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The Chemistry of Fats and Oils for Healthy Choices

Ikeoluwa Folasade ADEOYE (PhD)

Department of Integrated Science,

School of Secondary Education (Science Programmes)

Emmanuel Alayande College of Education,

Oyo, Oyo State.

Nigeria.

Email: ikeoluboye@yahoo.com Mobile: +2348038235302

Abstract

Fats and oils are essential components of a good diet consisting of edible and non-edible fats. The compositions and constituents of fats and oils have health implications on the consumers. It is important for consumers to be aware of the chemistry of fats and oils to make rightful choices for their diets and other uses. The sources, chemical compositions, structures, classes, physical and chemical properties, and the uses of fats and oils are reviewed. The choice of consumptions of fats and oils should be based on their health values and other beneficiary purposes.

Key words: Fatty acids, glycerol, triglyceride, esterification, saponification and rancidity.

Introduction

Fats and oils occur naturally in living things. There are two major sources of fats and oils which are from the tissues of animals either from marine and terrestrial habitats and from plants. Fats and oils from animals include fish oil and cod-liver oil from fish and butter, tallow and lard from land animals. Fats and oils that are found in fruits and seeds of plants are cocoa butter, palm oil, coconut oil, cotton seed oil, corn oil, groundnut oil, sunflower seed oil, soya bean oil and olive oils. These oils are called vegetable oil.

Functions of Fats and Oils

Fats and oils are essential ingredients for food. They provide energy for living organisms, insulate body organs, and transport fat-soluble vitamins through the blood. Fats and oils are used in manufacturing of margarine, soaps, as shortening and emulsifier in baking cake, confectionaries, candles, paints and varnishes.

Chemical Compositions of Fats and Oils

Fats and oils are called triglycerides because they are natural esters composed of three long-chain fatty acid units joined to glycerol, a trihydroxy alkanol. The trihydroxy alkanol is propane-1, 2, 3-triol known as glycerol and a fatty acid is monoalkanoic acid with long straight chain of 12 carbon or more carbon atoms. Therefore, fats and oils are glycerol esters, glycerides which are the mixture of propane -1, 2, 3 - triol and long chain fatty acid (Ojokuku, 2017). Naturally occurring fats and oils cannot be represented with a single formula because they are highly complex mixtures of triglycerides in which many different fatty acids are present.

The constituents of fats and oils in some oils are:

Palm oil has palmitic acid with 44 - 45 % balanced level of saturated fatty acid that is almost equal to that of unsaturated fatty acid. It has oleic acid, 39 – 40 % as major constituent acid with linoleic of 11 % and trace amount of linolenic (Lawson, 2013). The low level of linoleic acid and the virtually absence of linolenic acid make palm oil relatively stable to oxidation. The dark red coloured palm oil has high concentration of carotenoids and anthocyanins as antioxidants. It also contains high concentrations of vitamin E that is present as tocopherols and tocotrienols that have health values.

Canola oil is obtained from rapeseed plant. It has a low level of saturated fatty acids of about 6 %. The stability of the oil is limited by presence of linolenic acid, chlorophyll and its decomposition products rind other minor components with high chemical reactivity. It is high in tocopherol (Ogori, 2020).

Olive oil: Virgin oil is obtained from the fruits of the olive tree. It is a mixture of triglyceride with majorly palmitic, palmitoleic, oleic and linoleic acids. It has 71 % of unsaturated oleic acid. Virgin olive oil has not been deodorised to remove natural olive oil flavour elements which has health values for the consumers.

Soybean oil extracted soybeans which are the biggest source of edible oil in the world. The high polyunsaturated fatty acid content (over 60 %, including 6 - 10 % α-linolenic acid) in soybean oil makes it very attractive, as it meets our requirement for essential fatty acid. The polyunsaturated fats in soybean oil are linked to lowing cholesterol levels and reduce risk of heart disease. It also contains heart-healthy omega-3 fatty acids.

