**CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE**

**Faculty of Tropical AgriSciences**

# CHEMICAL ANALYSIS OF LIPIDS, FATTY ACIDS AND VOLATILE SUBSTANCES OF SELECTED TYPES OF NUTS AND SEEDS

MASTER'S THESIS

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# Declaration

I hereby declare that I have done this thesis entitled CHEMICAL ANALYSIS OF LIPIDS, FATTY ACIDS AND VOLATILE SUBSTANCES OF SELECTED TYPES OF NUTS AND SEEDS independently, all texts in this thesis are original, and all the sources have been quoted and acknowledged by means of complete references and according to Citation rules of the FTA.

In Prague 24/04/2024

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Ndah Morine Akuro

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## Abstract

Lack of comprehensive data on the chemical composition of some nuts and seeds has made proper dietary recommendation difficult. Thus, there is the growing need to understand what this nut offers to individual diets. Additionally, the diversity of nuts and seeds has made it more expedient to explore deep into what makes each nut and seed unique to be able to effectively classify them for use and get the best of what such nuts and seeds offer rather than just eating it for fun.

The aim of the work was to analyse the fatty acids and volatile compounds of selected nuts and seeds such as rondelles (*Afrostyrax lepidophyllus)*, Njangsang (*Ricinodendron heudelotii*), tiger nut *Cyperus esculentus*), and sacha inchi or caso nuts *Plukenetia volubilis*) from Cameroon.

To achieve this, the **Soxhlet Extraction method** for the oil extraction was used, while the GC-MS was used for analysis.

It was discovered that tiger nuts had 9 fatty acids comprising of Oleic acid (76.19%), Palmitic acid (11.35%), and Stearic acid (8.01%) as the major ones. In addition, sacha inchi peanuts had 7, with mainly Linolenic acid (94.57%). Furthermore, two varieties of njansang were used i.e., njansang (*R. heudelotii var. africanum.*) and njansang *(R. heudelotii var. heudelotii)***.** It was discovered that both varieties are rich in polyunsaturated fatty acids comprising of were Eleostearic acid (51.7-54.83%), Linoleic acid (28.68-32%), and Linolenic acid (10.04%), Stearic acid (7.07%).and Palmitic acid (4.7%). While Rondelles had 14 fatty acids with palmitic acid (57.88%), Lauric acid (19.43%), and Myristic acid (3.89%)

For the volatile components, 27 volatile components were identified in tiger nuts,comprising mainly of Benzene, 1-ethyl-2-methyl-1-methyl-3-(1-methylethyl) (24.22%), and γ-terpinene (23.83). Furthermore, 12 in sacha inchi peanut comprising mainly of m-Cymene (43.56%), γ-Terpinene (36.5%). Additionally, njansang (*R. heudelotii var. africanum*) had 23 with pentanal (29.64%), 2-hexenal (12.19%), 2-heptenal (12.14%), as leading quantities. While *(R. heudelotii var. heudelotii)* contained 32, with same major compounds as *heudelotii var. africanum*). Finally, Rondelles had 6 components identified, Bis(methylthiomethyl) disulfide (74.19%), major ones.

**Key words**: nut, seeds, fatty acid, FAME, Soxhlet extraction, SPME, GC-MS

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## List of the abbreviations used in the thesis.

| | |
|---|---|
| ALA | Alpha-linolenic acid |
| Cal IR | Calculated Retention Index |
| CHD | Coronary Heart Disease |
| $CO_2$ | Carbon dioxide |
| DHA | Docosahexaenoic acid |
| EFA | Essential Fatty Acids |
| EPA | eicosapentaenoic acid |
| FA | Fatty Acids |
| FAME | Fatty Acid Methyl Ester |
| GC | Gas Chromatography |
| HDL | High-Density Lipoprotein |
| IUPAC | International Unit of Pure and Applied Chemistry |
| LCFA | Long Chain Saturated Fatty Acids |
| LDL | Low-Density Lipoprotein |
| MCFA | Medium chain Saturated Fatty Acids |
| MCT | Medium chain triacylglycerols |
| MS | Mass Spectrometry |
| MUFA | Monounsaturated Fatty Acid |
| MW | Molecular weight |
| NIST | National Institute of Standards and Technology |
| pH | Potential Hydrogen |
| PUFA | Polyunsaturated Fatty Acid |
| RI LIT | Retention Index Literature |
| RI | Retention Index |
| RT | Retention Time |

| | |
|---|---|
| SCFE | Supercritical Fluid Extraction |
| SDE | Simultaneous Distillation Extraction |
| SFA | Saturated Fatty Acid |
| SI | Sacha inchi |
| SPME | Solid-Phase Microextraction |
| TAG | Triacylglycerides |
| TEI | Total Energy Intake |
| USA | united states of America |
| Var | Variety |
| VLCFA | Very Long Chain Saturated Fatty Acids |
| WHO | World Health Organization |

# 1. Introduction and Literature Review

## 1.1. Introduction

Nuts can be seen as dry fruits with indehiscent characteristics and are known to have one seed and a hard pericarp (Edu et al. 2023). The classification of nuts and seeds could be quite confusing, this is because from their description, many nuts are classified as fruits and consumed as such, and some others see it as seeds (George et al. 2022). However, they are one of the most popular snacks that is known to man. Over the years, nuts and seeds have been known to be an important part of the human diet and they offer a good source of nutrients and healthy snacking option because they contain protein, fibre, fat, vitamins, and minerals and as well as antioxidants which helps in protecting the body (Abbas et al. 2022; Gupta and Mishra 2021). Nuts are known to have low water content which is usually less than 50 % with some few exceptions (Verde et al. 2022). The low water content helps in extending the shelf life unlike other fruits which are highly perishable due to the water content (Farooq et al. 2021). Other advantage that its low water content gives is the reduced risk of microbial growth and the high concentration of nutrients in it (Farooq et al. 2021). Nuts are not only valued for their nutritional value, but they are also valued because of their taste and texture, which makes it desirable as a food substance (Hernandez-Lopez et al. 2022). As such nuts are being included as parts of diets because of the recognition and their nutritional benefit and thus its reference as a nutritional powerhouse.

Historically, nuts and seeds have been known to be a part of the human diet for a long time with nuts such as almonds, hazelnuts, macadamias, pecans, pine nuts, pistachios, walnuts, cashew nuts, kolanut, groundnut, tiger nuts, and palm kernel nuts among others. Before civilisation, nuts and seeds have been recognised as a major source of feed and scavenging communities depends on these nuts and seeds to meet their nutritional needs (Alasalvar et al. 2020). According to findings, nuts such as acorns, chestnuts, and various wild seeds were staples in many ancient diets and this contributed to their survival before the introduction of commercial production of food crops (Maraschi, 2019; Godeto et al. 2021). Additionally, nuts can be seen to have cultural values in being used for cultural ceremonies such as weddings, clan meetings and religious ceremonies among some cultures in Africa and in some Mediterranean and Middle Eastern traditions where some nuts represent good luck (Okech and Timothy 2023; Samanci 2020). This shows that nuts and seeds have different uses and are deeply embedded into the lives of people across the world.

The commercial production of nuts varies for individual nut plants and involves a complex process and different value and supply chains. This is because it involves a wide variety of nut types with each having unique characteristics, varying market demand and importance depending on the culture. Some of the most produced nuts include almonds, walnuts, cashews, pecans, pistachios, hazelnuts, macadamia nuts, and peanuts.

The global demand for nuts has continually increased due to increasing health consciousness and the need for healthier snack options aside processed food options. According to a Statista data (2023) as shown in figure 1, the estimated value for the nuts and seeds market worldwide in 2021, the global value of the nuts and seeds trade was about 1301.4 billion U.S. dollars, and this is expected to reach about 1422.09 US dollars by the year 2027. Showing the increasing relevance of nuts as part of people's diet.

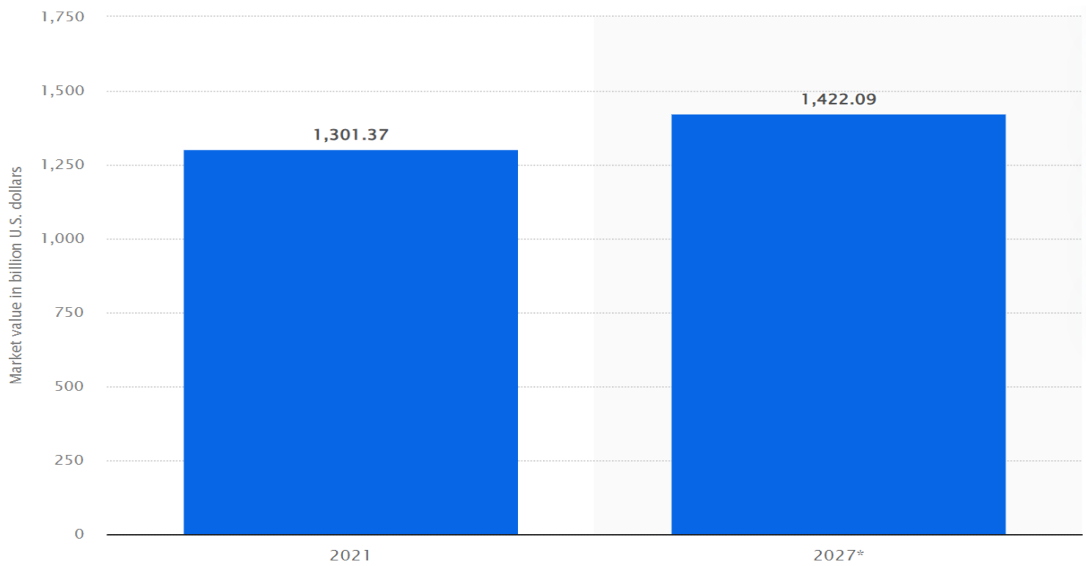


**Figure 1. Global value of nuts and seeds market for 2021 and the forecasted value for 2027. (Source: Statista, 2023).**

The common trends that have positively influenced the consumption of nuts and seeds include increased demand for plant-based protein diets which has seen people transit from consumption of animal-based protein to plant based sources (Estell et al. 2021).

Nuts and seeds however fit into this profile because it is known to be rich in plant-based protein. Additionally, the desire for healthy diets may have also contributed to the increased consumption of nuts and seeds making it a healthy option because of the presence of some essential vitamins, minerals, fibre contents among other important characteristics (Lu et al. 2023). Other trends that are likely to have influenced the consumption of nuts and seeds include increase in snacking culture among people and with nuts falling among major snacking options, it is reckoned as such (Almoraie et al. 2022). Furthermore, nuts and seeds can be found to fall into sustainably produced products with the minimal use of synthetics and minimal processing giving it a sustainable and organic option (Chesti et al. 2023). These trends have continued to support the increasing demand for nuts and seeds. Thereby making it an essential global trade item with high value.

Although, there are challenges to the productions of nuts and seeds which include climate variability which influences the yield of the tree crop, pest and diseases, and deforestation and land use change, market volatility because of fluctuating supply and demand, issues as regards food safety and quality control and as well as labour intensity of production (Volk et al. 2023).

However, this does not dispute the fact that nuts and seeds have valuable impact and thus necessitating the need to look at its chemical position to further understand what benefits can be gotten from it. One of such is lipids and fatty acids, which includes fats and oils and are one of the key macronutrients found in nuts and seeds (Dodevska et al. 2022). Lipids are known to be essential for human health by serving as a concentrated source of energy and contributing to the absorption of fat-soluble vitamins (Rafeq et al. 2020). They are also known to be essential for hormone production, brain health among other importance (Kao et al. 2020). Additionally, lipids in nuts and seeds often consist of various types of fatty acids, including saturated, monounsaturated, and polyunsaturated fatty acids (Huang et al. 2020; Auteleyeva et al. 2023). The specific fatty acid profile can significantly impact the nutritional and health properties of these food items and even the consumers (Goncalves et al. 2023; Tu et al. 2021). For example, the presence of heart-healthy unsaturated fatty acids like oleic acid or omega-3 fatty acids can enhance the dietary benefits of consumers who consume nuts and seeds (Pradhan et al. 2020). In addition to lipids and fatty acids, volatile substances found in nuts and seeds can play a crucial role in their sensory attributes, such as aroma and flavour (Peng et al. 2023; Noguera-Artiaga et al. 2019). This is because volatile compounds are responsible for the characteristic scents and tastes that helps in differentiating one type of nuts and seeds from another. As such, the chemical analysis of these volatile substances is vital for understanding the sensory qualities of these food items, to further optimise processes, such as roasting and flavour development that involves nuts and seeds.

Therefore, this study will widen knowledge by drawing from the field of analytical chemistry, nutrition, and food science and to gain knowledge into the basic components of lipids, fatty acids, and volatile substances in selected types of nuts and seeds. This analysis serves several purposes which include ensuring the quality and chemical composition of nuts and seeds in the food industry to advance our understanding of the potential health benefits associated with their consumption. Moreover, it provides valuable information for individuals seeking to make informed dietary choices, especially those interested in embracing the nutritional advantages and culinary delights of nuts and seeds. Additionally, the study enhances a deeper appreciation of the role of nuts and seeds in our diets and its potential to enhance both health and culinary experiences among consumers.

### 1.1.1. Problem Statement

Nuts and seeds have continued to gain relevance in terms of consumption and other uses with projected increase in the consumption of nuts and seeds expected in the coming years due to their relative importance (Mapes et al., 2022). As such, there is the need for certain clarity as to the component of this food element. This is because there is lack of comprehensive data on the chemical composition of these nuts and seeds and to make proper dietary recommendation there is the growing need to understand what this nut offers to individual diets.

Additionally, the diversity of nuts and seeds has made it more expedient to explore deep into what makes each nut and seed unique to be able to effectively classify them for use and get the best of what such nuts and seeds offer rather than just eating it for fun. Especially in areas of nutrition where targeted approach to nutrition is becoming a necessity and people need to make informed dietary choices (Stylianou et al. 2021).

This is because lipids and fatty acids are known to have health implications in areas of cardiovascular health, cognitive function, and anti-inflammatory properties among others (Djuticic and Calder, 2021; Kumar et al., 2019; Simonetto et al. 2019). Thereby making it more expedient for more research to establish the precise relationships between these nuts' lipid and fatty acid components as well as health outcomes.

Also, lack of food labelling for nuts and seeds is seen as a challenge for consumers. This was reported by Soon and Wahab (2021) who discovered that tree nuts were the most undeclared food allergens, and this can be seen to be caused by lack of information thereby greatly affecting consumer choices as to the potential benefits which nuts and seeds portends to their health and wellbeing.

