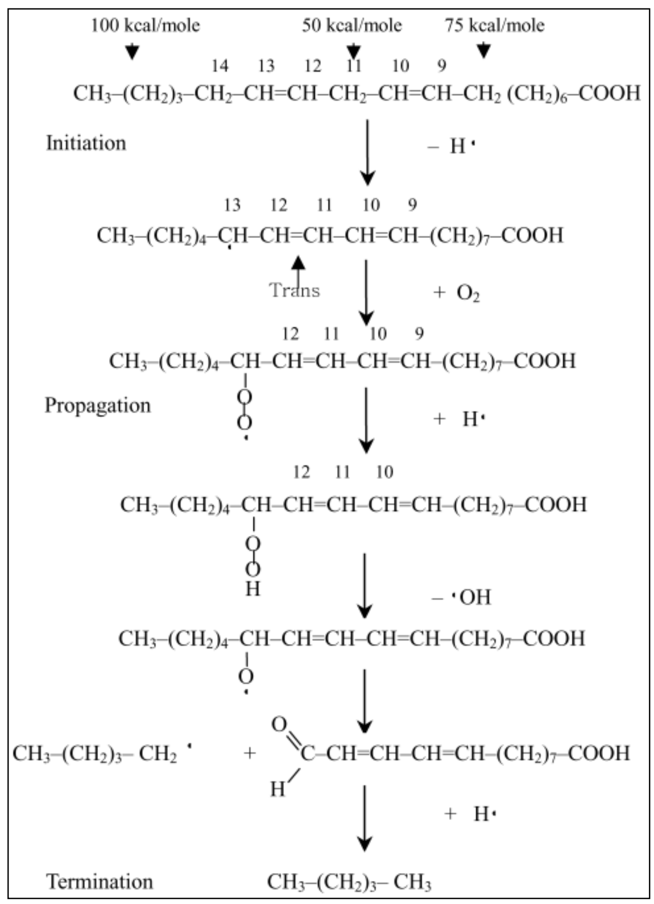

Fig. 5: Chemical Reactions taken place during oxidation (Choe and Min, 2007)

3. Polymerization

Volatile compounds greatly influence the flavor of fried food and frying oil; nevertheless, the concentration of volatile substances in products from the decomposition of frying oil is only a few parts per million (Oke *et al.* 2018; Choe and Min, 2007; Nawar, W.W. 1985). Higher linoleic acid oil content promotes polymerization more readily than higher oleic acid oil concentrations. Oxygen-rich and strongly conjugated polymers leave behind a residue that resembles resin in color (Choe and Min, 2009). Foam creation can occasionally be attributed to polymerization. Food that has been fried may become less oily due to thermal or oxidative polymerization; oil viscosity rises as a result of polymerization, and oil absorption rises as viscosity increases due to polymerization (OOrthoefer and List, 2007). Triacylglycerol dimers and polymers, together with nonvolatile polar molecules, are the main byproducts of frying oil degradation (Choe and Min, 2007).

Effects of frying on the physicochemical properties of foods

1. Moisture content

Food products absorb oil when moisture is removed from them; the higher fat content indicates a higher starting moisture content. Less initial moisture means less internal oil space taken up and less time spent frying (Asokapandian *et al.* 2020). One term for moisture loss that occurs during frying is the "desorption phenomenon" (MMillin *et al.* 2016).

Moisture content of raw potato strips was 79% wb after the complete frying process went on, decreasing with different frying temperatures, as at 170°C, 180°C, and 190°C, it was 37.9%, 27.9%, and 32.8%, respectively (Millin *et al.* 2016).

Initial moisture content (g/100 g) of three different varieties of sweet potato were TA 67±1, TB 73±1, TC 64±0.1, which goes on decreasing during deep fat frying and becomes TA 8±0.1, TB 4± 0.1, and TC 3±0.1 (Caetano *et al.* 2017).

Moisture content (g/100g) for lotus rhizome chips at different frying temperatures (180°C, 190°C, and 200°C) was 4.80±3.3, 3.94±0.5, and 3.48±0.5, respectively. Initial moisture content was 23.36±0.2 (Wipawee Yodkraisri and Rajeev Bhat, 2012).

2. Texture

Changes in protein, lipid, and carbohydrate polymers that resemble those that happen during boiling or baking combine to give food its characteristic texture during the frying process (Fellows, P.J. 2022). The processes of water evaporation and capillary development result in pores. When water evaporates, extreme heat causes an explosion that opens up large pores. There is the formation of a surface crust. The formation of holes and food shrinkage are also caused by protein denaturation and starch gelatinization (Bordin *et al.* 2013). The internal characteristics and structure of the raw material, such as cell size, surface area-specific gravity, starch, pectin, and total lipids, are strongly connected with the texture of the fruits and vegetables after frying (Moyano *et al.* 2007). The crispness of any fried food is an important indicator of its freshness. The crispness of the final product is also correlated with the amount of starch in the fried dish. During the first stage of frying, evaporation causes water to travel throughout the food, resulting in a soggy, rubbery product and the gelatinization of starch. Granules of starch become gelatinized when heated to a low moisture content, giving fried food a distinctive texture (Yamsaengsung *et al.* 2011). Chips are overdone and brittle when fried at a temperature too high, while they are soft and unpleasant to eat when fried at a temperature too low. Therefore, frying at the optimum temperature is necessary for product crispness (James Makame, 2015).

3. Fat content

As time passes, the fat content rises. Foods originating from plants absorb more than those originating from animals. Fried veggies such as peeled eggplant, tomatoes, onions, mushrooms, and pineapple meat have been shown to have the maximum fat absorption. Additionally, white bread absorbs a lot of fat. After 70 seconds, the fat percentage in peeled potatoes was 19.4%, which is more than the fat in fried chicken (Pokorny, J. 1999). The fat content (g/100 g) of raw material is 1.27± 0.03, but after deep fat frying, it becomes 45.85± 1.60, i.e., increases. The fat content in the raw sweet potato was 0.1%, and in deep fat frying it became 28% (Caetano *et al.* 2017).

Fat content (g/100 g) in raw lotus rhizome was 0.50±0.2; during deep fat frying at different temperature levels, it changed for 180°C, 190°C, and 200°C. Fat content (g/100 g) was 21.78±0.5, 23.15±2.7, and 23.00±1.3 (Wipawee Yodkraisri and Rajeev Bhat, 2012).

Fat content in raw sweet potatoes was 0.05 g/100 g, and after frying sweet potatoes, the fat content became 24.7 g/100 g (Teferi Damto and Geremew Chala, 2019).

4. Protein content

The combination of a protein's quality and amount determines its nutritional value. The term "quality" refers to the functional content of the protein that an organism consumes and uses. The amount of protein in the diet is represented by quantity. Heat treatment has the potential to alter the quality of protein composition in food by destroying certain amino acids and reducing the quantity of protein (Henry, C.K. 1998). When the samples were fried in palm oil, the amount of amino acids decreased the most during the frying process (Oluwaniyi *et al.* 2010).