Classifications of Fats and Oils

Glycerol has three hydroxyl groups to combine with one, two or three molecules of a fatty acid to give a monoglyceride, diglyceride or triglyceride, respectively. If all three OH groups on the glycerol molecule are esterified with the same fatty acid, the resulting ester is called a simple triglyceride. These triglycerides can be synthesised in the laboratory. They rarely occurred in nature. However, a typical triglyceride obtained from naturally occurring fats and oils contains two or three different fatty acid components. This is known as a mixed triglyceride.

$CH_2 — O — H$ $\qquad\qquad\qquad\qquad$ $R' COOCH_2$

$CH — O — H \quad + \quad 3R'COOH \longrightarrow R' COOCH \quad + 3H_2O$

CH_2 —O— H R′ $COOCH_2$

Propane-1, 2, 3-triol Fatty Acid ($R \geq 12$) Simple glyceride

(Glycerol)

Example is tristearin

H_2C — O — C — CH_2 $(CH_2)_{13}$ CH_3

| O ||

HC — O — C — CH_2 $(CH_2)_{13}$ CH_3

| O ||

H_2C — O — C — CH_2 $(CH_2)_{13}$ CH_3

A simple triglyceride

When R is different, mixed glyceride is produced; R′$COOCH_2$

|

R″COOCH

|

R‴$COOCH_2$

O ||

H_2C — O — C — CH_2 $(CH_2)_{11}$ CH_3

| O ||

HC — O — C — CH_2 $(CH_2)_{13}$ CH_3

| O ||

H_2C — O — C — $(CH_2)_7$ CH = CH$(CH_2)_7$

Mixed glyceride

Fats and oils can also be classified as saturated if the alkyl groups in the fatty acid are singly-bonded while those with one or more double bonds are known as unsaturated glycerides. The saturated glycerides are fats that generally of animal origin while the unsaturated glycerides are oils from plant origin.

Examples of natural common triglycerides are:

1. Palmitic acid (palm oil), hexadecanoic acid; $CH_3(CH_2)_{14}COOH$

2. Stearic acid (animal fats), octadecanoic acid; $CH_3(CH_2)_{16}COOH$

3. Oleic acid (peanuts oil, olive oil), octadeca- 9 -enoic acid;

$CH_3(CH_2)_7CH=CH(CH_2)_7 COOH$

4. Linoleic acid (vegetable oil), octadeca - 9, 12 - dienoic acid; $CH_3(CH_2)_4CH=CHCH_2CH=CH(CH_2)_7$ COOH

5. Linolenic (vegetable oils), octadeca - 9, 12, 15 - trienoic acid;

$CH_3(CH_2)_2CH=CHCH=CHCH_2CH=CH(CH_2)_7COOH$

Physical Properties of Fats and Oils

Fats and oils are general insoluble in water but are highly soluble in organic solvents such as benzene, ether, alcohol and chloroform (trichloromethane). Fats are more saturated than oils as a result fats melts at higher temperature than oils because fats contain higher proportion of esters of saturated fatty acids. Fats and oils have no pure forms; they have no sharp melting or boiling points because they are homogenous mixtures of two or more triglycerides. Fats are solid or semi-solid at room temperature because they triglycerides contain more of saturated fatty acids e.g. palmitic and stearic acids. Oils contain unsaturated fatty acid and therefore are liquid at room temperature. Pure fats and oils are colourless and odourless. If colour and odour are observed, they are due to the presence of small quantity of non-fatty substances. Fats and oils can decompose at temperature above 300°C.

Chemical Properties of Fats and Oils

The chemical reactions of fats and oils are essentials in chemical industries. Fats and oils undergo the following reactions.