Additionally, volatile substances are often overlooked in food analysis and these nuts and seeds are known for their role in the flavour, aroma, and nutritional value of nuts and seeds (Liu et al. 2022). These volatile substances could also play an important role in unlocking the potentiality of nuts and seeds and the need to position nuts and seeds as a healthy snack option. In addition, the food industry is an innovative industry with the aim of designing products that are both healthy and appealing. However, lack of information on what makes up these nuts and seeds could hamper it. This is because the markets for nuts and seeds rest on proper information, which can guide proper processing of these nuts and seeds. Especially in being able to know the desirable and undesirable volatile substances (Thewes et al. 2022) in these items and ensuring that the necessary ones are preserved while also providing precautions against the undesirable ones.

Furthermore, seed improvements are a means of improving the nutritional contents of various seeds and nuts. However, the veracity of these can only be confirmed through a proper chemical analysis to see what changes have occurred and what could have influenced such changes. This is important to understand how improvements in seeds can alter or maintain the chemical composition of nuts and seeds. As such, this research aims to address a knowledge gap and investigate the chemical composition of some selected seeds and nuts by examining the lippy, fatty acid and volatile components of selected seeds and nuts, which are common in Cameroon but have limited information on them. The selected nuts are: rondelles (*Afrostyrax lepidophyllus),* njansang, (*Ricinodendron heudelotii),* sacha inchi (*Plukenetia volubilis)* and tiger nuts (*Cyperus* *esculentus)*. They have been selected because, they all grow naturally in the wild, and their existence is being threatened due to deforestation in Cameroon. Some of them such as njasang and rondelles have the highest economic value compared to all nuts in the country. As it is a major source of income in some rural areas, while others such as caso nuts and rondelles do not have information about the chemical composition of their fatty acids and the volatile compounds present in them. They are eaten based on their taste and aroma. As such, this research is to break this gap.

## 1.2. Literature Review

### 1.2.1. Economic importance of nuts and seeds.

Nuts and seeds are some of the underrated food elements found in nature and which have been with man for years. The importance of nuts and seeds can be evaluated from two angles. First from the angle of the nutritional benefits and secondly based on its importance to the health of man.

Based on the nutritional benefits, nuts and seeds are sometimes referred to as the nutritional powerhouse this is because they contain nutrients such fats such as fatty acids, proteins, and Amino Acids.

Additionally, Nuts and seeds contains healthy fats in different quantities depending on the nuts or seeds (Albuquerque et al. 2020). It is noted that these nuts and seeds are rich in monounsaturated and polyunsaturated fats such as omega 3 and 6 fatty acid which have been noted to reduce the risk of heart disease and helps improve brain health (Albuquerque et al. 2020). One striking thing about the omega 3 and 6 fatty acids is their presence in certain animal sources such as Titus's fish and the presence of it in Nuts and seeds, further strengthens the call for it as a good alternative to animal protein (Albuquerque et al. 2020).

Furthermore, nuts and seeds contain both essential and non-essential amino acids which are necessary for body functions (Doedevska et al. 2022). The major amino acids found in seeds and nuts include Lysine which is important for tissue growth and repair and found in almonds, sunflower seeds among others (Oso and Ashafa, 2021). Another one is Arginine which is common in walnuts, hazelnuts and pistachios and can be said to help in building strong immune system and blood formation (Arslan et al. 2020). Other

Amino acids which have been found in Nuts and seeds include Methionine found in Sesame seeds and Brazil nuts, Trytophan found in peanuts and cashew and can help in regulating sleep and diet as well as glutamic acid which is common in most nuts and support proper brain function (De 2020).

Other nutrient compositions of nuts and seeds include vitamins, minerals and even fibre which are beneficial to human health. The vitamins which are found in Nuts and seeds include vitamins E and B while the minerals are made of magnesium, iron, potassium, and Zinc among others. Some of the benefits of vitamins, mineral and fibres found in Nuts and seeds include the fact that they serve as antioxidant, helps in fluid balance, and can also enhance the digestive system as the case of fibres.

Apart from the nutritional benefits and importance of Nuts and seed it also has health benefits which include reduced risk of health disease by helping to lower the cholesterol levels. For instance, almonds are known to be associated with the health of the heart, chia seeds are believed to contain omega-3 fatty acids, and flaxseeds are believed to aid digestive health (Sharma 2022; Luvian-Morales et al. 2022). Moreso, some studies have even linked the consumption of nuts and seeds to the lower risks of diabetes by stabilising blood sugar, cancer through the presence of some alkaloids that attacks cancer cells and even in weight loss as a result if the high concentration of protein and fibre which ensures satiety and thereby reducing the demand for calories (Balakrishna et al. 2022).

Furthermore, in the quest for sustainability, Nuts and seeds can play a prominent role, this is because it can help in wildlife conservation by replacing animal protein with the plant source (Alae-Carew et al. 2020). The limited amount of water required to produce many nuts and seeds also makes it a water conservation plant. In essence, nuts and seeds have the potential to further enhance the environmental sustainability drive because of their inherent benefit (Orooji et al. 2022).

Nuts and seeds can also serve as a source of income and foreign exchange earning if well positioned based on its benefits. This could be seen in the way countries like the US, China among others have positioned their nuts and seeds as potential income earners for the country (Sharma et al. 2020).

However, despite the economic importance of nuts and seeds the energy dense nature of these seeds and nuts can also portend danger. This is because too much of it can lead to weight gain if not well managed through a balanced diet procedure (Nishi et al. 2021). Also, despite the presence of diverse nutrients some of these nuts and seeds contain anti nutritional factors and allergens which can affect the absorption of essential nutrients and could pose grave danger if consumed by people with allergies. For instance, Phytic acid is an anti-nutritional factor that can hinder the absorption of minerals like calcium and zinc. Additionally, the processing and introduction of additives to these nuts and sees can affect the balance of the nutrients in it. For example, the addition of salts to nuts and seeds can increase the sodium contents in the nuts and seeds (Samtiya et al., 2020).

Thus, nuts and seeds are said to be important component of our diet and offer balanced composition of nutrients for our intake while contributing to the improvement of our health. Additionally, the awareness of the benefits which nuts and seeds offer may be low. Thus, it is important to note that targeted research like the one being carried out in this study can help in creating more awareness and move people towards a more sustainable diet which has minimal impact on the environment at large and offers a wide range of benefits to consumers in their health and wellness.

### 1.2.2. Contributions of lipid and fatty acid profiles of nuts and seeds to their health-promoting properties.

Fatty acids are some of the common components of the nutrient dense nuts and seeds (Di-Renzo et al. 2021). Very many times, we tend to discard nuts and seeds as being less important in our diets, but we have failed to take cognisance of the fact that the lippy and fatty acids in it have some contributions to the potential health benefits of the nuts and the seeds (Di-Renzo et al. 2021).

Firstly, the composition of nuts and seeds is made up of healthy fats components with saturated fat content that is believed to be low. This saturated fat content is believed to predispose to diseases related to the heart and other chronic conditions. Thus, Nuts and seeds are known to be very rich in unsaturated fats like monounsaturated fatty acids and the poly unsaturated fatty acids (De et al., 2020). Examples of monounsaturated fatty acids found in nuts and seeds include oleic acid while for the polyunsaturated fatty acids, the examples include linoleic (omega-6 fatty acid) and alpha-linoleic acids (omega-6 fatty acid) (Polat et al. 2023). The presence of monounsaturated fatty acids and polyunsaturated fatty acids in nuts and seeds have been known to reduce the level of bad cholesterol which ultimately improves the health of the heart and reduces the risk of other heart related diseases (Polat et al. 2023). These unsaturated fats in nuts and seeds, functions in preventing the oxidation of LDL cholesterol. They also help reduce inflammatory conditions and brain health (Rincon-cervera et al. 2022). Monounsaturated acids are mostly found in nuts and seeds like cashew, macadamia nuts, hazelnuts, pecans, almonds, peanuts, brazil nuts, pistachio nuts while,

examples of nuts and seeds with polyunsaturated fatty acid are walnuts, almonds, lax seeds, and chia seeds (Rincon-cervera et al. 2022).

Essentially, some nuts and seeds can help to supply the body with some fatty acids which are essential for the body but are not produced by the body like the omega-3 and omega-6 fatty acids which are seen as essential, but the body does not have the capacity to produce it except through our diet (Mariamenatu and Abdu 2021).

Additionally, the presence of phytosterols in nuts and seeds which are naturally occurring compounds in plants and similar in structure to cholesterol can help to reduce cholesterol in the body by competing with it for absorption in the body. Thereby helping to reduce the risk of heart disease. The recommended level of intake of Phytosterols is about 2 mg daily and the composition of different seeds and nuts and their Phytosterol level is shown in table 1 bellow. Other benefit of the Phytosterol content in nuts and seeds include the reduction of inflammation and improvement in immune function (Poli et al., 2021). Example of nuts with these include almond, cashew nuts pistachios, sunflower seeds, and others (Mariamenatu and Abdu 2021).

**Table 20. Nuts with Phytosterols and their savings.**

| **Food** | **Serving** | **Phytosterols* (mg)** |
|---|---|---|
| Sesame | 1 tablespoon (14 g) | 118 |
| Pistachio nuts | 1 ounce (49 kernels) | 61 |
| Cashew nuts | 1 ounce | 45 |
| Cottonseed | 1 tablespoon (14 g) | 44 |
| Macadamia nuts | 1ounce (10-12 kernels) | 33 |
| Almonds, | 1 ounce | 32 |
| Sunflower seed | 10 g | 43 |

**Source: Higdon et al., 2017**

Also, the presence of fats and lipids in nuts is quite essential to the absorption of fat-soluble vitamins like vitamin E which can be found in almonds, sunflower and hazelnuts while also rich in antioxidants which protect the body from harmful substances (Mariamenatu and Abdu 2021). The fatty acid in nuts and seeds helps to improve absorption of fat-soluble antioxidants like vitamin E, which is present in almonds walnuts, hazelnuts among others (Poli et al. 2021). The presence of antioxidants in these nuts and seeds helps in relieving stress, reducing inflammation and have cell protecting characteristics (Carlsen et al. 2011). The chemical associated with these antioxidants in nuts and seeds include lipids, tocols, phytosterols, sphingolipids, carotenoids, chlorophylls, and alkyl phenols. Studies of Alasalvar and Boiling (2015) has revealed that nuts and seeds have varying types of antioxidants which have different properties. They have further established the fact that when the consumption of nuts and seeds increases the level of defence the body enjoys from antioxidants also increases. Thus reduces the potentiality for cardiovascular diseases and inflammation. It has further been established through studies that the antioxidative properties of nuts and seeds may also contribute to the reduce risk of cancer, asthma, and other inflammatory disease (Alsalvar and Boiling, 2015).

Carlsen et al. (2011) analysed the presence of antioxidants in different nuts and reported that walnuts have the highest level of antioxidants among the nuts with about 20 mmol antioxidants in about 100 g of the nut. Other nuts with massive number of antioxidants at different quantities include Pecans, chestnuts, pistachios, and sunflower. Other nuts were also found to have different amounts of antioxidants but not as much as the previously mentioned nuts. However, they noted that antioxidants variation in nuts and seeds could also be influenced by the growing condition of the plant, changes in season, gene difference, condition of storage, processing among other significant reasons.

In all the fatty and lipid acids in nuts and seeds contribute to the level of satisfaction we feel when we consume these nuts and seeds and even play a prominent role in improving the taste we feel when these nuts and seeds are consumed and they also play a prominent role in weight management due to the satisfying effect which helps control appetite and calories intake and based on the fact that it supplies the healthy fatty acid that the body needs to sustain itself.

### 1.2.3. Fatty Acid Composition

Nuts and Seeds are made up of different types of fatty acids which enhance its acceptability and nutrient composition. A fatty acid is referred to as a carboxylic acid (—COOH) which has an aliphatic chain with hydrogen atoms at one end of the chain while the carboxyl is attached at the other end (Azizova et al. 2023). As a general description, fatty acids are straight chain hydrocarbon with an even number of carbon atoms.

Generally, a fatty acid consists of a straight chain of an even number of carbon atoms, with hydrogen atoms along the length of the chain and at one end of the chain and a carboxyl group (—COOH) at the other end (Azizova et al. 2023). Fatty acid is either referred to as saturated or unsaturated and they are found in forms of triglycerides, phospholipids, and cholesteryl esters. Classification of fatty acids can also be in form of their length or the arrangement of the carbon atoms. The type of fatty acids found in nuts and seeds are naturally occurring and they have unbranched chain of carbon atoms (Sardesai, 2020).

#### 1.2.3.1. Monounsaturated Fatty Acids (MUFA)

Monounsaturated fatty acid (MUFA) is a type of unsaturated fatty acid which have a double bond in their carbon chain. These double bonds allow the MUFA to be liquid at room temperature and solid when placed in a cool environment, but they do not oxidise as polyunsaturated fatty acids (Lund and Rustan 2020). MUFAs are common in plant sources which include nuts and seeds and are considered as healthy fats (Saini et al. 2021). MUFAs are found in nuts and seeds like almonds and cashew among others (Saini et al. 2024).

#### 1.2.3.2. Polyunsaturated Fatty Acid

Polyunsaturated fatty acids (PUFA) are a form of fats that are healthy, and they contain two or more double bond in the carbon chain (Kapoor et al. 2021). Like the MUFA, they are liquid at room temperature, and they are common in plant-based sources such as seeds and nuts (Kapoor et al. 2021). The two major types of PUFA are omega-3 and omega-6 fatty acids (Kapoor et al., 2021). The two types of fatty acids are essential for the body.

#### *1.2.3.2.1 Omega-3 Fatty Acid*

Omega-3 fatty acid is found in animal and plant sources. The major plant sources include chia seeds, flaxseeds, and walnuts. The structure of the omega-3 fatty acid gets its name from the presence of the double bond at the third carbon when counted from the methyl attachment to the carbon chain in the chemical structure (Saini et al. 2021). The double bond is what makes the omega-3 fatty acid polyunsaturated (Bhatt et al. 2020). The omega-3 fatty acid is referred to as essential fatty acid and there are three types which are important for man such as alpha-linolenic acid (ALA), eicosapentaenoic acid (EPA), and docosahexaenoic acid (DHA). The common omega-3 fatty acid found in plants are ALA while DHA and EPA are found in animal sources like algae and fish (Bhatt et al. 2020).

#### *1.2.3.2.2 Omega-6 Fatty Acid*

Omega-6 fatty acids are common in plant-based sources such as nuts and seeds. Omega-6 is also a form of PUFA, which has two or more double in its hydrocarbon chain (Mariamenatu and Abdu, 2021). The structure of the omega-6 fatty acid is the presence of a double bond, which is on the sixth carbon from the methyl group in the chemical structure (Sartaj and Prasad 2020). The presence of the double bond makes the fatty acid a polyunsaturated one. Omega-6 fatty acid is present in nuts and seeds such as walnuts, sunflower seeds, dried pine nuts, Brazil nuts, sesame seeds among others. Linoleic acid (18:2) and arachidonic acid (20:4) are the two essential omega-6 fatty acids which are common (Sartaj and Prasad 2020). As much as Omega-6 fatty acid are good they must also be consumed in moderation because they can lead to inflammation and other health challenges.

