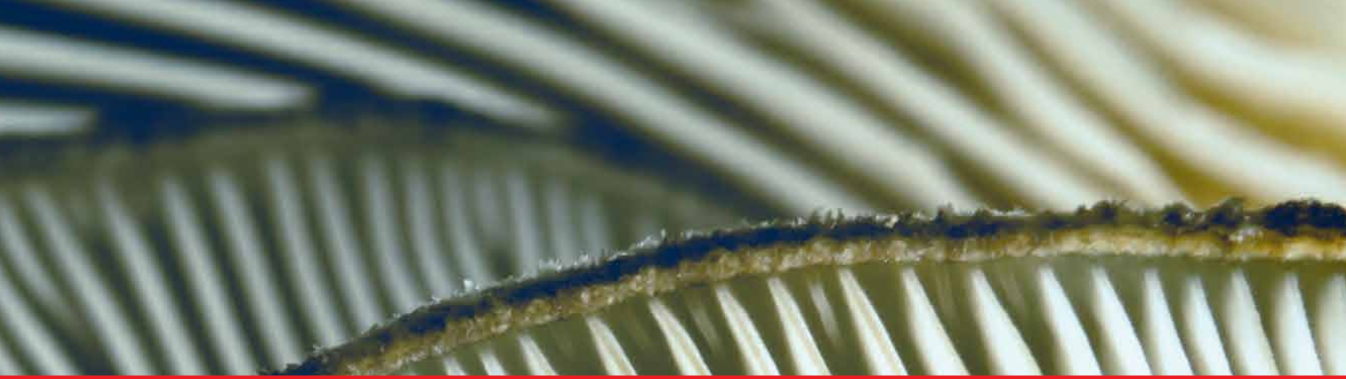

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Nut Consumption and its Usefulness in the Modern World

*Edited by Romina Alina Vlaic Marc,
Crina Carmen Mureșan
and Alina Narcisa Postolache*

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Food Science and Nutrition

Volume 6

Aims and Scope of the Series

The significance of food is undeniable, especially in light of the impending challenge facing humanity: ensuring there will be enough food to meet the basic needs of a population expected to reach approximately 10 billion by 2050. These food-related challenges align with some of the United Nations' sustainable development goals, with a target to achieve them by 2030. One thing is certain: food should be not only nourishing and safe but also tailored to the diverse needs of individuals throughout their lifetimes, all while meeting consumers' sensory expectations. Understanding the diverse chemical composition of food, often referred to as biodiversity, and how these components can contribute to human health by considering factors like bioaccessibility, bioavailability, and bioactivity at the organ level, is crucial for grasping and promoting a healthy diet. Thanks to the continuous evolution of analytical methods and interdisciplinary research, significant strides have been made in the field of food science and nutrition.

Meet the Series Editor

Maria Rosário Bronze has been working in Analytical Chemistry since 1986. Her Ph.D. in 1999 contributed to the study of food products using capillary electrophoresis. The main goal of her research since 1999 has been focused on Analytical Chemistry applied mainly to the analysis of foods and by-products of food industry. She conducted research in collaboration with national and international research groups, at iBET and ITQB Technology Division. From 2017 until 2021 she was head of Food & Health Division at iBET and head of the Food Functionality and Bioactives Laboratory. MR Bronze has been an Associate Professor at the Pharmacy Faculty of Lisbon University and head of the Structural Analysis Laboratory since 2012. As a researcher, MR Bronze is a Senior Scientific Advisor at Food & Health Division at iBET and Head of Food Functionality and Bioactives Laboratory at the same Institute, Collaborator at iMED and Researcher at ITQB NOVA. Her current research is focused on quality and beneficial health effects of food components. Gas and liquid chromatography associated with mass spectrometry are used by MR Bronze in the characterization of samples. Sensory evaluation is also an important area of her research. The main food products studied by her are olive tree products (olive, olive oil, leaves), cereals such as maize, legumes (faba bean, pea, chickpea, lentils) fruits (apple, grapes, opuntia ficus), fruit juices and wine, among others. More recently her interests have also involved biodiversity, bioaccessibility, and bioavailability studies on food products and their components, mainly phytochemicals as phenolic compounds, using different analytical tools such as mass spectrometry. As a senior scientific advisor at Food & Health Division at iBET she is involved in different areas: (i) isolation, characterization and formulation of bioactive and functional compounds or extracts from natural sources and wastes from food and other related industries; (ii) pre-clinical assays to provide support to understand health claims related with the beneficial effects of food nutrients/bioactive components; (iii) establishment of analytical methodologies including mass spectrometry state-of-the-art to fully characterize different matrices, from food products, natural extracts or biological fluids (Food Functionality and Bioactives Laboratory).