1. Hydrogenation of Oils

Oil can be changed into fat by hydrogenation known as hardening of oil because it produces solid fats. The process involves passing hydrogen into unsaturated oil at about 200°C and pressure within 2-5 atmospheres in the presence of finely divided nickel catalyst. The unsaturated part of the oil is saturated and the oil becomes hardened.

$$\text{Vegetable oil} \underset{H_2,\ Ni}{\overset{200^\circ C\ 5atm.}{\rightleftharpoons}} \text{Margarine}$$

In the preparation of margarine, for example, partially hydrogenated oils are mixed with water, salt, and non-fat dry milk, along with flavouring agents, colouring agents, and vitamins A and D, which are added to approximate the look, taste, and nutrition of butter.

2. Formation of soap (Saponification)

The general process of alkaline hydrolysis fats and oils with either sodium or potassium yields propane-1, 2, 3-triol and the correspondinding sodium or potassium salts of the component fatty acids. These salts are the principal constituents of soap. The reaction equation is as shown.

$R^{/}COOCH_2$			$R^{/}COONa$		$HO\text{-}CH_2$
$R^{//}COOCH$	$+ 3NaOH$	$\longrightarrow$	$R^{//}COONa$	$+$	$HO\text{-}CH$
$R^{///}COOCH_2$			$R^{//}COONa$		$HO\text{-}CH_2$
Fat or Oil	Caustic alkali		Soaps		Propane-1, 2, 3-triol

Commercially, soap is produced from animal fats or vegetable oils. The oils are steam-heated in large vats with sodium or potassium hydroxide until saponification is completed. A concentrated sodium chloride solution is then added to decrease the solubility of the soap so that it separates (salting) out as a hard cake on the surface on cooling. Dyes, perfumes and disinfectants are added as required, before the soap is pressed into bars or tablets.

The properties of the soap produced depend on the alkali and the fat or oil used. Hard soaps used for laundering are chiefly composed of the sodium salts of saturated acids while softer toilet soaps are composed of the potassium salts of unsaturated acids.

Soap molecule possesses a long hydrocarbon chain R, attached to an ionic head which is either COO^-Na^+ or $COO^- K^+$. For example, sodium octadecanoate (stearate) with the formula $CH_3(CH_2)_{16}COO^-Na^+$ has along non-polar hydrocarbon tail R; $C_{17}H_{35}$ that is hydrophobic and a polar end of COO^-Na^+ which hydrophilic in nature. The hydrocarbon tail, hydrophobic (water-hating) is insoluble in water but soluble in oil or organic solvents while ionic head, hydrophilic (water-loving) is soluble in water. As a result of this dual nature, at the interphase of an aqueous-oil layer, soap molecules arrange themselves when dissolved in water to form spherical clusters called micelles. Repulsion between the similarly charged ionic head keeps the micelles apart.

When soap solution as a cleansing agent is applied to a grease-coated piece of fabric, the soap molecules first approach the grease spot. At the interphase of the grease and water, the hydrophobic tails of the soap particles dissolve in grease while the hydrophilic heads dissolve in the water. The water molecules attract the polar ionic heads of the soap molecules. This action helps to lift the grease spot upwards, enabling more soap particles to dissolve in the grease. With mechanical scrubbing, the grease patch is emulsified and is removed.

The cleansing power of the soap increases as the hotness of the water that is used in washing increases and the dirts are removed easily. The hard water which contains dissolved calcium, magnesium or iron (II) reacts with soap to form a dirty-white insoluble salt called scum. The scum limits soap from forming lather. In acidic water, the anion in soap; $RCOO^-$ combines with H^+ to form RCOOH which reduces the cleansing power of the soap.

Soap is a detergent which is any substance that has the ability to clean an object. Detergent includes soaps, soap powders and washing liquids as well as water. Detergents are grouped into two main types as soapy detergent and soapless detergents. Soapy detergents are simply soap of sodium or potassium salts of fatty acids. Soap is a good cleansing agent in soft water. In hard water, it forms scum. In acidic water it reacts with the excess hydrogen ions to form unionized fatty acids. This lowers the cleaning action of the soap. Soap is also biodegradable, that is, it can easily be decomposed by bacterial into simple inorganic substances so it does not cause water pollution.