### 1.2.4. Saturated Fatty Acids

Saturated fatty acids are known to be solid at room temperature and are present in many foods such as nuts and seeds. Nuts and seeds that have a high content of saturated fats include coconut, Brazil nuts, macadamia nuts, cashew nuts, pine nuts among others. The level of saturated fat in nuts and seeds is basically low and sometimes assumed to be about 4 to 16% with the remaining level of fatty acid in nuts and seeds making up most of the nuts and seed content (Ponamapalam et al. 2021).

In terms of structure, saturated fats lack the double bond unlike the unsaturated one which has the double bond. The structure of the carbon atoms which gives it a straight structure allows it to have a solid structure due to the packed carbon atoms. Saturated fats are described as less desirable type of fatty acids because of its link to increased LDL cholesterol level (Mariamenatu and Abdu 2021). However, it is believed that some saturated fats have different metabolic effect which makes it less similar in behaviour to others saturated fatty acids and thus giving it a beneficial effect. For instance, the saturated fat in coconut is classified as a medium chain triglyceride and have different metabolic effect when compared to other saturated fatty acid sources (Ponamapalam et al. 2021).

#### 1.2.4.1. Trans Fatty Acids

Trans fats are described based on the presence of at least one trans double bond between the Carbon atoms in its structure (Nagpal et al. 2021). The effect of the Trans configuration alters the physical and biological properties of Trans fat. Trans fats are usually not naturally occurring and is an unsaturated fatty acid which is common in processed foods (Rizo et al. 2023). The difference between a trans-fat and other unsaturated fat is in the placement of the double bond with the unsaturated fat having a cis formation (Nagpal et al. 2021). Trans fats are usually considered as unhealthy with increased LDL cholesterol and inflammation (Nagpal et al. 2021). Trans fats are not found in Nuts and seeds but can occur during the process of processing or extraction of oils from the nuts and seeds (Rizo et al. 2023).

### 1.2.5. Lipid Composition of Nuts and Seeds

Lipids are a group of organic molecules that are not soluble in water and have a waxy nature with hydrophilic and hydrophobic parts (Asokapandan et al. 2021). Lipids play a very critical role in many bodily functions such as energy storage, which helps in maintaining body temperature, they serve as building block for cell membrane, serves as precursors to steroid hormones, which helps in reproduction and metabolism (Dominiguez et al. 2022). Other functions of lipids include insulation of the body and enhancing the body’s absorption of heat. Lipids are classified into fats, oils, cholesterol, and lipoproteins. The fats and oils consist of triglycerides, which consists of three fatty acids and a glycerol molecule (Sinkjewicz 2023). Cholesterol on the other hand, is mainly found in animal sources while lipoproteins can be described as complexes of lipids and proteins that helps in transporting lipids in the blood (Dominiguez et al. 2022). Some of the lipids that are found in nuts and sees include:

#### 1.2.5.1. Triglycerides

These comprises of three fatty acids which is attached to a glycerol molecule and are the main form of storing energy in the energy body (Guasch-Ferre et al. 2023). Triglycerides are the most common types of lipids that are found in seeds and nuts, and they provide most of the calorie content of the seed and nut (Atamimi et al. 2020). However, Triglycerides are seen as one of the main causes of weight gain in nuts and seeds because it serves as the main energy storage (Guasch-Ferre et al. 2023).

#### 1.2.5.2. Phospholipids

Phospholipids are made up of two fatty acids compound and a phosphate group and are the phospholipid found in cell membrane structure and function (Gangopadhyay 2021). Lecithin is the major type of phospholipid found in nuts and seeds and are known to be safe with beneficial effect on the body (Gangopadhyay 2021).

#### 1.2.5.3. Sterols

Sterols are also another common type of lipids with cholesterol seen as the very common type of sterol, which is found in cells of animals and in plant sources. Sterols serves the function of enhancing the steroid hormones and while helping in cell signalling pathway. The main sources of sterols in nuts and seeds are almonds and sunflower (Gangopadhyay 2021).

#### 1.2.5.4. Free Fatty Acids (FFA)

These are present in in nuts and seeds but in very small amounts when compared to triglycerides (Jardim et al. 2023). The free fatty acids are the major building blocks for triglycerides and other lipids and can come in different forms, which include the saturated, the unsaturated and the trans-fat (Yanti et al., 2023). The presence of FFA in nuts and seeds have an influencing factor on the taste of the nuts, the aroma it gives, the satiety level and even the storage ability of the nuts and the seeds. However, good the FFA might be in preserving the shelf life of the nuts and seeds, lipid oxidation may still occur which may significantly affect the sensory attribute of the nuts and the seeds (Yanti et al. 2023).

#### 1.2.5.5. Waxes

Waxes do not form a major component of nuts and seeds, but they play an important part in providing a protective covering for the nuts and the seeds. They are protective covering that are derived from the long chain of fatty acids in these nuts and seeds (Mumtaz et al. 2020). However, they also play an important role in preserving and protecting theses seeds and nuts.

### 1.2.6. Volatile Substances Composition of Nuts and Seeds

Nuts and seeds are known for their protein, fibre, and the presence of healthy fats; however, the presence of volatile substance is even makes it more presentable and acceptable to the consumers. Volatile substances are not profiled as part of the essential parts of nuts and seeds, but they play a good part in determining the acceptability of the nuts and the seeds. Volatile substance are also organic compounds like fatty acids and lipids, but the difference is that they are seen as easily volatile and at room temperature they tend to evaporate, thereby releasing the aromas and flavours associated with them (Gong et al. 2023).

Volatile substances in nuts and seeds contains a combination of different elements, which include oxygen, nitrogen, and sulphur among others (Gong et al. 2023). These elements play a significant role in their attractive taste and the smell that they give out. The formation of the volatile substance is usually done during the process of metabolism and these volatile substances are stored in the plants in cells or glands till the time of release when they are exposed to atmospheric temperature (Valdes-Garcia et al. 2021). The release of these volatile substances occurs in the process of eating them, exposure to heat, crushing and other processes that tampers with the original structure of the seeds and the nuts thus releasing the attractive taste and the aroma to the consumer (Gong et al. 2023).

Different nuts and seeds are known to have different characteristics taste and aroma conferred by the presence of different volatile substances (Valdes-Garcia et al. 2021). For instance, in almonds the presence of benzaldehyde and cis-hexanol gives it some of the taste and aroma which is felt in the nuts (Lipan et al. 2021). For walnuts, the feel of bitter taste as an after taste is a result of some volatile compound like 2-heptanal, alpha-pinene, and limonene. In hazelnuts eugenol, limonene and furaneol which are volatile compounds also contributes to the type of taste and aroma which the nuts gives while for sesame, the volatile compounds are pyrazines, pyrroles, furaneol and methional (Grilo and Wang 2021).

### 1.2.7. Types of Volatile Compounds in Nuts and Seeds

The type of volatile compounds found in different nuts and seeds vary from seeds and nuts to the others. This is because of the various factors such as the processing of the seeds and nuts the geographical location where it is produced and the genetic makeup of the seed and the nut (Grilo and Wang 2021). The common types of volatile compounds that are found in seeds and nuts are discussed as follows.

#### 1.2.7.1. Aldehydes

They are a type of volatile organic compound that are found in nuts and seeds and the production of these volatile compound is during the oxidation of unsaturated fatty acid in nuts and seeds (Valdes-Garcia et al. 2021). Aldehydes are one of the common volatile substances in nuts and seeds asides from alcohol and are usually responsible for the nutty and roasted aroma which is found in some nuts (Behaghel et al. 2020). Some types of aldehydes which are common in nuts and responsible for taste and aroma are hexanal, octanal, nonanal (Valdes-Garcia et al., 2021).

#### 1.2.7.2. Ketones

Ketones are produced during the oxidation of unsaturated fatty acid and are also a type of volatile compound which is found in seeds and nuts. Common ketones with characteristic flavour are 2-pentanone and 2-heptanone (Valdes-Garcia et al. 2021).

#### 1.2.7.3. Alcohol

The volatile alcohol found in seeds and nuts are said to be different from the class of alcohol that are used in beverages (Valdes-Garcia et al. 2021). Alcohol volatile compounds consists of short chain alcohol, and they are the most common type with examples such as methanol, ethanol, propanol, and butanol which exist in very small quantities in the seed and nuts. The other type is the sugar alcohol which includes sorbitol, mannitol, and xylitol and they give tasted to the nuts and seeds by supplying a low-calorie sweetening option (Gonzalez-Gamallo et al. 2021).

Volatile compound alcohol in nuts and seeds include almonds which has methanol and ethanol, walnuts which has butanol and propanol, pistachios nut which has methanol and ethanol and cashew nut which has propanol (Gonzalez-Gamallo et al. 2021). It should be noted that these alcohols are present in trace amounts, and they contribute to the aroma of nuts and seeds despite their low quantity in the nuts and the seeds (Oliveira-Alves et al. 2020).

### 1.2.7.4. Esters

Esters have a distinctive structure, and they are characterised by a distinctive structure, which includes a carbonyl group (C=O) from the acid with an oxygen atom which is linked to an alkyl group (Oliveira-Alves et al., 2020). The molecular arrangement of esters makes it polar molecules which has a significant impact on their volatility property with its characteristics smell (Oliveira-Alves et al. 2020).

Esters contribute to the fruity and sweet aroma in seeds and nuts with examples such as ethyl acetate. Examples include benzyl acetate found in almond, ethyl 2-methylbutyrate found in walnuts, methyl furfural found in hazelnuts among others which all contribute different tastes and aroma to the acceptance of the different nuts and seeds in which they are found (Hu et al. 2022).

### 1.2.7.5. Pyrazines

Pyrazines are another form of volatile compounds which have been found in nuts and seeds (Oliveira-Alves et al., 2020). Examples include 2,5-dimethylpyrazine and 2-ethyl-3,5-dimethylpyrazine which are common in roasted peanuts by contributing to its flavour (Valdes-Garcia et al., 2021). Pyrazines are referred to as an aromatic hydrocarbon which has two nitrogen atoms and are responsible for the scents of the seeds and nuts when exposed to heat. Pyrazines are an aromatic hydrocarbon which has two Nitrogen and four carbon atoms (Adelina et al. 2021). The structure of pyrazine allows it to create a roasted flavour sensation (Valdes-Garcia et al. 2021).

Nuts and seeds with pyrazine volatile compound include almonds which has 2,5-dimethylpyrazine, a pyrazine, walnuts which contains 2-ethyl-5-methylpyrazine, Hazelnuts with 2-acetylpyrazine, and sesame seeds which contains 2,5-dimethylpyrazine and 2-ethyl-5-methylpyrazine (Valdes-Garcia et al. 2021). Additionally, it should be noted that the roasting smell of pyrazine can be used to set markers for degree of roasting in nuts and seeds which can be good in setting standard in the food industry (Adelina et al. 2021).

#### 1.2.7.6. Terpenes

Terpenes is a diverse group of organic molecules, which are built from repeating units of five carbon atoms (Kalogiouri et al. 2021). Terpenes such as limonene and pinene, are present in different nuts and seeds and they also contribute to their aroma. The presence of limonene in almonds and pinene in walnuts have been fingered in some of the tasty feeling in these nuts (Valdes-Garcia et al. 2021).

#### 1.2.7.7. Other Volatile Compounds in Nuts and seeds

Apart from the major volatile compounds which have there are still other categories of volatile compounds that are found in nuts and seeds such as furans, Thiophenes, sulphur compounds, Furfural among many others which have been found in nuts and seeds. However, the presence of volatile compounds in nuts and seeds can vary significantly based on the types of nuts and seeds, processing methods of the nuts and seeds, condition of storage among many other things (Valdes-Garcia et al. 2021). The use of gas chromatography-mass spectrometry is the commonly used method to profile volatile compounds in nuts and seeds (Manzano et al. 2023).

### 1.2.8. Importance of volatile compounds in the sensory quality of nuts and seeds.

Volatile substances place significant role in nuts and seeds and have been identified in certain qualities which nuts and seeds possesses. Such as in the development of taste and flavour which are characteristics of some certain nuts like cashew nuts, walnuts and even the roasted feeling in peanuts (Manzano et al. 2023).

Additionally, the presence of volatile compounds in nuts and seeds can serve as an important quality indicator for nuts and seeds through the release of certain smells when the nuts and seeds are spoilt which is different from the original small of the nuts and seeds. This is usually cause because of lipid oxidation in the nuts and seeds which causes certain volatile compounds to be released as a sign that the quality of the nuts and seeds has been reduced (Valdes-Garcia et al. 2021).

Another important quality which volatile compounds gives is during the processing of these nuts and seeds such as roasting, extraction among whereby some of these volatile compounds are released to give flavour while also enhancing the sensory quality of these products to the consumers (Kalogiouri et al. 2021).

Furthermore, the storage life of nuts and sees can help in improving the storage life by providing indicators to ensure that the storage life of nuts and seeds is improved (Kalogiouri et al., 2021). However, because of the presence of lipids in nuts and seeds it can affect the shelf life as these can shorten the life especially when stored in unfavourable condition thereby causing lipid oxidation because of unfavourable atmospheric condition and exposure to oxygen (Riveros et al. 2022). Thus, the presence of volatile compounds can serve as a storage indicator.

Finally, the presence of volatile compounds may also have benefits in health such as the antioxidative properties whereby some compounds contribute to the absorption of certain vitamins and minerals. A good example are the polyphenols and the terpenes which can also serve as antioxidant in these nuts and seeds (Adelina et al. 2021).

### 1.2.9. Factors influencing fatty acid, lipid and volatile substance profiles of Nuts and seeds.

The presence of fatty acids, lipids and volatile substance in nuts and seeds vary across seeds and nuts and can at times vary among seeds and nuts of the same family due to certain factors (Valdes-Garcia et al. 2021). It should be specifically noted that although nuts and seeds have this profile of fatty acids, lipids, and volatile substances but they could vary in their composition due to factors such as geographical region of production, the climatic condition, the condition of storage, among other post-harvest handling of the seeds and nuts. Some of the influencing factors are further enumerated subsequently.

#### 1.2.9.1. Geographical region of Production

The region where the nuts and seeds are produced could influence a lot of things such as the type of soil used in production whose composition vary from one location to the other. The variety of the plant species and the weather condition also vary from one location to the other. This could significantly affect the presence of fatty acids and lipids in seeds and nuts. (Ozcan et al. 2020).