Frying does not alter the protein's digestibility if it is done so without the addition of any other ingredients, as is often the case. For example, the digestibility of protein and carbohydrates is somewhat but considerably reduced when reducing chemicals are added to fried meals (Ghidurus *et al.* 2010). There is conflicting information in the literature on the loss of vital amino acids. But, since lysine is the first amino acid to participate in the Millard reaction, it should be lost during cooking (Bordin *et al.* 2013). The protein content of a fresh sweet potato was 5.98±0.22, and after frying, it was 3.74±0.10 (Anwar and Ghani, 2019).

5. Mineral Content

Mineral components undergo significant modifications during culinary processes like boiling, but their changes during frying are insignificant. Fried food loses weight due to water loss. Wet-weight mineral content increases due to non-volatile components, while dry-weight metal content decreases with increased frying oil intake (Pokorny, J., 1999). The amount of minerals lost while frying food in deep fat ranges from 1% for potatoes to substantially less than when the same meal is boiled (Giudius *et al.* 2010). Research indicates that frying, particularly at high temperatures (165°C to 185°C) and short cooking times, preserves minerals somewhat (Gokoglu *et al.* 2004; Avallone *et al.* 2009). Frying dramatically raises the levels of micro- and macronutrients as well as heavy metals (Na, Mg, Ca, Cu, Fe, Zn, Pb, Cd, and Hg), with the exception of the K and Mg contents of mussels and shrimp, respectively (Anna and Kamila, 2013).

6. Carbohydrate content

Studies have looked at how frying affects the amount of carbohydrates in potatoes, potato products, breaded meat, and fish. The outcome showed that, based on the kind of food, the percentage of carbohydrates retained ranged from 95% to 100%, suggesting that the frying technique had an impact (Bognar, A. 1998). The amount of resistant starch increases dramatically when deep-frying french fries, while the backing of frozen fries has little influence on starch composition when compared to raw samples. The creation of amylose-lipid complexes is implicated in this to some extent. Fryers obtain more nutritional fiber from potatoes while losing some of their digestible starch content. Consuming dietary fiber is crucial for preventing conditions including diabetes, heart disease, and colon cancer (Fillion and Henry, 1998).

7. Colour (L,a and b values)

It is proposed that color is the best way to describe a chip's quality. It is influenced by the raw material's chemical makeup and dictates processing capacity

(Lisinska and Leszczynski, 1989). One of the most important and distinctive qualities of fried food is its golden hue, which plays a major role in influencing customer approval (García-Segovia *et al.* 2016). Fry foods' color is influenced by physicochemical changes brought on by the heat and mass transfer events during deep-frying. Potatoes gain their color, scent, and texture due to a combination of water loss, oil absorption, and non-enzymatic browning processes. The dehydration that follows creates a tough exterior (Moyano and Pedreschi, 2006). The International Commission on Illumination (CIE) adopted the LA B unit of measurement in 1976 as an international standard for measuring color. This unit is typically used to determine the color of fried food. L*a*b* specifies the brightness or lightness (0 to 100), the gradient from blue to yellow (-120 to 120), and the gradient from green to red (Sangmithra Asokapandian 2019). Since chips are a heterogeneously colored product, color is currently measured in L*a*b* units from RGB pictures using a computer vision system (Moyano and Pedreschi, 2006).

The two process variables that influence the color characteristics during frying are the oil temperature and the amount of frying time. At greater temperatures, the phenomenon of color shifts becomes more severe. The color coordinates of kohlrabi slices cooked at varying oil temperatures significantly decreased; at 190 degrees Celsius, final values of a* = 23.80 and b* = 39.05 were achieved (Salehi, F. 2019). At every frying temperature, there was an initial increase in the Hunter L value, followed by a drop. At higher frying temperatures, the tendency became more noticeable. While the greatest "L" values were attained at 7, 3, and 1 minute, corresponding to frying temperatures of 140, 160, and 180 °C, the initial Hunter lightness (L) was around 53.1. The maximum L value was obtained after 9 minutes of frying at 120 °C. Due to moisture loss, which causes the product to turn white, the Hunter Lightness (L) value first increased before decreasing as a result of oil impingement and the production of Millard reaction products from the reduction of carbohydrates and proteins. The pace of change in color was discovered to be significantly reliant on temperature, and the product's color development during deep fat frying is dependent on the drying rate (moisture loss), oil absorption, and heat transfer coefficient during the various phases of frying. After 15 minutes of frying, the Hunter redness value grew from 2.48 to 5.77, 7.52, 12.71, and 18.53 at frying temperatures of 120, 140, 160, and 180 °C, respectively. Hunter redness grew linearly as frying time increased, and at higher frying temperatures, color development occurred at a faster pace.

From 19.08 to 27.17, hunter yellowness (b) values were observed. Upon deep-fat frying the Gethi strips, no discernible pattern of variation in Hunter yellowness was noticed regarding frying temperature or duration (Manjunatha *et al.* 2014).

8. Vitamin content

The interior temperature of food and the frying process affect the oxidation of vitamins, which are thermosensitive. Heat sensitivity is often greatest for vitamin C. The most often impacted B-group vitamins are B6, thiamine, riboflavin, and niacin (Reda, S. Y., 2004). As heating occurs, unsaturated fatty acids oxidize, and vitamin E is lost as well. The quantity of frying oil that is absorbed by the food when it is cooking is determined by its quality, which has an impact on the net intake of vitamin E (Andrikopoulos *et al.* 2003).

The frying oil's vitamin E takes part in free radical reactions, slowing down their pace (Pokorny, J. 1999). When compared to shallow-fried meals, beta-carotene losses from deep-fat frying were twice as high in veggies. The cooking oil may absorb some beta-carotene (vitamin A). A quarter of the beta-carotene in the cabbage was destroyed in the frying process (Pokorny, J. 1999).

Different kinds of chips made from fruits, vegetables, and tuber crops are shown in Table 2.