Soapless detergent is more favoured and all-purpose cleansing agent because it is not affected by hardness of water. Soapless detergents are made from petroleum products, so vegetable oils are saved for other uses. A typical soapless detergent is made from a complex alkene of about 12 to 18 carbon. The alkene is first treated with concentrated tetraoxosulphate (VI) acid that is sulphonated.

$$C_{15}H_{31(aq)} + H_2SO_{4(aq)} \longrightarrow C_{15}H_{31}SO_3H_{(aq)} + H_2O$$

Alkene Sulphonated alkene

The resulting sulphonated alkene is treated with sodium hydroxide solution to convert it to the sodium salt of the sulphonated alkene which is the detergent.

$$C_{15}H_{31}SO_3H_{(aq)} + NaOH \longrightarrow C_{15}H_{31}SO_3Na + H_2O$$

Detergent

The most widely used soapless detergents are the alkylbenzesulphonates abbreviated as ABS. like soap, the detergent molecule has a hydrophobic tail and a hydrophilic head. The hydrophobic tail is either a long chain hydrocarbon or a benzene ring with a long alkyl group attached. The hydrophilic head, unlike soap molecules can be positively or negatively charged or even neutral. The high solubility of soapless detergents in water is due to the $–SO_3^- Na^+$ group that is present in the molecules. Soapless detergents do not form scum or react with hydrogen ions in acidic water. They retain their cleansing properties, in respective of the type of water used. In aqueous solution, detergents are neutral, whereas soaps hydrolysed to give a slightly alkaline solution which may not be suitable for washing acid-sensitive fabrics.

Soapless detergents are not biodegradable, and so, create water pollution problems when their foams clog up waterways. Nowadays, most detergents are manufactured with straight hydrocarbon chains, and so are biodegradable. Soapless does not form scum with hard water because their calcium and magnesium are soluble in water. Commercial detergents, even soaps also contain substances such as perfumes, brighteners, dyes and antiseptics. The most common of these is sodium tripolyphosphate. Since phosphates are good fertilizers, the cause the algae in waterways to multiply beyond control and clog water ways.

3. Acid Hydrolysis of Fats and Oils

When fats and oils are boiled with water in the presence of concentrated tetraoxosulphate (VI), H_2SO_4, produces propane-1, 2, 3-triol (glycerol) and a mixture of saturated or unsaturated fatty acids depending on the glyceride. The mixed glyceride products are shown:

$C_{17}H_{35}COOCH_2$		$C_{17}H_{35}COOH$		$H - O - CH_2$
$C_{17}H_{33}COOCH$	$+ H_2O\ H^+ \longrightarrow$	$C_{17}H_{33}COOH$	+	$H - O - CH$
$C_{15}H_{31}COOCH_2$		$C_{15}H_{31}COOH$		$H - O - CH_2$
		3 molecules of different fatty acids		Propane-1, 2, 3-triol (glycerol)

For single glyceride, the products are as shown:

$C_{17}H_{35}COOCH_2$		$C_{17}H_{35}COOH$		$H - O - CH_2$
$C_{17}H_{35}COOCH$	$+ H_2O\ H^+ \longrightarrow$	$C_{17}H_{35}COOH$	+	$H - O - CH$
$C_{17}H_{35}COOCH_2$		$C_{17}H_{35}COOH$		$H - O - CH_2$
Octadecanoate		3 molecules of octadecanoic acids		Propane-1, 2, 3-triol (glycerol)

These products can be separated by fractional distillation.