#### 1.2.9.2. Climate

Climate which is the atmospheric weather condition of a place over a long period of time can be seen as playing a very significant part in the composition of lipids, fatty acid and volatile substance of nuts and seeds (Ozcan et al. 2020).

#### 1.2.9.3. Storage Conditions

The storage condition is one of the important factors in maintaining quality of nuts and seeds. This is because exposure to undesirable conditions can cause the nuts and seeds to lose the volatile compounds because of lipid oxidation caused by high temperature and humidity (Cong et al. 2020). This can significantly alter the fatty acid and lipid profile and even cause the nuts and seeds to lose its aroma and taste in way that it would be less appealing to the consumers (Wang et al. 2020).

#### 1.2.9.4. Genetic Factors

Genetic makeups of nuts and seeds also plays a role in determining the level of these lipids, fatty acids, and volatile substance. This is because plants of the same genus and different species could have different composition of these substances as is the case in some species of walnuts, tiger nuts and other nuts which show variations in the chemical profile from one species to the other (Kapoor et al. 2021).

### 1.2.10. Extraction methods for oils from nuts and seeds

There are different extraction methods used in obtaining oils from nuts and seeds. The process of extraction is quite complex and diverse. The method depends on different options such as the type of nuts and seeds from which extraction is being done, the expected level of efficiency required the use for which the oil is to be used for (Ouzir et al. 2021). For instance, production of oil used for industrial production will be different from that expected to be consumes domestically. Finally, the cost of production could also play an important role in determining what method to be used because of the affordability constraint, which must be taking into consideration during production (Nde and Foncha 2020).

Other consideration for the method to be used in extraction include the level of yield expected and the desired level of purity, impact of the extraction method on the environment and the level of nutrient preservation required for the oil (Ouzir et al. 2021). Some of these methods include:

#### 1.2.10.1. Mechanical Pressing

The process for the mechanical pressing involves the use of hydraulic press for the extraction of oils from the nuts and seeds (Kaur et al., 2022). In the use of the process, the seeds are crushed. Then pressed and squeezed under high pressure to release the oils in the seeds and nuts. The pressure introduced plays an important part in the release of the oil from the seed.

The main advantage of the use of mechanical pressing is the simplicity of the method, which fits well for small-scale operations and can help prevent loss of certain fatty acids, lipids and volatile substance in the nuts and the seeds (Rani et al. 2021). However, the efficiency of this method is low because it may not achieve the best efficiency in extracting the oil from the nuts and seeds. On the other hand, the process of extraction may not be best suited for large-scale production because of the level of efficiency and the production level of this method (Rani et al. 2021).

#### 1.2.10.2. Solvent Extraction

This involves the use of solvents of organic origin such as hexane with evaporating properties to dissolve the oil from the nuts and seeds. After the oil extraction, the organic solvents are allowed to evaporate at favourable condition with the extracted oil remaining (Aremu et al. 2015).

The main advantage of the use of this method is the high yield and efficiency involved in the process when compared to the mechanical pressing methods thus making it a good method for large-scale production. It also fits well as a good method for extracting oil especially from nuts and seeds with very low oil contents. However, the disadvantage comes from the use of the solvent, which leaves some residue after it has evaporated from the oil. These may lead to safety and health concern issues about the oil extracted using these approach (Garcia-Vaquero et al. 2020). Additionally, there are environmental concerns as to the way the solvents are released to the atmosphere (Aremu et al. 2015).

### 1.2.10.3. Supercritical Fluid Extraction (SCFE)

This process involves crushing of seeds and nuts and then exposing them to supercritical fluids such as carbon dioxide (CO2) under critical pressure and temperature where the supercritical fluid shows both liquid and gaseous properties. The supercritical fluid used, extracts the oil from the nuts and the seeds without affecting other components of the nuts and the seeds (Ahangari et al. 2021).

The advantage of this technique for extraction is the fact that it is an efficient and clean method for extracting and producing oils of high quality with the solvent used being classified as safe for the environment. Additionally, the method allows for selective extraction of some compounds from the nuts and seeds and helps in preserving volatile compounds in the nuts and seeds (Ahangari et al. 2021). The disadvantage of this approach is the fact that the process is expensive as the equipment required for the process may not be affordable and might be energy consuming because of the requirement for high temperature and pressure for the extraction (Vafaei et al. 2022). Thus, making it an expensive option for small-scale businesses.

### 1.2.10.4. Cold Pressing

The cold pressing method is like the mechanical pressing method with the use of a screw press and expeller but with cold pressing the pressure and temperature during the pressing process is reduced (Chew, 2020). The cold pressing method does not involve any form of heat.

The major advantage of the use of cold pressing method is the preservation of volatile compounds and nutritional quality of the seeds and nuts, which are heat sensitive. Like the mechanical pressing methods, this process is not efficient, gives oils with lower quantities, and may take more time in extraction (Tungmunnithum et al. 2020). It is also not a suited method for extracting oil from seeds and nuts with low oil content (Chew 2020).

### 1.2.10.5. Enzyme-Assisted Extraction

The use of enzyme-assisted extraction comes from the use of a catalyst to aid extraction of the oil from nuts and seeds. The method involves using grounding the oil seeds and nut with water to form a slurry, which is treated with enzymes such as cellulose, hemicellulose, pectinase, and protease, at the best temperature and pH (Das et al. 2021). The enzymes act by digesting the cell wall of the nuts and the seeds and then releasing the oil. The enzymes hydrolyse the complex carbohydrates, proteins, and lipids that are in the cells of the nuts and the seeds, thereby, making the oilseeds porous and easier to extract (Macedo et al. 2021). Centrifugation or filtration is used in separating the oil from the slur, which is further refined to remove impurities (Das et al. 2021).

The use of this process helps in improving the yield of the oil and can also enhance the sensory properties and nutritional properties of the oil by preserving the volatile compound content of the oil, the fatty acid, and the lipid content among other nutritional content (Costa et al. 2020). The major disadvantage of this method is the fact that it is expensive and requires specificity in terms of optimum temperature and pH for the enzyme activity to take place (Das et al. 2021). Additionally, enzymatic hydrolysis can lead to loss of some bioactive compounds such as antioxidants, which are useful to health while it may also lead to the loss of modification of certain useful compounds in the oil (Macedo et al. 2021).

### 1.2.11. Background and Production of Nuts and Seeds

It is a generally known fact that nuts are grown in orchards or groves and require specific climatic conditions and thus the distribution of different nuts across geographical zones and climate (Avramadis 2023; Rodrigo-Comino et al. 2021). For instance, almonds and pistachios survive well in arid climates, while walnuts and hazelnuts are well suited for temperate regions (Mir et al., 2023; Mirzadi et al. 2023). Harvesting of nuts varies greatly from one plant to the other and some are done mechanically by shaking the trees, while others are picked by hand (Afsah-Hejri et al. 2022). In the area of processing, nuts go through different processing such as hulling, shelling, drying, and sorting while some others such as Almond undergo blanching or roasting to enhance its flavour and texture (Franklin and Mitchel 2019). Nuts can be consumed as raw, roasted, salted, or as ingredients in various food products (Bagheri 2020).

These nuts are produced at different degrees, have their different growth requirement and processing methods. The United States is among the leading producer of nuts with nuts such as almonds and walnuts (Ajibade and Saghaian 2022). China also falls among the major producers with the production of peanuts and walnuts, India with the production of cashew nuts while the Mediterranean region is known to produce pistachios and almonds (Mir et al. 2023). In the area of national production countries such as China is referenced as the highest producer of walnut with the United States being ranked as second with a production of about 650 thousand metric tons as at 2021/2022 production season. China is also the largest producer of peanuts globally with production volumes amounting to about 18 million metric tons and this is followed by India while more than half of the world's pistachios produced comes from the United States (Vuppalapati 2023). This has revealed that the production of nuts and seeds spread across different areas and geographical zones with some areas with significant level of advantage in producing some nuts over others.

Data obtained from Statista (2023), shows that about 5.3 million metric tonnes of tree nuts were produced globally between 2022 and 2023 while almond was the highest produced nuts among tree nuts within the period of 2022 and 2023 with about 1.4 million metric tonnes of almond produced on an annual basis. Additionally, nuts such as walnuts and cashews, were the second and third most produced nuts at over one million metric tons in production (Statista 2023). This shows that nuts are an economic crop and can serve as source of livelihood and foreign exchange earnings. As shown in the level of export being generated from it. For instance, the United States was reported to export over 8 billion dollars of nuts as of 2022 while Turkey's export in nuts was valued at about 1.5 billion dollars (Statista 2023). Other major nut exporters include China, Australia, Czech Republic, and Spain (Jansen, 2020; Owolabi et al. 2023).

On the other hand, countries, which import nuts in large quantities, include Germany, China, India, and Italy (Kumar et al. 2023). This is showing that nuts are not just locally consumed snacks, but it also commands a global audience. However, their availability on a global scale is influenced by the location of production, geographical restrictions and even cost. Thus, leading to inequalities in getting access to these nuts from one country with some nuts readily available in some certain areas while it is scarce or not available in other areas.

**Table 21. Major producers of Nut in the world**

| Nut | Largest Producer | Second Largest Producer |
|---|---|---|
| Chestnut | China | Iran |
| Walnut | China | India |
| Peanut | China | United States |
| Pistachio | Iran | India |
| Cashew Nut | Nigeria | Mali |
| Shea Nut | Nigeria | Italy |
| Hazelnut | Turkey | Iran |
| Almond | United States | India |

**Source: Mind Map Charts, 2023**

Though Cameroon is not one of the major producers of nuts, there are few ones which are common but there is limited information about them. They include, rondelles (Afrostyrax *lepidophyllus),* njansang (*Ricinodendron heudelotii*,), caso nuts or sacha inchi peanut, *Plukenetia volubilis* and tiger nut (*Cyperus esculentus*).

### 1.2.11.1. Rondelles nuts *(Afrostyrax lepidophyllus)*

*Afrostyrax lepidophyllus*, which mainly referred to as rondelles, is from the Huaceae family and common in countries such as Cameroon, Gabon, and Ghana. The plant is threatened plant species (Gallois et al. 2021). However, the plant grows tall, and it survives more in humid African rain forest. The fruit is in the shape of a miniature coconut with hard and woody shells (Mfoumou et al. 2024).

In the area of its economic importance, the extract gotten from the bark of the tree can be used as pesticides against some nematodes and arthropods (Gallois et al. 2021). They are used as spices and this is because of the pleasant aroma which it has, like that of onions and garlic. The nuts are also known to have antioxidant properties. Indigenously, the hard shell of the nuts can be used for ornamental purposes with the kernel being a good source of protein and healthy fats (Tegang et al. 2022).

### 1.2.11.2. Njangsang nuts (*Ricinodendron heudelotii*)

*Ricinodendron heudelotii* also known as Njansang and tree species that is common to the West African region of Africa which include Ghana, Nigeria, Cameroon, and Ivory Coast (Hounsou-Dindin et al. 2022). The seeds of Njangsang are known to be oily and they are used for different purposes both domestically and industrially (Hounsou-Dindin et al. 2022). Ricinodendron belongs to the Euphorbiaceae family, and only one species (R. heudelotii) is known. Two morphotypes of this species are known: R. *heudelotii* var. *heudelotii* and R. heudelotii var. africanum. *R. heudelotii* (Bail.) is native to tropical Africa. (N. F. Adome et al. 2022)

Njangsang seeds has a high content of oleic acid, which is a monounsaturated fatty acid and contains flavonoids, which has antioxidant properties and properties against carcinogens (Adome et al. 2022). The nut is a threatened species because of destruction of natural occurring habitat due to urban development. On the other hand, it is dioecious nature thus making it a very difficult crop to cultivate because of the requirement for the male and female flowers, which grows on separate trees to be in proximity for there to be a successful cultivation of fruits on the tree (Hounsou-Dindin et al. 2022).

### 1.2.11.3. Tiger nuts (*Cyperus esculentus*)

Tiger nuts have the scientific name *Cyperus esculentus* and they are of the sedge family. The nuts are found in Africa, the Middle East, Southern Europe, and India (Wetters et al. 2023). Tiger nut has different names such as chufa, earth almond, yellow nutsedge, and edible rush. It referred to as "earth almonds" because of the sweet nut-like taste and hard shell it possesses (Yawembe et al. 2020).

The plant survives well in mild climates above 30 degrees and can easily adapted to grow in sandy and soils with loose characteristics (Yang et al. 2022). The nut is a good snacking option and used for the preparation of tiger nut milk (Gasperre et al. 2020). The high presence of tocopherol, polyphenols and phytosterols in the nut gives it some health benefitting properties. It has high content of fibre, vitamins mineral and phytochemicals (Edo et al. 2023). They are free of gluten, high in oleic acid and low in calories (Edo et al. 2023; Gasparre et al. 2020)

### 1.2.11.4. Sacha inchi peanut or Caso nuts (*Plukenetia volubilis*)

*Plukenetia volubilis* is a perennial plant and from the family of Euphorbiaceae and common to the tropical part of South America (Haros et al. 2023). Another name for the nut is Sacha inchi and inca-peanuts (Haros et al. 2023). The nuts produce edible nuts, which has a high level of fibre, healthy fats, protein, and some volatile compounds (Haros et al. 2023). Sacha inchi (SI) nuts contain flavonoids and rich in tocopherols and MUFA, which confer on it some properties of being an antioxidant, and other important properties which are good for health (Mosquera et al. 2022).

At present, SI seeds are emerging as a potential source of macro- and micronutrients, α-linolenic acid, and phytochemicals. This review attempts to elucidate the nutrients, phytonutrients, safety, toxicity, health benefits and food applications of SI seed. Recent scientific studies have associated the consumption of SI seed/oil with reduced risk of chronic inflammatory diseases. However, lack of awareness and in-depth understanding has resulted in it being neglected at both the consumer and industrial level. In all, SI is an underutilized and undervalued oleaginous crop, which not only has the potential to mitigate food and nutritional insecurity but also offers humongous opportunities for the development of novel value-added food products. (Ankit et al 2022).

The cultivation of the plant is usually in warm climates and the soil conditions requires that it is well drained and with availability of water almost all year round (Jacobsen et al. 2023).

### 1.2.12. Review on GC-MS (Gas chromatography-Mass Spectrometry)

GC-MS is a combination of two key techniques for analysis, which involves the combination of the separation techniques of gas chromatography with the mass spectrometry quality of being able to identify and quantify qualities. The method finds its usefulness in areas such as chemistry, environmental science, food science, pharmaceutical industry, and metabolomics among other areas (Mota et al. 2021). It is also important for the identification and analyses of volatile compounds, semi volatile compounds, drugs, pesticide among other areas (Gruber et al. 2020).