Table 2: Chips of different fruits vegetables and tubers crops

Sl. No.	Chips	Oil used	Treatment	Temperature	Packaging material	References
1	Chayote Chips	Refined Soybean oil	Blanching in water at 85 °C for 4 min Oven dryed at 60°C for 24 hrs	150°C 160°C 170°C for 5s, 10s, 15s	LDPE Aluminium Coated Laminate	Raleng *et al.* 2022
2	Potato strips	Sunflower oil, Palm oil, Vegetable oil (1:6)	Blancching in water at 85 °c for 5 min With 0.5% aq. slo^{n}. of calcium chloride 1 %Citric acid CMC Carboxy Methyl Cellulose 1 % Drying in oven 150 °C for 3 hrs	180 °C±10°C		Suzana *et al.* 2004
3	Sweet Potato		0.2% sodium metabisulphite for 15 min	180°C for 90 s		Anwar, N.Z.R. and Ghani, A.A., 2019
4	Mushroom chips	Air frying	180°C for 10 min predried in oven	180°C for 5 min		Ibrahim and Khattak, 2020
5	Lotus Rhizome	Sunflower oil	85°C for 3.5 hrs Oven dried at 60°c for 24 hrs	180°C 190°C 200°C for 15-20 s		Yodkraisri, W. and Bhat, R., 2012
6	Pineapple chips vaccum fried	Rice bran oil	60 mmHg pressure	(90°C for 50 minutes, 90°C for 60 minutes, 95°C for 50 minutes, 95°C for 60 minutes)		Wanakamol, W. and Poonlarp, P., 2018.
7	Yam chips	dehyadrofrozen Deep frying		170°C for 5 min		Adedeji *et al.*2022.
8	Beetroot chips	Vaccum frying	A maximum vacuum of\1.0 kPa maximum rotational speed of 2000 rpm	180 ± 2°C for 5 min. Traditional frying		Juvvi *et al.* 2016

Sl. No.	Chips	Oil used	Treatment	Temperature	Packaging material	References
9	Turnip	1% sodium chloride and 0.2% citric acid at 100°C for 1 min. After rapid cooling, the slices were immersed into a 20% sucrose solution (soaking treatment) for 1 h. Then, the turnip slices obtained were frozen at - 18 °C overnight.	Hot air drying (AD), infrared drying (ID), explosion puff drying (EPD) and freeze drying (FD)			Xue *et al.* 2020
10	Shitake mushroom chips	Palm oil	(1) blanched as control, (2) blanched and immersed in MD solution (50% w/v) at 25◎ C for 60 min, (3) blanched, immersed in the solution, and then immersed in a dilute CMC solution (0.5% w/v) at 25◎ C for 15 min, (4) blanched, immersed in the MD solution, and then freezed at −20◎ C for 12 h.	100 g shiitake mushroom in 50 L of palm oil e oil temperature was 90 ± 2◎ C and vacuum degree was −0.095 MPa during frying		Ren *et al.* 2018
11	strawberry			at 70°C for 120 minutes (P1), 110 minutes (P2), and 100 minutes (P3)		Srimiati *et al.* 2023
12	Casava	Palm oil		150°C for 70s 160°C for 90s		Vitrac *et al.* 2001
13	Purple potato purple majesty	Sunflower oil	microwave drying pre-treatment for 2 min at 750 W in	pre-frying process for 1 min at 180 ± 3°C frozen for -20°C frying for 2.5 min at 180±3°C.		Romano *et al.* 2022
14	Plantain (Dodo)	Vegetable oil		temperatures (150 - 190 °C) time intervals (120 - 240 sec).		Adeyanju *et al.* 2021

Sl. No.	Chips	Oil used	Treatment	Temperature	Packaging material	References
15	Mango	Canola oil	Osmotic dehydration at 22°C and 40°C,Maltodextrin and 0.15% of citric acid	140 °C for 25 s at a speed of 225 rpm		Nunes and Moreira, 2009.
16	Banana	RBD palm oil (refined bleached deoderised)	Deep Fat frying	180±5°C for 3 min		Ammawath *et al.*2001
17	Chinese purple yam	Soybean oill	Blanching 100°C for 2 min Feezing at -18°C for 20 h	Vacuum frying (100°C, 0.09 MPa, 15 min) oil removal (450 rpm, 5 min)		Fang *et al.*2011
18	Tarro	sunflower, safflower, cottonseed, peanut, canola, or soybean oil		260–300°F for 2 min	opaque laminated plastic	Hollyer *et al.* 2000
19	Gethi strips	Sunflower oil Ratio 1:25 w/v	Soacked in potassium meta bisulphite (0.1 %) for 30 min,blanched in boiling water at 95 °C for 5 min	120°C,140°C, 160°C,180°C, 3,6,9,12,15 min time		Manjunatha *et al.*2014
20	Jerusalem Artichoke		1% sodium metabisulphite solution and 2 % Xanthan gum	120s, 180s and 240s at 160°C, 170°C, 180°C and 190°C		Baltacıoğlu, C., 2012
21	Mango		FD -80°C for 6 hrs Air drying Explosion puff drying			
22	White pitaya		FD -80°C for 6 hrs Air drying Explosion puff drying			
23	Carica papaya		FD -80°C for 6 hrs Air drying Explosion puff drying			Yi *et al.* 2017

Sl. No.	Chips	Oil used	Treatment	Temperature	Packaging material	References
24	Pear chips	Blended oil Palm oil and sesame oil	Conventional frying Blanching 100°C ± 2°C for 3 min Dried at room temperature (25°C ± 2°C) for 8–10 hr	175±5°C for 4 min		Juvvi *et al.* 2020
			Vaccum frying	93-127°C 43-177 mbar 2-7 min		Juvvi *et al.* 2020
25	Plantain chips		Pre blanching70°C for 10 min Blanching 70°C for 30 s	180°C	heat-sealed polyethylene pouches	Onyejegbu and Olorunda, 1995
26	apple		Soaking in citric acid (5.8%) for 5 s Blanching in 1 min Cold water for 5 min	Atm frying 140°C,150°C, 160°C For 2,4,6,8,10,15 min		Mariscal and Bouchon, 2008
				Vaccume frying 95°C,105°C,115°C o.15 bar pressure		
27	Breadfruit (Artocarpus communis)			190 °C		Omobuwajo, T.O., 2003
28	eggplant	sunflower oil	2% Chitosan, 2% Carboxy methylcellulose (CMC), 0.1% Sodium metabisulfite (SO2) or 4% sodium chloride or with water,steam blanching for 3 min	4, 6 and 8 min at 170, 180 and 190 ± 0.5 o C		Eissa *et al.* 2013.
29	Pumpkin	Soybean oil		180 °C for 10 min		Ahromrit and Nema, 2010
30	carrot	Palm oil	Fermented carrots at 25°C in 0.9% brine	at 170°C for 1 min 50 s		Skrede *et al.* 1997
31	Bitter gourd chips	Rice bran and palm oil at the ratio 80:20	Vaccum frying Freezing -30ºC for 8 h and ,blanhing2 min at 95ºC, drying70ºC for 1 h 30 min, 1.5% guar gum coating @90°C for 30 min	6-13 kPa 1000 rpm		Pooja and Sudheer, 2018.