4. Oxidation Reaction of Fats and Oils

Rancidity occurs when fats and oils are exposed to air, light, moisture or by bacterial action, resulting into unpleasant taste and odour. Rancidity generally is the complete or incomplete oxidation or hydrolysis of fats and oils when expose to light, air, moisture or bacterial activity. Oils oxidation occurs in two stages called primary and secondary oxidation. Primary oxidation is addition of oxygen to double bond position to form peroxides. The peroxides have no taste or smell, but are very harmful. Oil can have a large percentage of peroxides but still smell and taste as when it was fresh. The change to the oil's sensory attributes occurs when the peroxides break down in the process of secondary oxidation. Secondary oxidation produces volatile fatty acid compound which affect the taste and smell of the oil. This is the method used in sensory analysis. The rate of oxidation is greatly accelerated at high temperature. The stability of a fat or oil may be predicted to some degree by determining the Oxidative Stability Index (OSI). The more unsaturated the fat or oil, the greater will be its susceptibility to oxidative rancidity than predominantly saturated oils (i.e., coconut oil, palm oil). Dimethylsilicone; Si $(CH_3)_2O$, a tasteless, odourless and non-toxic substance is usually added to frying fats and oils to reduce oxidation tendency and foaming at elevated temperatures.

Fats and oils react with moist air at room temperature eventually undergo oxidation and hydrolysis reactions that cause them to turn rancid, acquiring a characteristic disagreeable odour. The cause of the odour is the release of volatile fatty acids by hydrolysis of the ester bonds. For example, butter releases foul-smelling butanoic (butyric), octanoic (caprylic) and decanoic (capric) acids. The process is catalysed by presence of microorganisms in the air. Hydrolytic rancidity can easily be prevented by covering the fat or oil and keeping it in a refrigerator. Antioxidants are whose affinity for oxygen is greater than that of the lipids are added to products made from fats and oils.

Types of Fats

1. Saturated fats: is a type of fat in which the fatty acid chains have all single bonds and are mostly solid at room temperature. Example includes beef, pork, lamb, dark chicken meat, high-fat dairy food (whole milk, butter, cheese, tropical oils e. g. coconut oil, cocoa butter, lard (pork). They are called 'bad fat' because they raise blood cholesterol.

2. Monounsaturated fats (MUFA): are fatty acids that have one double bond in the fatty acid chain. Examples are almonds, cashews, sesame, peanut, sunflower and soybean. Omega-9 fatty acids are monounsaturated that one double bond located nine carbons from the omega end of the fatty acid molecule. Oleic is the most common abundant fats in most cells in the body. Garg, 1998 and Gerhard et al, 2004 found that high-monounsaturated fat diets could reduce plasma triglycerides by 19 % and a very low-density-lipoprotein (bad fat) cholesterol by 22 % in patients with diabetes. Finucane et al (2015) found that feeding mice with diets high in monounsaturated fats improved insulin sensitivity, decrease inflammation, protect the heart, promote weight loss, and healthy energy levels. Healthy choices include avocado, macadamia nuts, olives and olive oil while less healthy choices are canola oil (unless it is organic, canola oil is made from Genetically Modified Organisms (GMOs) and is highly processed and refined. Peanuts tend to be high in

moulds, which produce a aflatoxin, a toxin known to cause cancer. Peanuts also cause inflammation and are highly allergenic.

3. Polyunsaturated Fats (PUFA) have more than two double bonds in all the fatty acid chains. These include flax seed or oil, fish such as mackerel, herring, salmon, corn oil, soybean and safflower. Polyunsaturated fat contains Omega 3 and Omega 6 fats. Omega 3 reduces inflammation, support healthy hormone levels and cell membranes. Omega 6 fatty acids are important to support healthy brain and muscle functions. However, they promote inflammation in the body. A small amount of omega 6 fatty acids is needed. Corn, soybean, safflower, cottonseed, grape seed and sunflower oils are all high in omega 6.