GC-MS consists of four components which a sample injector, GC column, data system and MS detector. In the process, the sample injector is where the sample is passed into the gas chromatography column. From the gas chromatography column, vaporisation takes place and then an inert gas such as hydrogen or helium is introduced to convey the vaporised content through the column (Amirav et al. 2020). In the gas chromatography column separation of the sample into individual component takes place based on the boiling point, polarity, and affinity to the stationary phase (Talebi et al. 2020). After which ionisation takes place in the MS detector by an electron beam which detects the mass-to-charge ratio. The data system then records the mass spectra to compare with a library information from which classification into different component is done (Maciel et al. 2022).

The advantage of the GC-MS is that it is highly sensitive and can identify trace compounds from a sample of complex compounds and the level of accuracy is high. The method is also consistent and reliable, and the result gotten from is reproducible using the same strategy (Garcia-Bellido et al. 2020).

The identified limitations of this technique include the fact that it is only useful for compounds that are stable or volatile (Dies-Simon et al. 2020). Matrix effects, such as co-elution, ion suppression, can influence the method and contamination and this can reduce the sensitivity and accuracy of the method. Additionally, the result from the GC-MS is complex to interpret and requires expertise especially in identifying complex compounds (Rodriguez et al. 2020). The method may also be quite expensive and complex because of the equipment and other things required to implement it (Dies-Simon et al. 2020). Other disadvantages include the fact that the separation of polar compounds may be limited because of the non-polar nature of GC columns and then some sample may involve additional processing to improve volatility (Garcia-Bellido et al. 2020).

GC-MS can be seen as a technique that will continue to evolve in its use as new challenges arises and thus causing improvements in the field of science.

#### 1.2.12.1. Obtaining the Fatty Acids

Fatty acids are commonly analysed by gas chromatography (GC). This technique requires fatty acids to be in their derivatized form, for instance fatty acids methyl esters (FAME), which are more volatile and therefore can be easily separated and quantified using GC, without the risk of thermal decomposition during analysis. Most methods include a few sample preparation steps prior to their analysis on gas chromatography.

Firstly, the fat undergoes a saponification reaction which produces free fatty acids and glycerol. Then, the free fatty acids are subjected to a transesterification reaction with methanol to obtain fatty acids methyl esters. Fatty acids methyl esters are then subsequently extracted with organic solvents from the reaction mixture and then can be analysed by GC. This usually involves the substitution of a functional group containing hydrogen to form esters, thioesters, or amides for analysis. Methyl esters are commonly studied derivatives, which are produced by methylation. In this method the ester bonds in complex lipids are hydrolysed to release free fatty acids, which are trans methylated to form fatty acid methyl esters (FAME). The resulting profile of FAME, determined by GC, is the fatty acid composition. Derivatization in general converts less volatile and thermally labile substances into compounds that can be analysed in the gaseous state. (Atapatty and Rosenfeld 2022).

The greater the concentration in the sample, the bigger the signal obtained which a computer then processes. The time from when the injection was made (Initial time) to when elution occurred is referred to as the retention time (RT). While the instrument is running, the computer generates a graph from the signal called chromatogram. Each of the peaks in the chromatogram represented the signal created when a compound is eluted from the gas chromatography column into the detector (Mohammed and Imad 2013). The x-axis showed the RT, and the y-axis measured the intensity of the signal to quantify the component in the sample injected. As individual compounds elute from the gas chromatographic column, they enter the electron ionization (mass spectroscopy) detector, where they are bombarded with a stream of electrons causing them to break apart into fragments. The fragments obtained are charged ions with a certain mass. The mass/charge (M/Z) ratio obtained is calibrated from the graph obtained, which was called the mass spectrum graph, which is the fingerprint of a molecule (Imad et al. 2014).

#### 1.2.12.2. Determination of volatile components

Solid phase micro extraction (SPME) technique is an innovative and sensitive solvent-free sample preparation technology, based on the principle of adsorption/absorption and desorption, SPME uses a coated fibre to concentrate volatile and semi-volatile compounds from a sample. (Merck 2023)

SPME is widely used for a variety of applications involving environmental, biological, and pharmaceutical samples, foods and beverages, flavours and fragrances, forensics and toxicology and product testing. Typical uses include Environmental analyses of water & air samples, Headspace analysis of trace impurities in polymers and solid samples, Part-per-trillion odour analyses, Flavour analyses of food products, Forensic analysis of arson and explosives samples, Toxicology analyses of blood alcohol or drugs in urine and serum. (Merck 2023)

SPME uses a fibre coated with an extraction phase: a liquid (polymer), a solid (sorbent), or a combination of both. The coated fibre is housed in a protective needle, and attached to a holder that looks like a syringe. (Merck 2023)

When the fibre is exposed to a sample, the sample's analytes partition from the sample matrix into the stationary phase until an equilibrium is established. The fibre's coating extracts compounds from the sample either by absorption (liquid coatings) or by adsorption (solid coatings). After a prescribed extraction time, the fibre is removed and inserted directly into a chromatographic instrument, usually gas chromatography (GC), for desorption and analysis. The desorption in GC of analytes is carried out thermally (Merck, 2023).

### 1.2.13. Determination of pH of nuts and seeds

pH measures the amount of acidity or alkalinity in a food or solution using a numerical scale between 1 and 14. A pH value of 1 is most acidic, a pH value of 7 is neutral, and values above 7 are referred to as basic or alkaline. Acidified foods have a pH value less than or equal to 4.6. It is very important that pH testing be done correctly and accurately. (B. Ingham 2009).

# 2. Aims of the Thesis

The aim of the work was to analyse the fatty acids and volatile compounds of selected nuts and seeds such as rondelles (*Afrostyrax lepidophyllus)*, Njangsang (*Ricinodendron heudelotii*), tiger nut *Cyperus esculentus*), and sacha inchi or caso nuts *Plukenetia volubilis*) from Cameroon.

## 2.1. Specific Objectives

1. To identify the volatile compounds of selected nuts and seed: rondelles (*Afrostyrax lepidophyllus)*, Njangsang (*Ricinodendron heudelotii*), tiger nut *Cyperus esculentus*), and sacha inchi or caso nuts *Plukenetia volubilis*) and seeds.
2. Characterise the fatty acid composition of selected nuts and seeds: rondelles (*Afrostyrax lepidophyllus)*, Njangsang (*Ricinodendron heudelotii*), tiger nut *Cyperus esculentus*), and sacha inchi or caso nuts *Plukenetia volubilis*) and seeds.
3. Determine the pH of the selected nuts and seeds: rondelles rondelles (*Afrostyrax lepidophyllus)*, Njangsang (*Ricinodendron heudelotii*), tiger nut (*Cyperus esculentus*), and sacha inchi or caso nuts (*Plukenetia volubilis*) and seeds.

# 3. Methods

This section outlines the materials and methods used in carrying out this research work.

## 3.1. Materials

The materials used were bought from the Douala central market of Cameroon. These includes dried raw 1. rondelles *(Afrostyrax lepidophyllus),* Njangsang *(Ricinodendron heudelotii),* tiger nut *Cyperus esculentus),* and sacha inchi or caso nuts *Plukenetia volubilis)* and seeds. They were transported under normal conditions to Czech Republic. Hexane was used as a solvent of extraction and the boiling stones were used as boiling aid in the Soxhlet method of oil extraction.


**Figure 2. pictures of tiger nuts, sacha inchi peanuts or caso nuts, njansang and rondelles**

## 3.2. Method

### 3.2.1. Preparation of Raw Material

All nuts were crushed in the blender to reduce the particle size and increase surface area for extraction of oils. The crushed nuts were stored in the fridge, where 10g of each sample were used for extraction but for caso nut, raw fresh nuts were received, pre-processed by removing the outer shell and cooked before taking to the laboratory for analysis. In the lab, the samples were crushed and dried for two (2) hours. After which some a portion was taken to the GC for volatile components analysis while another portion was use for the extraction of oils.

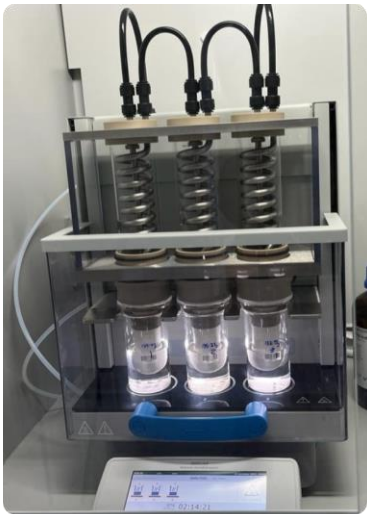

**Figure 3: oil extraction process**

### 3.2.2. Extraction of oils

To determine the fat component in the nuts and seed samples, fat extraction was conducted to the grounded samples following the **Soxhlet Extraction method** for the extraction of oils. The extractions were carried out using 10 g of each sample in the paper thimble  for a 125 mL volume of solvent (n-hexane Sigma Aldrich) with the aid of the boiling stone.  Modified method of fat extraction in oily seeds and nuts was the used program in the equipment, where the immersion time was set at 2 hours, followed by a removal stage with a set duration of 10 minutes. The washing stage followed with a duration set to 50 minutes and finally, the recovery period of 30 minutes. The whole process allows for the extraction of triacylglycerides (TAGs) with the solvent hexane from the sample. To separate the solvent n-Hexane from the fat, the final product was covered with aluminium foil and stored at room temperature for at least 2 days to allow the evaporation of the solvent.

The pure oils were then weighed, and the extraction yield was calculated according to the following formula:

$$Yield\ (\%) = \frac{wo}{ws} \times 100$$

where $wo$ and $ws$ are the mass of the extracted oils and mass of samples respectively.

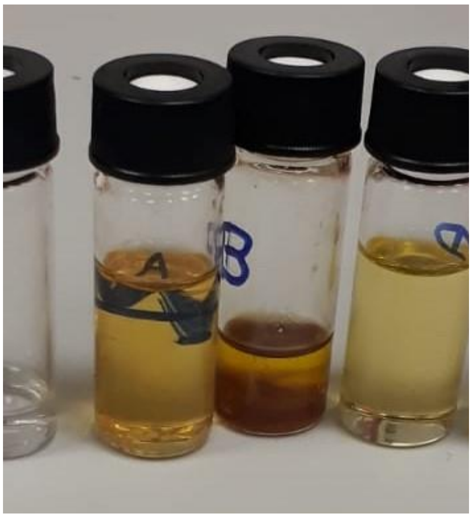


**Figure 4: Extracted oils.**

### 3.2.3. Transesterification

To analyse the TAGs extracted from the samples, transesterification was conducted to prepare fatty acid methyl ester (FAME) from TAGs. However, for this test, sodium methoxide/methanol (0.5 M) was used. Oil samples measuring 10 ml were put inside vials and were mixed with 1 ml of toluene, which was added as a solubilizer. Once the samples were dissolved, 4 ml of the reagent (sodium methoxide/methanol) was added. The mixture was stirred and allowed for 15 minutes so that the reaction can take place, then 5 ml of 5% aqueous acetic acid was added, followed by 6 ml of hexane. The mixture was shaken thoroughly and allowed to separate. Once the layers were visibly separated, the top layer was transferred to a small vial and used for GC-MS analysis.

The extracts were converted to fatty acid methyl esters (FAME) for subsequent chromatographic analysis. Three (3) replicates of each sample were used.

### 3.2.4. Fatty Acid Methyl Ester (FAME) Analysis

Fatty acid composition was analysed based on the method used by Khatun et al. (2021) where GC-MS (GC 7890B/5977A MSD Agilent Technologies USA) equipped with HP-5 column 0.25 mm x 60 m x 0.25 µm column (Sigma Aldrich, USA) was used and helium was utilized as the carrier gas with a rate of 1 ml/min. The initial temperature was set at 70 °C for 5 minutes and was gradually increased to 280 °C at the rate of 10 °C/min and the run time was 28 minutes. Data were processed using Mass Hunter Workstation Software Qualitative Analysis. The peak area was obtained from electronic integration. The identification of the substances was based on the comparison of the mass spectra of the detected substances with the mass spectra of the NIST/EPA/NIH version 2.2 library. The identification was confirmed by comparing the measured RI with the database of the National Institute of Standards and Technology (NIST, USA).

### 3.2.5. GC-MS Analysis (SPME)

Volatile compound analysis was conducted by headspace solid-phase microextraction coupled with GC-MS (Haber et al. 2019).

A blank measurement was run at the start of the day prior to any analysis to condition the equipment and make sure that there was no contamination between samples.

A 50/30 µm divinylbenzene/carboxen/polydimethylsiloxane (DVB/CAR/PDMS) fibre (Supelco, PA, USA) was used for volatile compound extraction. Grinded sample weighing 1 g was placed in a vial capped with a polytetrafluoroethylene septum and heated at 80 °C for 15 minutes while being agitated at 250 rpm. The extraction was performed by inserting the SPME fibre into the headspace, carefully avoiding contact between the fibre and the samples, while the samples were continuously heated and agitated with a magnetic stirrer for 30 minutes. After the extraction process, the fibre was transferred to the GC-MS injector. The GC-MS analysis was performed on GC 7890B/5977A MSD (Agilent Technologies, USA) equipped with HP-5 column where the injector temperature was set at 250 °C and helium was used as carrier gas with the rate of 1 ml/min. The oven temperature was set at 40 °C for 5 minutes, then increasing it to 200 °C at a rate of 5 °C/min, followed by an increase to 250 °C degrees at a rate of 10 °C (Haber et al. 2019). The identification of constituents was based on the comparison of their retention indices (RI) and spectra with the National Institute of Standards and Technology Library ver. 2.2.f (NIST, USA), together with the authentic standards and literature (Adams 2007). Data were processed using Mass Hunter Workstation Software Qualitative Analysis B.07.00. The peak area was obtained from electronic integration.

### 3.2.6. Determination of pH of the nuts and seeds

pH Test was conducted on the grinded samples using the pH meter (Orion Star A211 Benchtop pH meter, USA). To achieve this, 10 g of each sample was put into a beaker and 100 ml of distilled water added. The mixture was allowed for 10 mins. The pH of the mixture was then recorded using the pH meter. The pH meter was firstly calibrated where the pH electrode probe was immersed in the mixture after stirring until the reading was finished.

**Figure 5: pH measurement**

# 4. Results

Since tests were performed in triplicates, only the average recording obtained from the data has been used for the analysis.

## 4.1. Oil yield.

From the results on table 3 below, we noticed that sacha inchi (caso nuts), and both varieties of njansang produced a significant amount oil, implying that they can be good source oils. On the other hand, tiger nuts and rondelles have very poor oil content thus can only be used for other purposes such as snacks and flavorings respectively.