Sl. No.	Chips	Oil used	Treatment	Temperature	Packaging material	References
			Atm frying	165ºC, pressure of 101 kPa and time of 15 min		
32	Potato vaccum fried	Vegetable oil	Cool at temp 10 °C to 12 °C relative humidity 55% for 12 hrs	118 °C, 125 °C, and 140 °C and a vacuum pressure of 10 Torr.		Granda *et al.* 2004
33	Carrot chips vaccum fried	Sunflower oil		160°C and 180°C for atmospheric frying and 98°C and 118°C for vacuum frying 1.92 in. Hg		Dueik *et al.* 2010
34	Banana vacuum fried	Palm oil	sucrose solution (0.5% w/w) for 15 min Guar and xanthan gum coating 10 min 15:1	89°C for 90 min 140 rpm to 280 rpm 5 min		Sothornvit, R., 2011
35	Kiwi fruit	Response surface methodology		105ºC, 62 mbar, and 8 minutes		Maadyrad *et al.* 2011
36	Shallot	Palm oil		m 551 mm Hg, 108 °C and 13 minutes		Therdthai *et al.* 2007
37	okra	Vaccum fry	Blanched at 100° C for 3 minutes cold water for 2 minutes	100°C for 20 minutes.		Ag-Ind, A.J.F., 2009
38	Gembili (tuber)			75°C for varying time 20,25,30,35,40 min		Wibowo E. 2012
39	Jackfruit	Palm oil Atm frying	95°C blanching for 10 min 0.1 % KMS solution deeping 15 min	70°C		Molla *et al.* 2008
40	Jackfuit chips vaccum frying		30 ppm chlorinated water Blanch for 2 min	100mbar 90°C for 30 min Centrifuged 500 rpm for 8 min		Maity *et al.*2018

CONCLUSION

Food that has been fried has a nice, natural flavor and crunchy texture. Frying caramelizes the sugar in the food, giving it a lovely golden brown hue. Its tastes vary when fried in different oils. A number of factors causes the absorption of oil in food materials. It is a quick and simple cooking technique. Convenient and requires little setup. Food quality is minimally lost since heated fat seals the food's surface. Fried meals are often a rich source of vitamin E, even if oxidation causes some unsaturated fatty acids and antioxidant vitamins to be lost. It is true that when food is fried, some fat is unavoidably absorbed, which raises the energy density. Foods that are fried in oil provide a lot of calories, which, if consumed in excess, can cause weight gain. Risks associated with trans fats include cooking in certain oils to high degrees producing trans fats that are bad for the heart and can increase cholesterol.

Around 2500 BC, during the era of the Old Kingdom, fries are said to have first been seen in Egyptian kitchens. Food preservation is thought to be the reason frying was invented and put to use. Cakes that are now known as doughnuts were among the first foods to be fried.

The protein and mineral contents of potatoes, vegetables, coated chicken, fish, and poultry are considerably reduced by boiling and steaming. Coating while deep-frying preserves greater amounts of vitamins B1, B2, B6, and C while absorbing less fat. On the other hand, the fat content rises, and the moisture content falls. The color of meals that are fried is affected by mass transfer and heat. During cooking processes like boiling, mineral components change significantly; however, these changes are negligible during frying.

REFERENCES

A Adeyanju, J., E Alabi, B., O Abioye, A., A Adekunle, A. and A Oloyede, A. 2021. Effect of Frying Temperature and Time on Thermophysical Properties and Quality Attributes of Deep-Fat Fried Plantain (Dodo).

Acharya, N., Nanda, P., Panda, S. and Acharya, S., 2017. Analysis of properties and estimation of optimum blending ratio of blended mahua biodiesel. *Engineering Science and Technology, An International Journal*, **20**(2): 511-517.

Adedeji, O., Samuel, J. and Ayoola, B. 2022. Chemical composition, physical and sensory properties of dehydrofrozen yam chips as influenced by pre-drying conditions.

Ag-Ind, A.J.F. 2009. Effects of moisture heating and vacuum fry on organic and conventional okra quality.

Aguilera, J.M. and Gloria, H. 1997. Determination of oil in fried potato products by differential scanning calorimetry. *J. Agric. Food Chem.*, **45**: 781-785.

Agwu, O.E., Okon, A.N. and Udoh, F.D. 2015. A comparative study of diesel oil and soybean oil as oil-based drilling mud. *Journal of Petroleum Engineering*, pp.1-10.

Ahromrit, A. and Nema, P.K., 2010. Heat and mass transfer in deep-frying of pumpkin, sweet potato and taro. *Journal of Food Science and Technology*, **47**: 632-637.

Al-Janabi, A.M.A.A., 2021. Effect of Mixing Sunflower Oil with Butter Ghee in Physical Properties and Characteristics of the Product. *Tikrit Journal for Agricultural Sciences*, **21**(4): 122-128.

Álvarez, M.D., Morillo, M.J. and Canet, W. 2000. Characterization of the frying process of fresh and blanched potato strips using response surface methodology. *European Food Research and Technology*, **211**: 326-335.

Alvis, A., Vélez, C., Rada-Mendoza, M., Villamiel, M. and Villada, H.S., 2009. Heat transfer coefficient during deep-fat frying. *Food Control*, **20**(4): 321-325.

Ammawath, W., Che Man, Y.B., Yusof, S. and Rahman, R.A. 2001. Effects of variety and stage of fruit ripeness on the physicochemical and sensory characteristics of deep-fat-fried banana chips. *Journal of the Science of Food and Agriculture*, **81**(12): 1166-1171.

Andrikopoulos, N.K., Boskou, G., Dedoussis, G.V., Chiou, A., Tzamtzis, V.A. and Papathanasiou, A. 2003. Quality assessment of frying oils and fats from 63 restaurants in Athens, Greece. *Food Service Technology*, **3**(2): 49-59.

Anna, C. and Kamila, S. 2013. Effect of processing treatments (frozen, frying) on contents of minerals in tissues of 'frutti di mare'. *International Journal of Food Science & Technology*, **48**(2): 238-245.

Anwar, N.Z.R. and Ghani, A.A. 2019. Effect of different processing methods on the physicochemical properties and sensory evaluations of sweet potatoes chips. *Journal of Agrobiotechnology*, **10**(2): 51-63.

Anwar, N.Z.R. and Ghani, A.A. 2019. Effect of different processing methods on the physicochemical properties and sensory evaluations of sweet potatoes chips. *Journal of Agrobiotechnology*, **10**(2): 51-63.

Arawande, J.O. and Alademeyin, J.O. 2018. Influence of processing on some quality identities of crude sesame

(*Sesamum indicum*) seed oil. *International Journal of Food Nutrition and Safety*, **9**(1): 59-74.

Armour, R.P. 1959. Investigations on simarouba glauca dc. In el salvador. *Economic Botany*, **13**(1): 41-66.

Asokapandian, S., Swamy, G.J. and Hajjul, H. 2020. Deep fat frying of foods: A critical review on process and product parameters. *Critical Reviews in Food Science and Nutrition*, **60**(20): 3400-3413.

Avallone, S., Rojas-Gonzalez, J.A., Trystram, G. and Bohuon, P. 2009. Thermal sensitivity of some plantain micronutrients during deep-fat frying. *Journal of Food Science*, **74**(5): C339-C347.