Meet the Volume Editors

Dr. Eng. Habil. Romina Alina Marc obtained a Ph.D. in Agronomy from the University of Agricultural Sciences and Veterinary Medicine of Cluj-Napoca (USAMVCN), Romania, in 2015. She is a lecturer at the Faculty of Food Science and Technology, USAMVCN, and is responsible for research activity in plant food quality control, rheology in the food industry, quality management systems, and food safety. She has published more than 110 journal articles on plant science, innovative food product development, food safety, and traceability of bioactive compounds during processing. She also has more than 50 conferences, 11 books, 9 book chapters, and 37 research and innovation projects to her credit. She has participated in several research projects and has won numerous national and international awards.

Crina Carmen graduated with a degree in Chemical Engineering from Babeș-Bolyai University, Romania, in 1994, working in a quality control laboratory as a chemist. She completed her Ph.D. in Veterinary Medicine in 2010. In 2003, she joined the Faculty of Food Science and Technology, University of Agricultural Sciences and Veterinary Medicine of Cluj-Napoca (USAMVCN), Romania, where she teaches food quality control and food safety. She has been a doctoral coordinator in biotechnology since 2021. Dr. Carmen has participated in multiple projects on food engineering, product development, consumer preferences, and food quality control. She and her coauthors have presented more than thirty papers and posters at international conferences and published more than ninety papers in peer-reviewed journals and two international book chapters. Her research focus is quality assessment (gas chromatography mass spectrometry, spectrometry) of food.

Alina Narcisa Postolache obtained an engineering degree in food processing from "Ion Ionescu de la Brad" University of Life Sciences of Iași (IULS), Romania, in 2008. She also obtained a Ph.D. in Animal Products Technology from the same university in 2011. During her Ph.D., she conducted research on the quality parameters that define the quality of game meat, such as wild boar and red deer meat. Throughout her professional trajectory, Dr. Postolache has acquired extensive expertise, including in commercial and administrative operations, logistics activities, training, and fundamental research within the food business operators. In addition, her previous managerial role in quality assurance allowed her to advance in the field of food safety, accumulating more than a decade of expertise as a specialist, consultant, researcher, and international auditor for specific GFSI standards schemes [IFS, FSSC22000]. She has worked on enhancing the quality of products in the meat, milk, and bakery industries produced by various food processing companies. Additionally, she is responsible for creating, implementing, and auditing food safety programs with the shared goal of delivering safe products to consumers and expanding companies' market presence. She has authored more than fifty research articles in the field.

Contents

Preface

Tree nuts or fruit seeds with an edible grain and an indigestible hard shell are referred to as nuts in general. Nuts are like little culinary superheroes: full of omega-3s and antioxidants, they help keep your heart healthy and your brain in shape. Eating nuts provides the body with a lot of nutrients necessary for a healthy and balanced lifestyle.

The truth is, if consumed in moderation, nuts can be a healthy snack that energizes the body and also contributes to overall well-being.