4. Trans-fats are a form of unsaturated fat. They come in either natural or artificial. The natural include meat, dairy such as cattle, sheep and goats. However, artificial trans-fat partially hydrogenated fats to produced rancidities of peroxides and volatile unsaturated fatty acids. This is the worst type of fat *because i*t is a by-product of a process of hydrogenation that is used to turn healthy oils into solids and to prevent them from becoming rancid and are capable of increase heart disease and other health problems. Eating moderate amounts of polyunsaturated and monounsaturated fat in place of saturated and trans-fats have great health benefits.

PUFA can be further categorised into three main families according to the position of the first double bond starting from the methyl-end (the opposite side of the glycerol molecule) of the fatty acid chain:

- Omega-3 (or n-3) fatty acids have the first double bond at the third carbon atom and include mainly alpha linolenic acid (ALA) is a 18-carbon fatty acid and its derivatives eicosapentaenoic acid (EPA) is a 20-carbon fatty acid, and docosahexaenoic acid (DHA) a 22-carbon fatty acid.
- Omega-6 (or n-6) fatty acids have the first double bond at the sixth carbon atom and include mainly linoleic acid (LA) and its derivative arachidonic acid (ARA).

Polyunsaturated fats include omega-3 and omega-6 fats can help lower the Low Density Lipoprotein LDL (bad) cholesterol and reduces the risk for heart diseases. Cholesterol is a soft, waxy substance that can cause clogged or blocked arteries (blood vessels). Our bodies do not make essential fatty acids. They are gotten from diet. Omega-3 fatty acids help in reducing triglycerides, a type of bad fat in your blood, reduce the risk of developing an irregular heartbeat (arrhythmia), lowering the build-up of plaque in your arteries and slightly lower blood pressure. Omega-6 fatty acids are essential fatty acids for brain function and cell growth. They may also help the control blood sugar thereby reducing risk of heart attacks for diabetes and lower blood pressure (Hermandez, 2015 and Robertson, 2017).

Conclusion

Most of the foods man consumes have different types of fats and oils. The amounts of the fats and oils compositions are higher than the others in foods. Consumers are to check the total fats compositions in one serving food. We should avoid consumption of much saturated fat and trans-fat and make sure most of our daily fats are from monounsaturated and polyunsaturated, that are rich in omega-3 and omega-6 sources. Antioxidants can should be incorporated into our meals. The food rich in these substances are flaxseed, walnuts, blueberries and grapes to boost immune system, help protect against cancer and heart diseases.

References

Finucane, O.M., Lyons, C.L., & Murphy, A. M. (2015). Monounsaturated fatty acid-enriched high-fat diets impede adipose NLRP3 inflammasome-mediated IL-Iβ secretion and insulin resistance despite obesity. *Diabetes, 64(6), 2116-2128*.

Garg, A. (1998). High-monounsaturated-fat diets for patients with diabetes mellitus: a meta-analysis. *The American Journal of Clinical Nutrition, 67(3), 577-582*.

Gerhard, G. T., Ahmann, A., Meeuws, K., Murry, M. P., Duell, P. B. & Connor, W. E. (2004). Effects of a low-fat diet compared with those of a high-monounsaturated fat diet on body weight, plasmalipids and lipoproteins, and glycemic control in type 2 diabetes. *The American Journal of Clinical Nutrition, 80(3), 668-673.*

Lawson, H. W. (2013). Food Oil and Fats: Technology, Utilization and Nutrition. *Food and Nutrition Sciences, 4(1), 203-280.*

Ojokuku, G. O. (2017). *Understanding chemistry for Schools and Colleges*. Macchin Multmedia Designers.

Ogori, A.F. (2020). Source, extraction and constituents of fats and oils. *Journal of Food Science & Nutrition, 6:060, 2-8*.

Hermandez, E. M. (2015). Omega 3 oils and blends, trait-modified oils in foods. https://www.onlinelibrary.wiley.com

Robertson, R. (2017). *Omega-3-6-9 fatty acid: A complete overview.* https://www.healthline.com