**Table 22. Oil yield of nuts and seed samples**

| **Sample name** | **Sample weight (g)** | **Weight of oil (g)** | **Percentage oil yield (%)** |
|---|---|---|---|
| Njansang *(R.h africanum.)* | 10 | 4 | 40 |
| Tiger nuts | 10 | 2 | 20 |
| Caso nuts | 10 | 3.62 | 36.2 |
| Njansang *(R.h. var. heudelotii)* | 10 | 3.54 | 35.4 |
| Rondelles | 10 | 0.29 | 5 |

## 4.2. Fat analysis

The fatty acid composition of the nuts and seed samples was determined after the transesterification of fats with methanol and analysis in GC-MS. Retention Indices of fatty acid methyl esters were calculated and compared to the literature. The total number of fatty acids for each sample were identified from the corresponding fatty acid methyl esters detected during the fatty acid analysis of the five nuts and seed samples.

### 4.2.1. Tiger nuts

For the fatty acid analysis of tiger nuts, 9 peaks were observed each corresponding to a particular fatty acid. The retention time (RT) and the area percentage of the fatty acid were also recorded as shown on table 4 below. The major fatty acids present were Oleic acid (76.19%), Palmitic acid (11.35%), and Stearic acid (8.01%).

**Table 23. Retention indices of fatty acids for tiger nuts**

| Names | Area sum % | Cal RI | LIT |
|---|---|---|---|
| Palmitoleic acid | 0.17 | 1903 | 1944 |
| Palmitic acid | 11.35 | 1953 | 1933 |
| Linoleic acid | 8.01 | 2091 | 2091 |
| Oleic acid | 76.19 | 2128 | 2128 |
| Stearic acid | 2.05 | 2132 | 2135 |
| Gondoic acid | 0.24 | 2300 | * |
| Arachidic acid | 0.6 | 2319 | 2329 |
| 18-methylnonadecanoic acid | 0.58 | 2358 | * |
| 20-methylheneicosanoic acid | 0.09 | 2780 | 2760 |

*Key: * indicates that the retention index of fatty acid is not available in the literature used for comparison*

### 4.2.2. Caso nuts (sacha inchi peanut)

For caso nuts (sacha inchi peanut), seven (7) peaks were observed, each corresponding to a particular fatty acid as shown on table 5 below.

**Table 24. Retention indices of fatty acids for caso nuts**

| Name | Area sum % | Cal RI | LIT |
|---|---|---|---|
| Palmitic acid | 2.64 | 1953 | 1933 |
| Margaric acid | 0.14 | 2069 | 2069 |
| Linolenic acid | 94.57 | 2132 | 2134 |
| Linoleic acid | 0.18 | 2092 | 2092 |
| 10-Nonadecenoic acid | 0.32 | 2212 | 2212 |
| Gondoic acid | 1.8 | 2300 | * |
| Arachidic acid | 0.22 | 2358 | 2339 |

*Key: * indicates that the retention index of fatty acid not available in the literature used for comparison*

### 4.2.3. Njansang (*R. heudelotii var. africanum.*)

Nine (9) peaks were observed, corresponding to the same number of fatty acids in njansang (*R. heudelotii var. africanum.)* as shown in table 6 bellow. The major ones were Eleostearic acid (51.7%), Linoleic acid (28.68%), and Linolenic acid (10.04%), and Stearic acid (7.07%).

**Table 25. Retention indices of fatty acids for njansang (*R. heudelotii var. africanum.*)**

| common names | Area sum % | Cal RI | RI LIT |
|---|---|---|---|
| Palmitic acid | 1.82 | 1953 | 1933 |
| Margaric acid | 0.14 | 2069 | 2069 |
| Eleostearic acid | 51.7 | 2067 | * |
| Linoleic acid | 28.68 | 2067 | 2076 |
| Stearic acid | 7.07 | 2132 | 2135 |
| Linolenic acid | 10.04 | 2108 | 2108 |
| Gadoleic acid, | 0.6 | 2319 | * |
| Arachidic acid | 0.12 | 2358 | 2339 |

*Key: * indicates that the retention index of fatty acid is not available in the literature used for comparison*

### 4.2.4. Njansang *(R. heudelotii var. heudelotii)*

Eight (7) fatty acids were identified from njansang (*R. heudelotii var. africanum*) as shown on table 7 below. The major ones were Eleostearic acid (54.83%), linoleic acid (32.54 %), stearic acid (7.04 %) and palmitic acid (4.7%).

**Table 26: Retention indices of fatty acids for njansang (*R. heudelotii var. heudelotii*)**

| Names | Area sum % | Cal RI | LIT |
|---|---|---|---|
| Palmitic acid | 4.7 | 1953 | 1933 |
| Linoleic acid | 32.54 | 2067 | 2076 |
| Stearic acid | 7.04 | 2132 | 2135 |
| Linolenic acid | 0.11 | 2108 | 2108 |
| Gadoleic acid, | 0.6 | 2319 | * |
| Eleostearic acid | 54.83 | 2067 | * |
| Arachidic acid | 0.12 | 2358 | 2339 |

### 4.2.5. Rondelles

Up to fourteen (14) peaks were observed, representing the same number of fatty acids presents in rondelles with palmitic acid (57.88%), Lauric acid (19.43%), and Myristic acid (3.89%) as shown on table 8 below.

**Table 27: Retention indices of fatty acids for rondelles**

| Names | Area sum % | Cal RI | LIT |
|---|---|---|---|
| Caprylic acid | 0.58 | 1173 | 1171 |
| Capric acid | 0.77 | 1408 | 1404 |
| Lauric acid | 19.43 | 1533 | 1533 |
| Myristic acid | 3.89 | 1702 | 1706 |
| Pentadecanoic acid | 0.08 | 1844 | 1826 |
| Palmitic acid | 57.88 | 1953 | 1933 |
| 9-Heptadecenoic acid | 0.06 | 2000 | * |
| Margaric acid | 0.12 | 2069 | 2069 |
| Stearic acid | 7.38 | 2132 | 2135 |
| Catalpic acid | 0.32 | 2300 | * |
| Arachidic acid | 0.14 | 2319 | 2329 |
| Behenic acid | 0.06 | 2534 | 2531. |
| Lignoceric acid | 0.08 | 2740 | 2737 |
| Linoleic acid, phenylmethyl | 0.07 | 2839 | * |

*Key: * indicates that the retention index of fatty acids is not available in the literature used for comparison*

## 4.3. Volatile components (SPME analyses)

### 4.3.1. Tiger nuts

Twenty-nine (26) peaks were observed as shown in figure 6 below corresponding to same number of volatile components present in tiger nuts as shown in table 9 below. Most of them are in minute quantities with the major ones being m-cymene (24.22%), γ-terpinene (23.83%), n-hexane (6.17%), 1-chloro-5-methyl (4.85%), lactamide (4.57%), and amino urea (4.11%)

**Table 28. Retention indices of volatile components of tiger nuts**

| Name | Area sum % | Cal IR | LIT |
|---|---|---|---|
| Amino urea | 4.11 | - | * |
| Hydroxyurea | 1.1 | - | * |
| Lactamide | 4.57 | - | * |
| 3,3-Dimethyl-4-methylamino-butan-2-one | 0.27 | - | * |
| Allylurea | 0.5 | - | * |
| n-Hexane | 6.17 | - | * |
| 2-Ethyl-oxetane | 0.49 | - | * |
| Pentylene glycol | 1.5 | 716 | * |
| Toluene | 1.51 | 750 | 750 |
| Glyoxylic acid | 0.37 | 791 | * |
| 2,4-Dimethyl-1-heptene | 1.01 | 834 | 842 |
| Hexane 3-ethyl-6,6-trimethyl | 0.53 | 857 | * |
| o-Xylene | 0.4 | 866 | 850 |
| α-Thujene | 0.4 | 932 | 931. |
| Ethyltoluene | 0.62 | 963 | 973 |
| 1-Hexanone | 0.29 | 970 | * |
| β-Farneesene | 1.93 | 976 | * |
| Mesitylene | 1.55 | 992 | * |
| m-cymene | 24.22 | 1027 | 1030 |
| 1-Chloro-5-methyl | 4.85 | 1030 | * |
| 5,7-Dimethylundecane | 1.29 | 1058 | * |
| γ-Terpinene | 23.83 | 1062 | 1062 |
| 2-Methyl-2-undecanethiol | 1.43 | 1080 | * |
| 2,4,6-Trimethyldecane | 1.46 | 1102 | 1121 |
| 1,5-Hexadiene-3, 4-diol, 3, 4-dimethyl | 0.58 | 1108 | * |
| Pentane, 3, 3-dimethyl | 1.52 | 1115 | * |

*Key: - indicates that value of retention index is out of calibration, * indicates that the retention index of volatile compound is not available in the literature used for comparison*

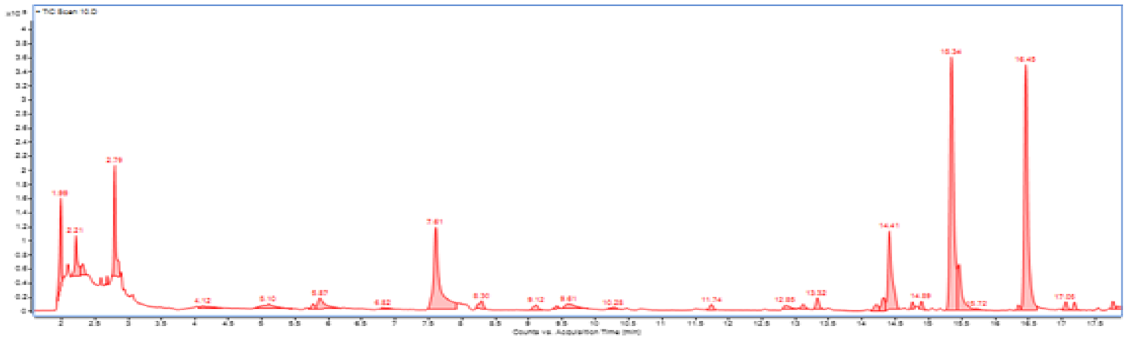

**Figure 6. Chromatogram of tiger nuts**

### 4.3.2. Sachi inchi peanut or caso nuts

Twelve (12) peaks were observed as shown in figure 7 below corresponding to the same number of volatile components as shown on table 10 below, with the major ones being m-Cymene (43.56%), γ-Terpinene (36.5%), 3,5-Octadien-2-one (4.85%), Ethanol (2.24%) and Trimethylene glycol (1.66%).

**Table 29. Retention indices of volatile components of caso nuts**

| **Name** | **Area sum %** | **Cal IR** | LIT |
|---|---|---|---|
| Trimethylene glycol | 1.66 | - | * |
| Ethanol | 2.24 | - | * |
| n-Hexane | 0.94 | - | * |
| Toluene | 0.99 | - | * |
| 2-Heptanone | 0.8 | 889 | 889 |
| 6-Dimethyl-2-methylene-heptane | 0.44 | 971 | * |
| β-Myrcene | 0.96 | 985 | 988 |
| 2,4-Heptadienal | 1.77 | 992 | 992 |
| m-Cymene | 43.56 | 998 | 1010 |
| γ-Terpinene | 36.5 | 1035 | 1035 |
| 3,5-Octadien-2-one | 4.85 | 1076 | * |
| Allyl disulphide | 0.94 | 1094 | 1095 |

*Key: - indicates that value of retention index is out of calibration, * indicates that the retention index of volatile compound is not available in the literature used for comparison.*

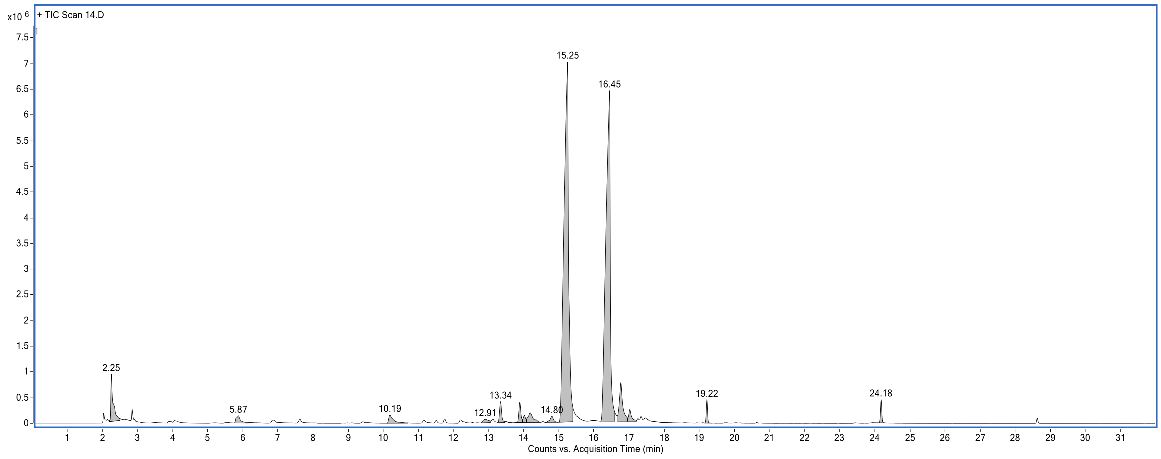


**Figure 7. Chromatogram of volatile components of caso nuts**

### 4.3.3. Njansang (*R. heudelotii var. africanum*)

For volatile compounds present in njansang (*R. heudelotii var. africanum*), 23 peaks were observed corresponding to the same number of volatile components as shown in figure 8 and table 11 below. Out of this 23, only 10 of them had an area sum percentage greater than 1%. These include pentanal (29.64%), 2-hexenal (12.19%), 2nonenal (12.14%), 2,4-nonadienal (10.48%), 2-butylfuran (7%), 2-heptenal (3.77%), valeric acid (3.13%), 2-octenal (2.36%) and 1-ethyl-5-methylcyclopentene (1.14%) in a decreasing order.