Azman, A.S., Bakar, N.N.A. and Abidin, S.Z. 2020. Study of viscosity and flash point of bio-lubricants (engine oil) from unused and used palm oil. *International Innovation Competition (innocom),* pp.459.

Baltacıoğlu, C. 2012. Production of chips and crisp from jerusalem artichoke.

Barrera-Arellano, D., Badan-Ribeiro, A.P. and Serna-Saldivar, S.O. 2019. Corn oil: composition, processing, and utilization. In *Corn* (pp. 593-613). AACC International Press.

Bello, E.I. and Agge, M. 2012. Biodiesel production from ground nut oil. *Journal of Emerging Trends in Engineering and Applied Sciences*, **3**(2): 276-280.

Bertran, E., Blanco, M., Coello, J., Iturriaga, H., Maspoch, S. and Montoliu, I. 1999. Determination of olive oil free fatty acid by Fourier transform infrared spectroscopy. *Journal of the American Oil Chemists' Society*, **76**(5): 611-616.

Bhattacharyya, D.K. 1984. Composition and utilisation of oil and non-oil constituents of sal seed and mowrah. *Oil seeds and their utilization/edited by RK Suri & KC Mathur*.

Bhavsar, G.J., Syed, H.M. and Andhale, R.R. 2017. Characterization and quality assessment of mechanically and solvent extracted Niger (*Guizotia abyssinica*) Seed oil. *Journal of Pharmacognosy and Phytochemistry*, **6**(2): 17-21.

Bognar, A. 1998. Comparative study of frying to other cooking techniques influence on the nutritive value. *Grasas y Aceites*, **49**(3-4): 250-260.

Bordin, K., Tomihe Kunitake, M., Kazue Aracava, K. and Silvia Favaro Trindade, C. 2013. Changes in food caused by deep fat frying-A review. *Archivos Latinoamericanos de Nutricion*, **63**(1): 5-13.

Bouchon, P. and Pyle, D.L. 2005. Modelling oil absorption during post-frying cooling: II: solution of the mathematical model, model testing and simulations. *Food and Bioproducts Processing*, **83**(4): 261-272.

Bouchon, P. 2009. Understanding oil absorption during deep-fat frying. *Advances in Food and Nutrition Research*, **57**: 209-234.

Brahmachari, B.B., 1935. Constants of Mustard Oil. *The Indian Medical Gazette*, **70**(6): 329.

Çeli̇k, Ş., Akgül, A. and Boydak, E. 2001. Seed and oil composition of some soybean cultivars experienced in Harran Plain.

Choe, E. and Min, D.B. 2007. Chemistry of deep-fat frying oils. *Journal of Food Science*, **72**(5): R77-R86.

Choe, E. and Min, D.B. 2009. Mechanisms of antioxidants in the oxidation of foods. *Comprehensive Reviews in Food Science and Food Safety*, **8**(4): 345-358.

Christian Gertz, 2014. Fundamentals of the frying process. *Eur. J. Lipid Sci. Technol.*, **116**: 0000-0000.

Chung, J., Lee, J. and Choe, E. 2004. Oxidative stability of soybean and sesame oil mixture during frying of flour dough. *Journal of Food Science*, **69**(7): 574-578.

Cobb, W.Y. and Johnson, B.R. 1973. Physicochemical properties of peanuts. *PEANUTS: Culture and Uses*: pp. 209-263.

Cornelius, J.A. 1977. International standards for palm oil. *Journal of the American Oil Chemists' Society*, **54**(12): A943-A950. Palm oil and palm Kernel oil. Progress in Chemistry of Fats and other Lipids. Pergamon Press. Great Britain. **15**: 5-27.

Costa, R.M., Oliveira, F.A., Delaney, O. and Gekas, V. 1999. Analysis of the heat transfer coefficient during potato frying. *Journal of Food Engineering*, **39**(3): 293-299.

Dana, D., Blumenthal, M.M. and Saguy, I.S. 2003. The protective role of water injection on oil quality in deep fat frying conditions. *European Food Research and Technology*, **217**: 104-109.

Das, A.K., Babylatha, R., Pavithra, A.S. and Khatoon, S. 2013. Thermal degradation of groundnut oil during continuous and intermittent frying. *Journal of Food Science and Technology*, **50**: 1186-1192.

Detwiler Jr, S.B. and Markley, K.S. 1940. Smoke, flash, and fire points of soybean and other vegetable oils. *Oil & Soap*, **17**(2): 39-40.

Devi, A. and Khatkar, B.S. 2017. Thermo-physical properties of fats and oils. *Int. J. Eng. Technocal. Res.*, **7**: 45.

Devi, S., Zhang, M., Ju, R. and Bhandari, B. 2021. Recent development of innovative methods for efficient frying technology. *Critical Reviews in Food Science and Nutrition*, **61**(22): 3709-3724.

Dijkstra, A.J. and Van Duijn, G. 2016. Vegetable oils: oil production and processing.

Dueik, V., Robert, P. and Bouchon, P. 2010. Vacuum frying reduces oil uptake and improves the quality parameters of carrot crisps. *Food Chemistry*, **119**(3): 1143-1149.

Dwivedi, S., Prajapati, P., Vyas, N., Malviya, S. and Kharia, A. 2017. A review on food preservation: methods, harmful effects and better alternatives. *Asian J. Pharm. Pharmacol.*, **3**(6): 193-199.

Eissa, H.A., Ramadan, M.T., Ali, H.S. and Ragab, G.H. 2013. Optimizing oil reduction in fried eggplant rings. *Journal of Applied Sciences Research*, **9**(6): 3708-3717.

Eryilmaz, T. and Yesilyurt, M.K. 2016. Influence of blending ratio on the physicochemical properties of safflower oil methyl ester-safflower oil, safflower oil methyl ester-diesel and safflower oil-diesel. *Renewable Energy*, **95**: 233-247.

Fang, Z., Wu, D., Yü, D., Ye, X., Liu, D. and Chen, J. 2011. Phenolic compounds in Chinese purple yam and changes during vacuum frying. *Food Chemistry*, **128**(4): 943-948.

Farinu, A. and Baik, O.D. 2007. Heat transfer coefficients during deep fat frying of sweet-potato: Effects of product size and oil temperature. *Food Research International*, **40**(8): 989-994.

Farkas, B.E., Singh, R.P. and Rumsey, T.R. 1996. Modeling heat and mass transfer in immersion frying. I, model development. *Journal of Food Engineering*, **29**(2): 211-226.

Fellows, P.J. 2022. *Food processing technology: principles and practice*. Woodhead publishing.

Fillion, L. and Henry, C.J.K. 1998. Nutrient losses and gains during frying: a review. *International Journal of Food Sciences and Nutrition*, **49**(2): 157-168.