The most common type of walnut is Juglans Regia, known as the English walnut. Also types of nuts are hazelnuts, peanuts, hazelnuts, almonds, pistachios, cashews, pecans, macadamia nuts or Brazil nuts, having in common the fact that they are fruits with a hard shell and an edible seed. They are also similar in many other ways, such as being high in fat and calories, but they have different shapes and flavors.

Nuts are rich in antioxidants, vitamins and minerals, fats, proteins, and omega-3. All these elements are necessary for the body and can contribute to the treatment or prevention of several types of ailments.

Considering the continuous evolution regarding the consumption of nuts and their properties, this book, *Nut Consumption and its Usefulness in the Modern World*, presents a comprehensive overview of nuts. The chapters are organized into four sections:

Section 1 – "An Overview of Nuts"

Section 2 – "Chemical Composition, Nutrients and the Beneficial Effects of Using Nuts"

Section 3 – "The Use of Nuts for Medicinal Purposes"

Section 4 – "Nut Contaminants"

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Section 1

An Overview of Nuts

Chapter 1

An Overview of the Characteristics, Advantages, and Uses of Nuts

Romina Alina Marc, Crina Carmen Mureșan, Anamaria Pop, Georgiana Smaranda Marțiș, Andruța Elena Mureșan, Andreea Pușcaș, Alina Narcisa Postolache, Florina Stoica, Ioana Cristina Crivei, Ionuț-Dumitru Veleșcu and Roxana Nicoleta Rațu

Abstract

Nuts possess a high concentration of essential nutrients and serve as a very effective source of bioactive chemicals that promote health. Therefore, they function as significant and nutritious snacks, while also being incorporated into numerous conventional and contemporary culinary preparations over the globe. It is strongly advised to regularly consume nuts in order to fully capitalize on the nutritional, bioactive, and antioxidant properties they possess, as well as to experience their desired taste and flavor. Robust scientific data indicate that individuals who consistently consume significant quantities of nuts (15 to 30 g of nuts) exhibit reduced prevalence of chronic non-communicable diseases. Nuts have been found to have positive health impacts, such as the potential to manage obesity and decrease the occurrence of cardiovascular disease (CVD), type 2 diabetes, several types of cancer, and other chronic diseases associated with food. The most robust and persistent positive impact of nut consumption is its correlation with decreased incidence of cardiovascular disease (CVD). Nuts find application in several food products within the food industry, encompassing oil, spreads, as well as in other sectors such as cosmetics and medicine, and as a viable source of biodiesel. The objective of this chapter is to provide a comprehensive overview of the characteristics, advantages, and uses of nuts.

Keywords: nuts, benefits, chemical composition, spreads, oil

1. Introduction

Tree nuts or fruit seeds with an edible grain and an indigestible hard shell are referred to as nuts in general. Nuts encompass a diverse array of food items that possess a broad spectrum of applications, primarily linked to their consumption in roasted or dried form. They are commonly incorporated into confectionery items such as cookies, cakes, and chocolate, as well as concealed inside commercial products such as sauces, oils, ice creams, butter, and pastes. Nevertheless, according to their nutritious composition, it is advisable to consume them as snacks or as an integral component of comprehensive meals [1, 2]. According to botanical definitions, tree nuts, which include walnuts, almonds, hazelnuts, cashews, pistachios, and pecans, are dry fruits with a single seed inside the ovary wall that hardens with maturation [3].

In botany, a "nut" is an indehiscent fruit that often sheds as a single-seeded unit. It is generated from multiple carpels, but only one of the seeds germinates and grows; the others fail. The pericarp is typically lignified and has a "cupule" encircling it either entirely or partially. Hazelnuts, *Corylus* spp. (*Corylaceae*), beechnuts, *Fagus* spp. (*Fagaceae*), and acorns, *Quercus* spp. (*Fagaceae)* are examples of true nuts. Any woody fruit or seed, including the walnut (drupe of *Juglans* spp., *Juglandaceae*), the peanut (indehiscent legume of Arachis hypogea, *Leguminosae subfamily Papilionoideae*), and the Brazil nut (seed of *Bertholletia excelsa*, *Lecythidaceae*), can also be generally referred to using this word. In common usage, it is also overused to refer to non-fruiting entities like root tubers [4].