**Table 30. Retention Indices of volatile components of njansang (*R. heudelotii var. africanum*)**

| Name | Area sum % | Cal RI | LIT RI |
|---|---|---|---|
| Butanal | 0.63 | - | * |
| Pentanal | 29.64 | - | * |
| 2-Hexanone | 0.58 | 756 | 750 |
| 2-Hexenal | 12.19 | 791 | * |
| 2-Butylfuran | 7 | 849 | * |
| 4-Isopropylcyclohexanol | 0.73 | 889 | * |
| Heptanal | 0.67 | 896 | 896 |
| 1-Ethyl-5-methylcyclopentene | 1.14 | 899 | * |
| 2-Heptenal | 3.77 | 928 | 947 |
| Valeric acid | 3.13 | 958 | * |
| 3-Heptenoic acid | 0.79 | 966 | * |
| 2-Pentylfurane | 3.34 | 992 | 992 |

| | | | |
|---|---|---|---|
| o-Cymene | 0.99 | 1027 | 1027 |
| Cyclopentanecarboxaldehyde, 2-methyl-3-methylene | 0.67 | 1034 | * |
| 2-Octenal | 2.36 | 1062 | 1062 |
| 5-Nonanone | 0.37 | 1078 | * |
| Valeric acid, butyl ester | 0.37 | 1097 | * |
| Nonanal | 0.44 | 1109 | 1109 |
| 5-Decanone | 0.55 | 1177 | * |
| L-Menthol | 0.8 | 1184 | * |
| 2-Nonenal | 12.14 | 1191 | 1171 |
| 2,4-Nonadienal | 10.48 | 1223 | 1223 |
| 2-Butyl-2-octenal | 0.58 | 1281 | * |

*Key: - indicates value of retention index is out of calibration, * indicates that retention index of volatile compound is not available in the literature used for comparison*

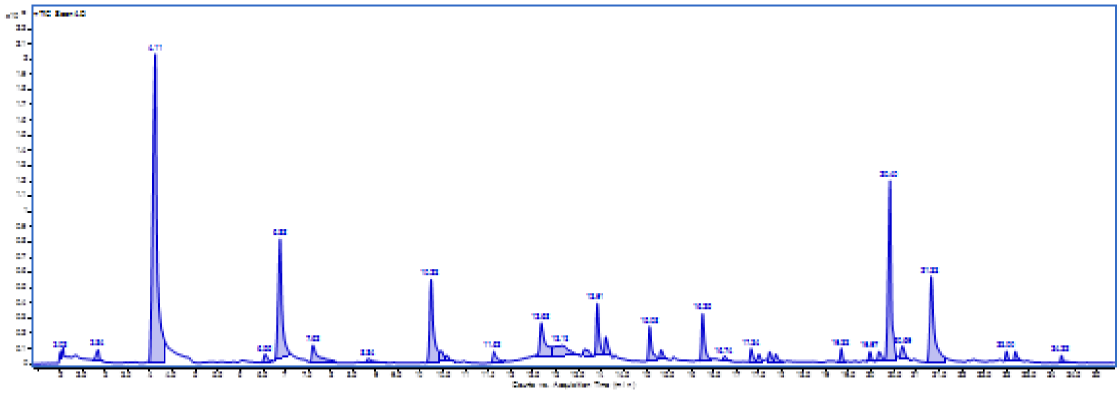

**Figure 8. Chromatogram of volatile components of njansang *(R. heudelotii var. africanum)***

### 4.3.4. Njansang *(R. heudelotii var. heudelotii)*

Thirty-two (32) peaks were observed for njangsang (*R. heudelotii var. heudelotii)* as shown on figure 9 and table 12 below corresponding to the same number of volatile components. 13 components had an area sum percentage greater than 1% including pentanal (22.21%), Styrene (12.15%), 1-chloro-5-methylhexane (11.65%), γ-terpinene (9.04%), γ-terpineol (8.84%), carbon dioxide (8.31%), triacetone triperoxide (1.89%), 1-pentanol (1.49%), n-hexane (1.42%), isopentyl alcohol (1.27%), and 2-nonanone (1.08%).

**Table 31. Retention Indices of volatile components of njansang (*R. heudelotii var. heudelotii*)**

| Name | Area Sum % | Cal IR | LIT |
|---|---|---|---|
| Carbon dioxide | 8.31 | - | * |
| Lactic acid | 0.85 | - | * |
| Triacetone triperoxide | 1.89 | - | * |
| 1-Propanol, 2-amino | 0.9 | - | * |
| (2-Aziridinylethyl) amine | 0.36 | - | * |
| n-Hexane | 1.42 | - | * |
| 2-Pentanone | 0.65 | - | * |
| Pentanal | 22.21 | - | * |
| Isopentyl alcohol | 1.27 | - | * |
| 1-Pentanol | 1.49 | - | * |
| 2-Hexanone | 0.67 | 778 | 788 |
| Hexanal | 0.46 | 791 | 791 |
| Hydroperoxide | 0.26 | 815 | * |
| Butyl oxide | 0.65 | 889 | 888 |
| Styrene | 12.15 | 896 | 895 |
| α-Pinene | 0.51 | 919 | 939 |
| 2-Heptenal, (Z) | 0.32 | 928 | 947 |
| β-Terpinen | 0.77 | 958 | * |
| Nona-3, 5-dien-2-one | 0.39 | 971 | * |
| 1-Bromo-3, 7-dimethyl-2, 6-octadiene | 0.51 | 985 | * |
| Pseudocumene | 0.53 | 992 | 992 |
| α-Phellandrene | 0.33 | - | * |
| 1-Methoxy-1,3,5,5-Cycloheptatriene, | 1.16 | - | * |
| m-Cymene | 0.26 | 998 | 1010 |
| 1-Chloro-5-methylhexane | 11.65 | 1027 | * |
| Eucalyptol | 1.89 | 1035 | 1035 |
| Cyclohexane,1,2,4-tris(methylene) | 0.82 | - | * |
| γ-Terpinene | 9.04 | 1076 | 1074 |

| | | | |
|---|---|---|---|
| 2-Nonanone | 1.08 | 1099 | 1096 |
| d-2-Camphanone | 0.24 | 1158 | 1144 |
| γ-Terpineol | 8.84 | 1185 | * |
| 2,4-Nonadienal, (E, E) | 0.3 | 1224 | 1224 |

*Key: - indicates value of retention index is out of calibration, * indicates that the retention index of volatile compound is not available in the literature used for comparison*

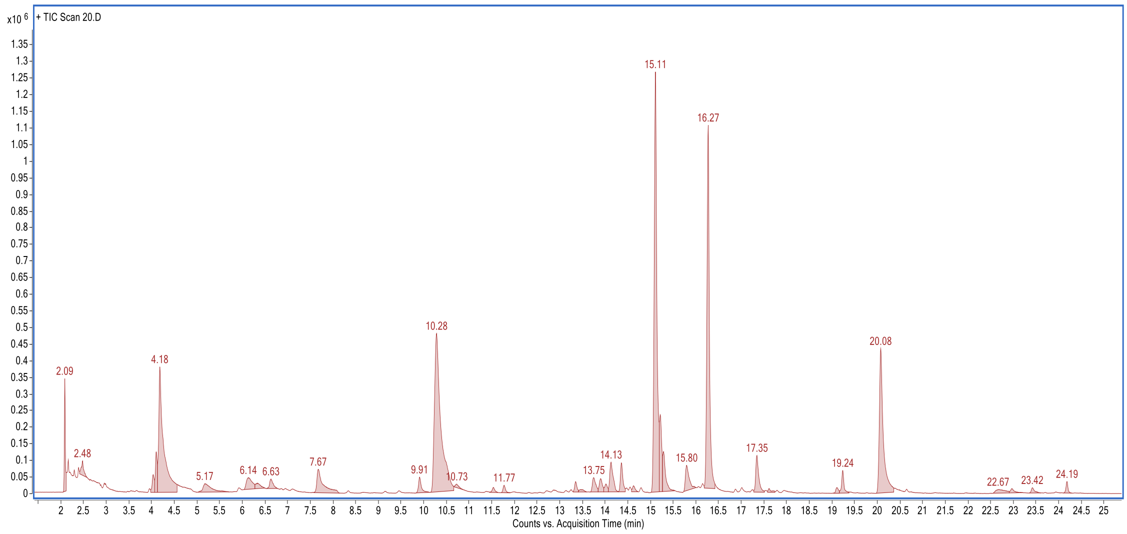


**Figure 9. Chromatogram of volatile components of njansang (*R. heudelotii var. heudelotii)***

### 4.3.5. Rondelles

Six (6) peaks were observed as shown in figure 6 corresponding to the same number of volatile components as shown on table 13 below. The major volatile components found were Bis(methylthiomethyl) disulfide (74.19%), 2,4,5-Trithiahexane (12.79%), and methanesulfonothioate (3.98%), γ-Terpinene (3.63%), and m-Cymene (3.26%).

**Table 32. Retention indices of volatile components of Rondelles**

| **Name** | **Area Sum %** | **Cal RI** | **LIT** |
|---|---|---|---|
| m-Cymene | 3.26 | 1035 | 1033 |
| γ-Terpinene | 3.63 | 1094 | 1088 |
| 2,3-Dimethyl-5-ethylpyrazine | 1.1 | 1111 | 1105 |
| 2,4,5-Trithiahexane | 12.79 | 1179 | * |
| Methanesulfonothioate | 3.98 | 1394 | * |
| Bis(methylthiomethyl) disulphide | 74.19 | 1570 | * |

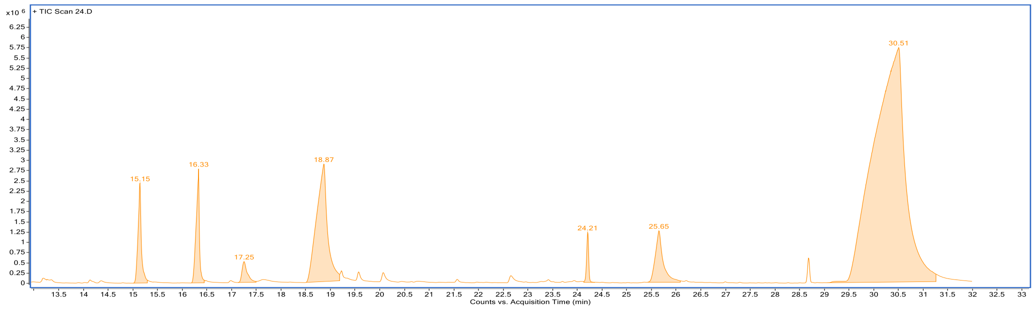


**Figure 10. Chromatogram of volatile components of Rondelles**

## 4.4. pH of nuts and seeds

All nuts and seed samples were within the neutral pH range as shown on table 14 below.

**Table 33. pH values of selected nuts and seeds**

| Nut and seed sample | pH value |
|---|---|
| Tiger nuts | 6.86 |
| Caso nuts | 6.33 |
| Njansang (*R. heudelotii var. africanum*) | 5.96 |
| Njansang (*R. heudelotii var. heudelotii)* | 6.55 |
| Rondelles | 5.64 |

## 4.5. Classification of Fatty acid

Many fatty acids identified from each nut samples which were classified into four groups of fatty acids that exits in nature, namely, monounsaturated (MUFA), saturated, polyunsaturated (PUFA), and unsaturated.

### 4.5.1. Tiger Nuts

In the fat analysis of tiger nuts, majority of the fatty acids present were MUFA. An overall of nine (9) fatty acid were identified. This includes four (4) MUFA, five (5) SFA and as shown on table 15 below.

**Table 34. Fatty acid composition of tiger nuts**

| Type of fatty acid | Names | Area sum % |
|---|---|---|
| MUFA | Gondoic acid | 0.24 |
| | Palmitoleic acid | 0.17 |
| | Linoleic acid | 8.01 |
| | Oleic acid | 76.19 |
| SFA | Palmitic acid | 11.35 |

| | | |
|---|---|---|
| | Stearic acid | 2.05 |
| | Arachidic acid | 0.6 |
| | 18-methylnonadecanoic acid | 0.58 |
| | 20-methylheneicosanoic acid | 0.09 |

*key: SFA, saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA polyunsaturated fatty acid. Note: Percentages may not add up to 100% due to some FA traces not listed*

### 4.5.2. Sacha inchi peanut or Caso nuts

For sasha inchi peanuts or caso nuts, an overall number of seven (7) fatty acids were identified, with many of them being saturated fatty acids. At total number of four (4) saturated fatty acids, two (2) PUFA and one (1) MUFA as shown table 16 below.

**Table 35. Fatty acid composition of Caso nuts**

| Type of fatty acid | Name | Area sum % |
|---|---|---|
| MUFA | Gondoic acid | 1.8 |
| SFA | Palmitic acid | 2.64 |
| | Arachidic acid | 0.22 |
| | Margaric acid | 0.14 |
| | 10-Nonadecenoic acid | 0.32 |
| PUFA | Linolenic acid | 94.57 |
| | Linoleic acid | 0.18 |

*Key: SFA, saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA polyunsaturated fatty acid. Note: Percentages may not add up to 100% due to some FA traces not listed*

### 4.5.3. Njansang (*R. heudelotii var. africanum*)

In the fatty acid analysis of Njansang *(R. heudelotii var. africanum)*, an overall number of seven (7) fatty acids were present consisting of one (1) monounsaturated fatty acid, three (3) polyunsaturated fatty acid, four (4) SFA and one (1) MUFA as shown on table 17 below.

**Table 36. Fatty acid composition of Njansang (*R. heudelotii var. africanum*)**

| Type of fatty acid | Name | Area sum % |
|---|---|---|
| MUFA | Gadoleic acid | 0.6 |
| SFA | Palmitic acid | 1.82 |
| | Stearic acid | 7.04 |
| | Margaric acid | 0.14 |
| | Arachidic acid | 0.12 |
| PUFA | Eleostearic acid | 51.7 |

| | | |
|---|---|---|
| | Linolenic acid | 10.04 |
| | Linoleic acid | 28.68 |

*key: SFA, saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA polyunsaturated fatty acid. Note: Percentages may not add up to 100% due to some FA traces not listed*

### 4.5.4. Njansang (*R. heudelotii var. heudelotii*)

The result on table 18 showed the fatty acid composition of njansang (*R. heudelotii var. heudelotii)*. Njansang consists of seven different types of fatty acid at different level of composition. PUFA makes up the highest composition of the nuts and seeds and this is followed by SFA. Monounsaturated fatty acid composition in the seed and nuts has the lowest composition.

**Table 37. Fatty acid composition of njansang (*R. heudelotii var. heudelotii*)**

| Type of fatty acid | Name | Area sum % |
|---|---|---|
| MUFA | Gadoleic acid | 0.6 |
| SFA | Palmitic acid | 4.7 |
| | Stearic acid | 7.04 |
| | Arachidic acid | 0.12 |
| PUFA | Linolenic acid | 0.11 |
| | Linoleic acid | 32.54 |
| | Eleostearic acid | 54.83 |

*key: SFA, saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA polyunsaturated fatty acid. Note: Percentages may not add up to 100% due to some FA traces not listed.*

### 4.5.5. Rondelles

Rondelles happened to be very rich in fatty acids, as up to fourteen (14) fatty acids were identified. Majority of the fatty acids were saturated fatty acids i.e., a total number of eleven (11) SFA, two (2) PUFA and one (1) MUFA were present. This result is shown on table 19 below.