Gamble, M.H., Rice, P. and Selman, J.D. 1987. Relationship between oil uptake and moisture loss during frying of potato slices from cv Record UK tubers. *International Journal of Food Science & Technology*, **22**(3): 233-241.

Garayo, J. and Moreira, R., 2002. Vacuum frying of potato chips. *Journal of Food Engineering*, **55**(2): 181-191.

García-Segovia, P., Urbano-Ramos, A.M., Fiszman, S. and Martínez-Monzó, J. 2016. Effects of processing conditions on the quality of vacuum fried cassava chips (*Manihot esculenta* Crantz). *LWT-Food Science and Technology*, **69**: 515-521.

Ghidurus, M.I.H.A.E.L.A., Turtoi, M., Boskou, G., Niculita, P.E.T.R.U. and Stan, V. 2010. Nutritional and health aspects related to frying (I). *Romanian Biotechnological Letters*, **15**(6): 5675-5682.

Gokoglu, N., Yerlikaya, P. and Cengiz, E., 2004. Effects of cooking methods on the proximate composition and mineral contents of rainbow trout (*Oncorhynchus mykiss*). *Food Chemistry*, **84**(1): 19-22.

Granda, C. and Moreira, R.G. 2005. Kinetics of acrylamide formation during traditional and vacuum frying of potato chips. *Journal of Food Process Engineering*, **28**(5): 478-493.

Granda, C., Moreira, R.G. and Tichy, S.E. 2004. Reduction of acrylamide formation in potato chips by low-temperature vacuum frying. *Journal of Food Science*, **69**(8): E405-E411.

Gupta, M., 2005. Frying Oils, Bailey's Industrial Oil and Fat Products, Fereidoon Shahidi (editör).

Gupta, M.K., 2005. Frying oils. *Bailey's Industrial Oil and Fat Products*, **6**: 1-31.

Henry, C.K. 1998. Impact of fried foods on macronutrient intake, with special reference to fat and protein. *Grasas y aceites*, **49**(3-4): 336-339.

Hollyer, J., Paull, R. and Huang, A. 2000. Processing taro chips.

Hwang, L.S. 2005. Sesame oil. *Bailey's Industrial Oil and Fat Products*, **2**: 547-552.

Ibrahim, N.I.F. and Khattak, M.M.A.K. 2020. Assessment of sensory attributes of mushroom chips, mixed herbs and spices using air frying method. *International Journal of Allied Healthsciences*, **4**(3): 1507-1520.

Innawong, B. 2001. Improving fried product and frying oil quality using nitrogen gas in a pressure frying system.

Ismail, R. 2005. Palm oil and palm olein frying applications. *Asia Pacific Journal of Clinical Nutrition*, **14**(4): 414.

Jamieson,G.1943. Vegetable Fats and Oils. Reinhold Publishing Corporation, New York,USA. pp. 262-280.

Jennings, B.H. and Akoh, C.C. 2009. Characterization of a rice bran oil structured lipid. *Journal of Agricultural and Food Chemistry*, **57**(8): 3346-3350.

Juvvi, P., Chakkaravarthi, A. and Debnath, S. 2016. Emerging technique for healthier frying for production of reduced-fat beetroot (*Beta vulgaris*) chips. *Journal of Food Science and Technology*, **53**: 3502-3511.

Juvvi, P., Selvi, M.K. and Debnath, S. 2020. Effect of vacuum frying on quality attributes of pear (*Pyrus communis* L) chips and blended oil. *Journal of Food Processing and Preservation*, **44**(6): p.e14488.

Kamath, K.S., PE, G., TM, P., KL, C. and TV, M. 1979. Sunflower seed oil physicochemical characteristics and industrial use.

Kapilan, N. and Reddy, R.P. 2008. Evaluation of methyl esters of mahua oil (Madhuca indica) as diesel fuel. *Journal of the American Oil Chemists' Society*, **85**: 185-188.

Katragadda, H.R., Fullana, A., Sidhu, S. and Carbonell-Barrachina, Á.A. 2010. Emissions of volatile aldehydes from heated cooking oils. *Food Chemistry*, **120**(1): 59-65.

Kumar, P.P. and Krishna, A.G. 2015. Physicochemical characteristics of commercial coconut oils produced in India. *Grasas y Aceites*, **66**(1): e062-e062.

Kumari, B., Yadav, R.P. and Singh, P.P. 2015. Ultrasonic assessment of adulteration in some edible oils using rheological parameters. *Int. J. Sci. Res.*, **6**: 2204-2208.

Lakshmikantam, V.1978. Tree Bourne Oilseeds- Resource for Gainful Employment. Directorate of oils and Soap Industry, KVIC, Irla Road, Vile parle, Bombay (Mumbai), India.1-66.

Lalam, S., Sandhu, J.S., Takhar, P.S., Thompson, L.D. and Alvarado, C. 2013. Experimental study on transport mechanisms during deep fat frying of chicken nuggets. *LWT-Food Science and Technology*, **50**(1): 110-119.

Lisinska, G. and Leszczynski, W. 1989. *Potato science and technology*. Springer Science & Business Media.

Lydersen, A. 1985. Mass transfer in engineering practice.

Maadyrad, A., Ghiassi, T.B., Bassiri, A. and Bamenimoghadam, M. 2011. Process optimization in vacuum frying of kiwi slices using response surface methodology.

Maity, T., Bawa, A.S. and Raju, P.S. 2018. Effect of preconditioning on physicochemical, microstructural, and sensory quality of vacuum-fried jackfruit chips. *Drying Technology*, **36**(1): 63-71.

Malavi Tagore, M., 1989. Physico-chemical characteristics and nutritional evaluation of oil blends based on mahua oil *(Madhuca latifolia)* and groundnut oil(Doctoral dissertation, Acharya N.G. Ranga Agricultural University, Rajendranagar Hyderabad).

Mallika, N.T., Rajalakshmi, S., Pashupathi, K.S., Ankaiah, K.N., Vibhakar, S., Krishnamurthy, M.N., Nagaraja, K.V. and Kapur, O.P. 1982. Studies on niger (*Guizotia abyssinica*) seed oil. *Journal of Food Science and Techologists'(India)*,**19**: 147-149.

Manjunatha, S.S., Ravi, N., Negi, P.S., Raju, P.S. and Bawa, A.S. 2014. Kinetics of moisture loss and oil uptake during deep fat frying of Gethi (*Dioscorea kamoonensis* Kunth) strips. *Journal of Food Science and Technology*, **51**: 3061-3071.

Mariscal, M. and Bouchon, P. 2008. Comparison between atmospheric and vacuum frying of apple slices. *Food Chemistry*, **107**(4): 1561-1569.

Millin, T.M., Medina-Meza, I.G., Walters, B.C., Huber, K.C., Rasco, B.A. and Ganjyal, G.M. 2016. Frying oil temperature: impact on physical and structural properties of French fries during the par and finish frying processes. *Food and Bioprocess Technology*, **9**: 2080-2091.