The scientific classification of these plants according to their reproductive mechanisms, physical traits, genetic makeup, and evolutionary references is known as the taxonomy of nuts:

Order: Fagales: This order includes many nut-producing trees. It encompasses families like *Fagaceae* (oaks, chestnuts) and *Betulaceae* (birches, hazelnuts). Oak acorns (*Quercus* sp.) are among the fruits whose economic worth was undervalued, but their biological and biochemical characteristics are slowly captivating interest recently. Various studies report on the incorporation of acorns into the human diet through the formulation of new desserts, etc. [5].

Family: Juglandaceae (Walnut family): This family includes trees that produce compound, indehiscent fruits, commonly known as nuts. Genus *Juglans* includes walnuts, characterized by pinnately compound leaves and drupaceous fruits (like *Juglans regia*—English walnut). Genus *Carya* includes pecans and hickory nuts, recognized by their pinnately compound leaves and husk-covered fruits. The walnut (genus *Juglans*) is a group of over 20 species of deciduous trees belonging to the *Juglandaceae* family that are indigenous to the West Indies, southern Europe, Asia, and North and South America.

Family: Fabaceae (Legume family): *Subfamily Faboideae* includes peanuts (*Arachis hypogaea*), which are legumes with pod-like fruits. Although peanuts and Brazil nuts are classified as legumes and seeds, respectively, by the botanical community, all of these foods are referred to as nuts due to their similar nutritional value and culinary use [3]. The peanut, originally from tropical South America, was brought to the Old World's tropical regions quite early on. The plant is especially beneficial as a soil-enriching crop because, like other legumes, it uses nitrogen-fixing bacteria to give nitrogen to the soil [4].

Family: Rosaceae (Rose family): This family includes a wide variety of fruit-bearing plants. *Genus Prunus* includes almonds (*Prunus dulcis*), characterized by their single-seeded fruits (drupes) enclosed in a hard shell. One of the most popular tree nuts in the world, almonds are grown commercially in arid regions like Australia, California, and Spain. Almonds are widely consumed in part because they may be used in a variety of goods, including dairy substitutes and gluten-free wheat flour substitute, and they can also be used as a source of plant-based protein [6].

Family: Anacardiaceae (Cashew family): This family includes flowering plants known for their often-resinous sap and compound leaves. Genus *Anacardium* includes cashew nuts (*Anacardium occidentale*), which are found attached to the bottom of a fleshy fruit (the cashew apple). Although it originated in Brazil, tropical regions worldwide now cultivate it. Because cashew nuts are in high demand, the production of them keeps rising. Over the past 5 years, cashew nut production with shells has grown [7].

Family: Lecythidaceae (Brazil nut family): This family includes tropical trees known for their large, edible seeds. *Genus Bertholletia* includes Brazil nuts (*Bertholletia excelsa*), characterized by their large, hard-shelled seeds. This edible seed grows in Ecuador, Brazil, Peru, Colombia, and the Amazon region. The Brazil nut is especially well known in the Brazilian state of Pará, where it is grown and known as castanha-do-pará, or the Pará nut. It is one of the most important nuts traded internationally [4].

Family: Betulaceae (Birch family): This family includes trees and shrubs known for their simple, serrated leaves. *Genus Corylus* includes hazelnuts or filberts (*Corylus avellana*), which produce small, hard-shelled nuts enclosed in a leafy husk. The genus contains roughly 15 kinds of edible nuts that are produced by shrubs and trees in the birch family (*Betulaceae*). Moreover, two Eurasian trees—the giant hazel, or giant filbert, *Corylus avellana* and its hybrid, the *American hazelnut*, or *C. americana*, and the beaked hazelnut, or *C. cornuta*—as well as hybrids of these species yield exceptional nuts [4].