**Table 38. Fatty acid composition of Rondelles**

| Type of fatty acid | Names | Area sum % |
|---|---|---|
| PUFA | Catalpic acid | 0.32 |
| | Linoleic acid | 0.07 |
| SFA | Caprylic acid | 0.58 |
| | Capric acid | 0.77 |
| | Lauric acid | 19.43 |
| | Myristic acid | 3.89 |
| | Palmitic acid | 57.88 |
| | Pentadecanoic acid | 0.08 |
| | Margaric acid | 0.06 |
| | Lignoceric acid | 0.08 |
| | Stearic acid | 7.38 |
| | Arachidic acid | 0.14 |
| | Behenic acid | 0.06 |
| MUFA | 9-Heptadecenoic acid | 0.12 |

*key: SFA, saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA polyunsaturated fatty acid. Note: Percentages may not add up to 100% due to some FA traces not listed.*

# 5. Discussion

## 5.1. Oil yield.

From the results on table 3 above we noticed that caso nuts, Njangsang (*R. heudelotii var. africanum* and *R. heudelotii var. heudelotii* yielded about 30 % of oil implying that they can be good sources of essential oils which can be commercialise, thus adding more economic value to the nuts. However, oil yield for rondelles was very low (less than 10 %) indicating that it is not an oil seed. Also, a slight difference noticed in the oil yields of both varieties of njansang. This suggests that there may be potential variability within the same species of plants. This could be due to factors such as genetic differences or growing conditions of the seeds. However, the higher oil yields of some of the nuts and seeds suggests that the seeds have nutritional and economic potentials, which can be explored. For instance, njansang can be considered a valuable seed for oil extraction as compared to tiger nuts which has low yield.

Additionally, the high oil content of njansang, and sacha inchi peanut could suggest a high nutrient density since oil is closely linked to high fatty acid content. However, this does not eliminate the relative importance of nuts and seeds with low oil content which is an alternative option for people who are on a strict diet control and require snacks with low oil content. According to Albuquerque, nuts and seeds with low oil content tend to have a lower level of fatty acid composition.

## 5.2. Fatty Acid Composition

This study showed that saturated fatty acids are predominantly present in varying quantities in all the nuts and seed samples selected, followed in order by monounsaturated fatty acids then polyunsaturated fatty acids. Tiger nuts was composed mainly of monounsaturated fatty acids (MUFA) with oleic acid (76.19%) and Linoleic acid (8.01%) being the most prominent fatty acids in it. However, it contained some level of SFA with Palmitic acid (11.35%) being the main source. Other fatty acids like Stearic acid, Arachidic acid among others were found in smaller quantities. Caso nuts highly contains polyunsaturated fatty acids (PUFA) such as linolenic acid (94.57%) with others found in lower quantities. Both varieties of njansang (*R. var heudelotii and R. var Afriacnum)* contained large quantities of PUFA Eleostearic acid (54.83% and

51.7%) and Linoleic acid (32.54% and 28.68%) respectively, with more linolenic acid (10.04%) in njansang (*R. var Afrianum).* Eleostearic acid is a valuable medicinal compound with antimicrobial, anti-inflammatory, anti-cancer, and antioxidant properties (Sateei et al. 2023). Rondelles is however abundant in two SFA palmitic acid (57.88%) and lauric acid (19.44%).

Saturated fats are described as less desirable type of the fatty acids because of its link to increased LDL cholesterol level (Mariamenatu and Abdu 2021). Rondelles had the highest SFA content (11 out of 14 fatty acids), and this was followed by sacha inchi peanuts (4 out of 7) and Tiger Nuts (3 out of 9). However, in terms of composition, rondelles has the highest content of saturated fatty acid among the nuts sampled with palmitic acid, lauric acid and stearic acid being the three highest fatty acid in the nut. Furthermore, palmitic acid which is a saturated fatty acid made up the second highest composition in tiger nut. For the other nuts, the presence of SFA in them were at a very low level.

Long chain (saturated) fatty acids (LCFA) including lauric, myristic, palmitic, and stearic acids have significant atherogenic and thrombogenic potentials. Consumption of saturated LCFA increases levels of cholesterol, namely that of low-density lipoprotein (LDL)-cholesterol, which relates to increased coronary heart disease (CHD) mortality. On the other hand, the high-density lipoprotein (HDL)-cholesterol lowering effect of saturated LCFA decreases. However, it has been suggested that stearic acid has the highest prothrombotic potential compared to other saturated LCFA, although this is under debate. However, for nuts such as rondelles which has high content of SFA.

Specifically, the palmitic acid found in substantial amount in rondelles, and tiger nuts contributes to elevated level LDL ("bad") cholesterol levels and increase the risk of cardiovascular diseases when consumed in large quantity. This was confirmed through the studies Shramko et al. (2020) and Unhapipatpong et al. (2021) who linked the palmitic acid compound with the risk of cardiovascular disease. However, lauric acid, which is a medium-chain, saturated fatty acid, found in relatively high amounts in rondelles has been reported to have a slightly beneficial effects on blood lipid profiles, and it may also have antimicrobial properties (Alfhli and Aljuraiban 2021; Zhao et al., 2022). However, its impact on cardiovascular health is still debated. Stearic acid, which is found in Rondelles, has been reported to have neutral effects on serum cholesterol levels and exhibits anti-inflammatory properties and can be used in dietary supplements due to its potential benefits for heart health (Balta et al. 2021). Additionally, stearic acid is good for the skin and used in many skins care product based on its anti-inflammatory property and ability to preserve body moisture (Kang et al. 2022).

Oleic acid is the major fatty acid and MUFA present in tiger nuts, same as the findings of Li et al (2021) and Nina et al (2020) where they reported the presence of Oleic acid in significant quantity in Tiger nut. Oleic acid has antiatherogenic and antithrombotic properties as it has been shown to increase the HDL-/LDL-cholesterol ratio and decrease aggregation of thrombocytes. Incorporation of oleic acid into cholesteryl esters, triacylglycerols and phospholipids of lipoprotein particles increases their resistance to lipoperoxidation (Bilal et al. 2021). Replacement of SFA by oleic acid (about 7% of total energy intake (TEI), when total fat is maximum 30% of TEI decreased concentration of triacylglycerols (TAG), LDL-cholesterol, increased concentration of HDL-cholesterol, and regulated insulin sensitivity (Eva Tvrzicka et al. 2011). This shows that Oleic acid found in tiger nuts has a regulating property. Other benefits of oleic acid found in tiger nuts include the fact that it helps in improving both mood and cognition and can reduce inflammation, lower cholesterol levels, and boost heart health while also contributing to skin health (Jikah et al. 2023).

Linoleic acid, a polyunsaturated fatty acid (PUFA) was the main fatty acid found in caso nut and both varieties of njansang. The presence of linoleic acid in njansang further positions it as a healthy option. This is because the PUFA linoleic and linolenic acids found in it are among the essential fatty acids which are common in foods of animal origin. PUFA are liquid at room temperature, with the popular examples being omega-3 and omega-6 fatty acids (Kapoor et al. 2021). These two types of fatty acids have a lot of benefit to the body, which include heart health, healthy eye function, brain function and healthy skin (Saini et al. 2021). This affirms the fact that proper utilisation of njnasang can further enhance human health and wellbeing due to the presence of these essential fatty acids. On the other hand, PUFA are known to easily oxidise if not stored properly. Thus, raising the need for proper handling of the nuts and seeds to preserve its PUFA when being processed (Mariemenatu and Abdu 2021).

Medium chain (saturated) fatty acids (MCFA) including caproic, caprylic, and capric acids, are resorbed directly and transported by the portal vein. Their intramitochondrial transfer does not need the presence of carnitine or carnitine palmitoyl transferases. Fat emulsions containing medium chain triacylglycerols (MCT) are used as nutritional support in enteral nutrition. These have shorter biological half-time and higher stability to lipoperoxidation. Thus, they are recommended in some cases of restrictive dietary regimen for obese individuals (Eva Tvrzicka et al. 2011). All these saturated fatty acids are present in rondelles.

In general, the more double bonds in the fatty acid, the more prone they are to lipoperoxidation. Endogenous PUFA mostly belong to the n-9 family, synthesized in increased amounts when there is a lack of essential fatty acids (EFA). These fatty acids (FA) are termed essential because they cannot be synthesized in humans, and they are considered parental FA for the n-3 and n-6. PUFA families. Essential FA exert beneficial antiatherogenic as well as antithrombotic effects. This is a result of their impact on lipoprotein concentration, membrane fluidity, function of membrane enzymes and receptors, modulation of eicosanoid production, regulation of blood pressure and metabolism of minerals (Eva Tvrzicka et al. 2011). Examples of such PUFA are Linolenic acid, linoleic acid, and Catalpic acid present in Njansang, rondelles and caso nuts.

## 5.3. Volatile components (SPME).

The volatile compound composition provides information on the aroma and flavour, which the different nuts and seeds used in the study possess. In tiger nut, the dominant volatile components were benzene (24.22%), γ-terpinene (23.83%), and hydroperoxide (3.59%). Specifically, benzene is a volatile organic compound with a sweet, aromatic, gasoline-like odour while γ-terpinene is a terpene compound with a citrusy scent. Although these two compounds may have dominant attribute on the sensory characteristics of the nut by giving it a sweet aroma and citrus scent, other volatile compound play an important role in aiding its sensory appeal.

The volatile substance in Caso nut were m-Cymene (43.56%) and γ-Terpinene (36.5%). These compounds are abundant volatile components and gives caso nut a citrusy or piney aroma. Specifically, m-Cymene, is an aromatic hydrocarbon which has pleasant, slightly spicy, and woody aroma (Xiao et al. 2023). It has the properties of an antioxidant, antimicrobial and soluble in organic solvents (Satira et al. 2021). γ-

Terpinene is a monoterpene with a fresh, citrusy, and pine-like aroma (Jo et al. 2023). The properties include antimicrobial, anti-Inflammatory and being soluble (Asiki et al. 2022). The attribute of the volatile compound contributes to the nutty and citrusy aroma of caso nuts. The distinctive flavour giving by the volatile compounds makes the nuts useful for culinary purpose (Goyal et al. 2022).

Pentanal was found to be dominant in both varieties of njansang. However, other volatile substance in njansang include a range of aldehydes, alcohols, and acids, which contribute to its aroma. Pentanal is an aldehyde, which is a colourless volatile liquid and has a smell described as fermented, bready, fruity, nutty, berry (Echeverria et al. 2021). These characteristics contribute to the nutty, fruity, and floral smell associated with Njansang.

Rondelles on the other hand, was dominated by volatile sulphur compounds such as bis(methylthiomethyl) disulfide (74.19%) and 2,4,5-Trithiahexane (12.79%). These sulphur volatile compounds give the pungent and savoury aroma (Sukchum et al., 2022) which rondelles is known for and makes it unique from other nuts and seeds. The presence of m-cymene (3.26%) and γ-terpinene (3.63%) in the volatile compound profile adds depth to the aroma profile of rondelles, by releasing it sweet aroma and citrus scent in minute quantity thereby contributing to nuts aroma. However, Rondelles will likely have a strong unpleasant pungent odour due to the high content of sulphur in it while the presence m-Cymene and γ-Terpinene will give it a slight citrusy or piney undertone.

In all, it should be noted that this volatile compound plays an important role in the acceptability of the nuts and gives it the appeal, which attracts consumers to it. However, it should be noted that volatile compounds exhibit under different condition and some which are seen as insignificant may become more expressed in the favourable condition such as when heated, during spoilage, or when exposed to certain conditions.

## 5.4. pH of nuts

All nuts had pH, ranging between 5.64 and 6.8 which a suggest a neutral pH range for all the nuts and seeds. The neutral pH range suggests that these nuts and seeds are stable and are not likely to change or degrade in nutrients because of acidity of alkalinity.

These could have implication on the shelf life of the nuts and the seeds and could suggest that the nuts and seeds have the tendency of having a long shelf life. Additionally, the neutral pH level shows that the nuts and seeds are less likely to cause any discomforts in the stomach when consumed due to the acidic nature of the stomach. This is because of the neutral nature of the nuts and seeds, which causes less stress to the digestive system when it is being consumed. Therefore, nuts and seeds with neutral pH are suitable for consumption for all and enhance the health of the digestive system.

The pH also contributes to the preservation of the natural flavour of the nuts and seeds. This is because when the pH is at both extremes it can alter the taste and aroma of the food due to chemical reactions leading to the release of flavour and taste that are not desirable. Thus, the neutrality of the pH is an adaptive means through which the fruits and nuts protects it flavour (Lopez et al. 2023).

Furthermore, a neutral pH values helps in creating an environment that is less favourable for the growth of harmful microorganisms. Thus, ensuring the safety of the nuts and the seeds for consumption and reduces microbial activity which contributes to food contamination and spoilage.

# 6. Conclusions

The study aimed at analysing the fatty acids and volatile compounds in some selected nuts and seeds such as rondelles (*Afrostyrax lepidophyllus),* (njangsang (*Ricinodendron heudelotii*) , tiger nut *(Cyperus esculentus*), and sacha inchi or caso nuts (*Plukenetia volubilis)* which was gotten from Cameroon. GC-MS analysis was used in the characterisation of the different compounds. From the findings of the study, it was discovered that the different nuts used in the study have different oil composition with the njasang and caso nut having the highest level of oil composition while tiger nuts had fair composition. However, the composition of oil in rondelles was found to be very low and of insignificant value. This therefore positions njasang and caso nuts as viable options for commercial production of oils for nuts and seeds.

The characterisation of the fatty acid composition in selected nuts and seeds revealed that saturated fatty acids are predominantly present in all the nuts and seed samples. However, tiger nuts were found to mainly composed of monounsaturated fatty acids (MUFA) like oleic acid in substantial quantity, SI nuts was found to contain polyunsaturated fatty acids (PUFA) like Linolenic acid in high quantities, njansang contained significant amount of PUFA Eleosteric acid in large quantities and Linoleic acid, while rondelles had saturated fatty acids (Palmitic acid and Lauric acid) in abundance. This shows the diversity of the nuts and seeds and their diverse nutrient capability. Hence, nuts and seeds are important to a healthy diet as contain essential fatty acids which are important to healthy living.

Additionally, the pH of the nuts and seeds were found to be neutral suggesting the seeds have a high level of stability in terms of storage.

Furthermore, it would been suggested that caution should be taken in the consumption rondelles, tiger nuts and SI peanuts because of the link of SFA compounds to increased risk of heart disease but it is not a problem because the oil content of these nuts is very low (less than 10%) rather, other beneficial components of the nuts can be exploited, and their consumption blended with other nuts rich in unsaturated fatty acids for a balanced diet.

Based on the results, we can confidently conclude that nuts and seed are very important in the diet as they are the only plant source essential fatty acids, which are present in animal products. Furthermore, the two varieties of njangsang differ both physically and chemically, njansang (*R. heudelotii var. heudelotii)* has a superior quality. Finally, all nuts were neutral in terms of pH but very rich in volatile compounds, giving them distinctive smells that enable some of them (e.g. njansang and rondelles) to be used as kitchen spices.

Therefore, it is suggested that focus should be placed on improving these nuts to unlock its potential for oil production and a source of healthy fatty acid.

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