Molla, M.M., Nasrin, T.A.A., Islam, M.N. and Bhuyan, M.A.J. 2008. Preparation and packaging of jackfruit chips. *International Journal of Sustainable Crop Production*, **3**(6): 41-47.

Moreira, R.G. and Barrufet, M.A. 1998. A new approach to describe oil absorption in fried foods: a simulation study. *Journal of Food Engineering*, **35**(1): 1-22.

Moreira, R.G., Castell-Perez, M.E. and Barrufet, M.A. 1999. Deep fat frying: Fundamentals and applications.

Moreira, R.G., Sun, X. and Chen, Y. 1997. Factors affecting oil uptake in tortilla chips in deep-fat frying. *Journal of Food Engineering*, **31**(4): 485-498.

Moyano, P.C. and Pedreschi, F. 2006. Kinetics of oil uptake during frying of potato slices:: Effect of pre-treatments. *LWT-Food Science and Technology*, **39**(3): 285-291.

Moyano, P.C., Troncoso, E. and Pedreschi, F. 2007. Modeling texture kinetics during thermal processing of potato products. *Journal of Food Science*, **72**(2): E102-E107.

Mujumdar, A.S. and Devahastin, S. 2008. Guide to Industrial Drying: Principles. *Equipments & New Developments*,.

Nagaraj, G. 1995. Quality and Utility of oilseeds, Directorate of oilseed Research, Hyderabad, India, pp. 28-30.

Nagaraj, G. 2009. Oilseeds-Properties, Processing, Products and Procedures. New India publication agency.

Nawar, W.W. 1985. Chemistry of thermal oxidation of lipids. *Flavor Chemistry of Fats and Oils*, pp. 39-60.

Naz, S., Siddiqi, R., Sheikh, H. and Sayeed, S.A. 2005. Deterioration of olive, corn and soybean oils due to air, light, heat and deep-frying. *Food Research International*, **38**(2): 127-134.

Noureddini, H., Bandlamudi, S.R. and Guthrie, E.A. 2009. A novel method for the production of biodiesel from the whole stillage-extracted corn oil. *Journal of the American Oil Chemists' Society*, **86**: 83-91.

Nunes, Y. and Moreira, R.G., 2009. Effect of osmotic dehydration and vacuum-frying parameters to produce high-quality mango chips. *Journal of Food Science*, **74**(7): E355-E362.

Nwadinobi, C.P. and Ikeme, P.C. 2021. Comparative Assessment of Coconut Oils Processed from Dry and Wet Extraction Techniques. *Journal of Global Agriculture and Ecology*, **11**(2): 44-52.

O'Brien, R.D. 2002. Cotton seed oil. In *Vegetable Oils in Food Technology: Composition, Properties and Uses* (pp. 203-230). Blackwell Publishing Ltd..

Ofodile, S.E., Boisa, N., Obunwo, C.C. and Frank, O.M. 2018. Characterisation of oil properties from Niger Delta crude. *J. Environ. Anal. Toxicol.*, **8**(2): 1-7.

Oke, E.K., Idowu, M.A., Sobukola, O.P., Adeyeye, S.A.O. and Akinsola, A.O. 2018. Frying of food: a critical review. *Journal of Culinary Science & Technology*, **16**(2): 107-127.

Oluwaniyi, O.O., Dosumu, O.O. and Awolola, G.V. 2010. Effect of local processing methods (boiling, frying and roasting) on the amino acid composition of four marine fishes commonly consumed in Nigeria. *Food Chemistry*, **123**(4): 1000-1006.

Omer, N.M.A., Ali, E.A., Mariod, A.A. and Mokhtar, M. 2015. Chemical reactions taken place during deep-fat frying and their products: a review. *SUST Journal of Natural and Medical Sciences*, **16**(1): 1-16.

Omobuwajo, T.O. 2003. Compositional characteristics and sensory quality of biscuits, prawn crackers and fried chips produced from beadfruit. *Innovative Food Science & Emerging Technologies*, **4**(2): 219-225.

Onyejegbu, C.A. and Olorunda, A.O. 1995. Effects of raw materials, processing conditions and packaging on the quality of plantain chips. *Journal of the Science of Food and Agriculture*, **68**(3): 279-283.

Orthoefer, F.T. and List, G.R. 2007. Dynamics of frying. In *Deep frying* (pp. 253-275). AOCS Press.

Osman, A. 2020. Cold pressed Niger (*Guizotia abyssinica* Cass.) seed oil. *Cold Pressed Oils*, pp. 385-390.

Ouchon, P.B., Aguilera, J.M. and Pyle, D.L. 2003. Structure oil-absorption relationships during deep-fat frying. *Journal of Food Science*, **68**(9): 2711-2716.

Pal, U.S., Patra, R.K., Sahoo, N.R., Bakhara, C.K. and Panda, M.K. 2015. Effect of refining on quality and composition of sunflower oil. *Journal of Food Science and Technology*, **52**: 4613-4618.

Pandey, A.K., Ravi, N. and Chauhan, O.P. 2020. Quality attributes of vacuum fried fruits and vegetables: a review. *Journal of Food Measurement and Characterization*, **14**(3): 1543-1556.

Parthasarathy, U., Nandakishore, O.P., Senthil Kumar, R. and Parthasarathy, V.A. 2014. A comparison on the physico-chemical parameters of seedbutters of selected *Indian garcinia* spp.

Pedreschi, F. and Aguilera, J.M. 2002. Some changes in potato chips during frying observed by confocal laser scanning microscopy (CLSM). *Food Science and Technology International*, **8**(4): 197-201.

Pedreschi, F. and Zúñiga, R.N., 2009. Kinetics of quality changes during frying. *Advances in Deep-fat Frying of Foods*, pp. 81-113.

Pokorny, J. 1999. Changes of nutrients at frying temperatures. *Frying of food Oxidation, nutrient and non-nutrient antioxidants, biologically active compounds and high temperatures. Technomic, Lancaster, PA*: 69-103.

Pokorny, J. 1999. Changes of nutrients at frying temperatures. *Frying of food Oxidation, nutrient and non-nutrient antioxidants, biologically active compounds and high temperatures. Technomic, Lancaster, PA*: 69-103.

Pokorny, J. 1999. Changes in nutrients at frying temratures. In:Frying of food. Eds:Boskou D., Elmadfa I. CRC Press.

Pooja, M.R. and Sudheer, K.P. 2018. Development and evaluation of process protocol for vacuum fried bitter gourd chips (*Momordica charantia*) (Doctoral dissertation, Department of Post-Harvest Technology and Agricultural Processing).