Family: Proteaceae (Protea family): This family includes flowering plants primarily found in the Southern Hemisphere. *Genus Macadamia* includes macadamia nuts (*Macadamia integrifolia*), which have hard, woody seed coats. It is the most popular nut in the world and is often eaten roasted or as a component of many confections [8]. The trees are grown commercially in several subtropical regions, but they originated in the coastal rainforests and scrubs of what is now Queensland in northeastern Australia.

It is well known that nuts are a common food group that are mostly consumed in the Mediterranean diet, although they are also advised for consumption by people worldwide. The most common products of this group are almonds (*Amygdalus communis* L.), Brazil nuts (*Bertholletia excelsa Humb. et Bonpl*.), cashews (*Anacardium occidentale* L.), hazelnuts (*Corylus avellana* L.), macadamia nuts (*Macadamia ternifolia F. v. Mueller*), pecan nuts (*Carya illinoiensis (Wangenh.) K. Koch*), pine nuts (*Pinus pinea* L.), pistachio nuts (*Pistacia vera* L.), and walnuts (*Juglans regia* L.) [2, 9].

Nowadays, creating a varied and well-balanced diet is becoming an issue for customers. Due to the increased awareness of nuts' remarkable nutritional content, flavor, and unique taste as well as their nutraceutical qualities and beneficial bioactive substances, the amount of nuts in the balanced diet has increased significantly [10].

2. Chemical composition of nuts

2.1 Phenolic compounds

Common edible nuts contain concentrations of phenolic compounds, such as flavonoids, phenolic acids, and caffeic acid phenethyl ester. The phenolic profile of the analyzed nuts differed greatly depending on their type [11]. Phenolic compounds are a class of nut components that are thought to be important phytochemicals for health and have a wide range of pharmacological activity, including anticancer, antioxidant, anti-inflammatory, antimicrobial, and antiviral properties [12–14]. Nut phenolics can be linked to other plant constituents such as proteins and carbohydrates. They are typically found in the highest concentration in the seed coat, which is the skin or pellicle that surrounds the kernel [15]. As a result, differences in total phenolics between varieties or cultivars of a specific nut species may be due to skin content differences. A certain amount of phenolic and polyphenolic compounds may be "unextractable" because they are bound to cell wall materials, such as polysaccharides, primarily *via* hydrogen-bond interactions. The strength of phenolic-carbohydrate binding increases as the number of OH groups on polyphenol molecules increases. In addition, high-molecular-weight polyphenols frequently interact with proteins [16]. This is especially noticeable in almonds, which can have significantly different skin thickness. In terms of composition, the most abundant phenolic compounds found in nuts can be classified into three major groups: phenolic acids, flavonoids, and tannins. Phenolic lignans and stilbene derivatives are less prevalent [16].

The most commonly identified phenols in nuts are gallic acid, ellagic acid, and catechin [17]. Flavonoids found in nuts include epicatechin, quercetin, naringenin, kaempferol, isorhamnetin, galangin, and apigenin. In turn, aromatic acids found in nuts include caffeic, coumaric, ferulic, vanillic, and syringic acids [16]. Each nut species has its own phenolic profile and content.

Phenolic acids. Walnuts contain a variety of derivatives of gallic and ellagic acids, such as galloyl and digalloyl hexosides, ellagic acid, and their esters with polyols (pentoside, hexoside, and rhamnoside) [18]. Brazil nuts contain primarily gallic, protocatechuic, and vanillic phenolic acids. They are mostly found as bound phenolics, but it is unclear whether they are also present as glycosides or conjugates. Similarly, hazelnut phenolic acids are primarily composed of hydroxybenzoic acid derivatives (gallic, protocatechuic, p-hydroxybenzoic, vanillic, syringic, and coumaric acids), which can be free or esterified [19].