Ramesh babu and Dr Sharanappa Godiganur, 2018. Niger Seed (*Guizotia Abyssinica*) as a Source of Biodiesel in India. International Journal of Engineering Research and Technology (I J E R T)

Ranganatha, A.R.G., Panday, A.K., Bisen, R., Jain, S. and Sharma, S. 2016. Niger. In *Breeding Oilseed Crops for Sustainable Production* (pp. 169-199). Academic Press.

Reda, S.Y. 2004. Comparative study of vegetable oil subjected to the thermal stress. Master Dissertation,Universidade Estadual De Ponta Gross.

Ren, A., Pan, S., Li, W., Chen, G. and Duan, X. 2018. Effect of various pretreatments on quality attributes of vacuum-fried shiitake mushroom chips. *Journal of Food Quality*, *pp.* 1-7.

Riaz, T., Iqbal, M.W., Mahmood, S., Yasmin, I., Leghari, A.A., Rehman, A., Mushtaq, A., Ali, K., Azam, M. and Bilal, M. 2023. Cottonseed oil: A review of extraction techniques, physicochemical, functional, and nutritional properties. *Critical Reviews in Food Science and Nutrition*, **63**(9): 1219-1237.

Romano, R., Aiello, A., De Luca, L., Pizzolongo, F., Durazzo, A., Lucarini, M., Severino, P., Souto, E.B. and Santini, A. 2022. Deep-frying purple potato Purple Majesty using sunflower oil: effect on the polyphenols, anthocyanins and antioxidant activity. *Heliyon*, **8**(5).

Salehi, F. 2019. Color changes kinetics during deep fat frying of kohlrabi (*Brassica oleracea var. gongylodes*) slice. *International Journal of Food Properties*, **22**(1): 511-519.

Sangmithra Asokapandian 2019

Setyawan, A.D., Sugiyarto, S., Solichatun, S. and Susilowati, A. 2013. Physical, physical chemistries, chemical and sensorial characteristics of the several fruits and vegetable chips produced by low-temperature of vacuum frying machine. *Nusantara Bioscience*, **5**(2).

Shenolikar, I.S. 1985. Nutritional qualities of rapeseed/mustard. In *Oilseed production: constraints and opportunities: proceedings of the Symposium on Oilseed Production and Utilisation--Constraints and Opportunities, September 1984, New Delhi/editors, HC Strivastava...[et al]*.

Skrede, G., Nilsson, A., Baardseth, P., Rosenfeld, H.J., Enersen, G. and Slinde, E. 1997. Evaluation of carrot varieties for production of deep fried carrot chips—III. Carotenoids. *Food Research International*, **30**(1): 73-81.

Sonntag, N.O.V., 1979. Composition and characteristics of individual fats and oils. *Bailey's Industrial Oil and Fat Products*, **1**: 289-477.

Sonntag, N.O.V. 1979. Composition and Characteristics of Individual Fats and Oils, *In*. Bailey's Industrial oil and Fat Products, Vol.1, Ed. D. Swern, A Wiley-Interscience Publication, New York. U.S.A.pp.311-398.

Sothornvit, R. 2011. Edible coating and post-frying centrifuge step effect on quality of vacuum-fried banana chips. *Journal of Food Engineering*, **107**(3-4): 319-325.

Srimiati, M., Maharani, A.R., Zahra, A.D., Harsanti, F. and Habibah, P. 2023. Frying Time on the Nutritional Content of Strawberry Chips as an Alternative Healthy Snack for Teenagers. *Journal Ilmiah Kesehatan (JIKA)*, **5**(1): 97-105.

Stevenson, S.G., Vaisey-Genser, M. and Eskin, N.A.M. 1984. Quality control in the use of deep frying oils. *Journal of the American Oil Chemists Society*, **61**: 1102-1108.

Tan, C.H., Ghazali, H.M., Kuntom, A., Tan, C.P. and Ariffin, A.A. 2009. Extraction and physicochemical properties of low free fatty acid crude palm oil. *Food Chemistry*, **113**(2): 645-650.

Therdthai, N., Wuttijumnong, P., Jangchud, A. and Kusucharid, C. 2007. Optimization of vacuum frying condition for shallot. *Agriculture and Natural Resources*, **41**(5): 338-342.

Tyagi, P. and Vasishtha, A.K. 1983. Component fatty acids and glycerides of oils from different genetic varieties of Sesamum indicum.

Ufheil, G. and Escher, F. 1996. Dynamics of oil uptake during deep-fat frying of potato slices. *LWT-Food Science and Technology*, **29**(7): 640-644.

Varela, G. and Ruiz-Rosso, B. 1998. Frying process in the relation fat/degenerative diseases. *Grasas y aceites*, **49**(3-4): 359-365.

Varela, G., Bender, A.E. and Morton, I.D. 1988. Frying of food: Principles, changes, new approaches. *(No Title)*.

Vibhakar, S., Rajalakshmi, S., Nagaraja, K.V. and Kapur, O.P. 1981. Physico-chemical characteristics of safflower oil. *Indian Food Packer*, **35**(1): 11-12.

Vitrac, O., Dufour, D., Trystram, G. and Raoult-Wack, A.L. 2001. Deep-fat frying of cassava: influence of raw material properties on chip quality. *Journal of the Science of Food and Agriculture*, **81**(2): 227-236.

Wanakamol, W. and Poonlarp, P. 2018. Effects of frying temperature, frying time and cycles on physicochemical properties of vacuum fried pineapple chips and shelf-life prediction. *International Food Research Journal*, **25**(6).

Warner, K. 2002. Chemistry of frying oils. *Food Lipids*, pp. 224-241.

Wibowo, E. 2012. Making of gembili chips (*Dioscorea esculenta* L.) with a variable length of frying time using vacuum fryer [Hon. Thesis]. Faculty of Engineering, Diponegoro University, Semarang. [Indonesian]

Williams, K.A. 1966. Oils fats and Fatty Foods, Their Practical Examination. J.A. Churchill Ltd. London, pp. 3-7.

Xue, Y.L., Han, H.T., Liu, C.J., Gao, Q., Li, J.H., Zhang, J.H., Li, D.J. and Liu, C.Q. 2020. Multivariate analyses of the volatile components in fresh and dried turnip (*Brassica rapa* L.) chips via HS-SPME–GC–MS. *Journal of Food Science and Technology*, **57**: 3390-3399.

Yamsaengsung, R., Ariyapuchai, T. and Prasertsit, K. 2011. Effects of vacuum frying on structural changes of bananas. *Journal of Food Engineering*, **106**(4): 298-305.

Yi, J.Y., Lyu, J., Bi, J.F., Zhou, L.Y. and Zhou, M. 2017. Hot air drying and freeze drying pre-treatments coupled to explosion puffing drying in terms of quality attributes of mango, pitaya, and papaya fruit chips. *Journal of Food Processing and Preservation*, **41**(6): e13300.

Yodkraisri, W. and Bhat, R. 2012. Quality evaluation of deep fried chips produced from lotus rhizome. *International Food Research Journal*, **19**(4).