Phenolic acids make up a minor fraction of the phenolics found in almond kernels. Bolling et al. [20] found total phenolic acids and aldehydes ranging from 5.2 to 12.0 μg/g of nut.

Protocatechuic, vanillic, and p-hydroxybenzoic acids are the predominant hydroxybenzoic acid derivatives, while chlorogenic acid is the largest hydroxycinnamic acid derivative. Colic et al. found this compound in almonds from Serbia at concentrations of up to 13.0 μg/g [21].

It has been demonstrated that the skins of pistachios have a substantially higher total phenolic acid content than the whole seeds. Gallic acid is the most prevalent compound, with 1.45 mg/g of skin reported by Tomaino et al. [22]. In whole seeds, concentrations ranging from 0.013 to 0.036 mg/g have been discovered [23].

Only the skin of peanuts has been found to contain phenolic acids. There have not yet been any reports of them being found in blanched peanuts. Yu et al. [24] identify ferulic and coumaric acids as the main phenolic acids in peanut skins, along with caffeic and chlorogenic acids.

Flavonoids. Harnly et al. [25] found significant variations in flavonoid concentrations across different types of nuts in a comprehensive study on flavonoid composition in various foods. Pecans contained the highest levels of cyanidin, delphinidin (anthocyanins), catechin, epicatechin, epicatechin gallate, and epigallocatechin gallate (flavanols). Catechin and epicatechin, as well as their gallic acid esters, are abundant in pistachios, hazelnuts, walnuts, cashew nuts, and peanuts [16]. Pistachios contain the majority of glycosylated anthocyanidins (cyanidin-3-O-galactoside and cyanidin-3-Oglucoside) [26]. Almonds are high in the flavonoids quercetin, kaempferol, and isorhamnetin, as well as glycosylated derivatives (galactoside, rutinoside, and glucoside) and the flavanone naringenin, which is an aglycone and glucoside derivative [27]. Peanut skin extracts have been reported to contain flavones luteolin, apigenin, and chrysin [28].

Tannins. Walnuts are distinguished by the presence of hydrolyzable tannins and related compounds (ellagic acid and derivatives) [29]. The structural analysis of major components classifies them as gallotannins or ellagitannins. Gallotannins are gallic acid esters that contain a polyol carbohydrate, typically glucose. Ellagitannins are esters of hexahydroxydiphenic acid (HHDP) and a polyol (typically glucose) that may contain a galloyl group. Walnuts contain a variety of ellagitannins including pedunculagin, casuarinin, casuarictin, strictinin, tellimagrandin, praecoxin, rugosin, and isostrictinin. Ellagic acid, gallotannins, ellagitannins, and derivatives contribute to the astringent taste of walnut kernels [16]. Hazelnuts, pecans, and almonds contain tannins from both groups: hydrolyzable and condensed tannins. Pelvan et al. [30] identified five hydrolyzable tannins and related compounds in Turkish hazelnut samples, including flavogallonic acid dilactone, valoneic acid dilactone, sanguisorbic acid dilactone, bis-(hexahydroxydiphenoyl)-glucose (HHDP-glucose), ellagic acid, and derivatives. According to Bolling [20], almond kernel contains 0.73 to 0.91 mg of hydrolyzable tannins (gallotannins, ellagitannins, and phlrotannins) per gram, based on literature analysis. Pistachios (2.40 mg/g), almonds (1.84 mg/g), and peanut skin contain significant amounts of proanthocyanidins [31]. The types and concentrations of proanthocyanidins may differ depending on the starting material (raw, roasted, or blanched peanuts) [20].

Phenolic lignans. Almonds, hazelnuts, peanuts, cashews, pecans, walnuts, pistachios, and Brazil nuts all contain minor amounts of phenolic lignans. These two materials may be the primary sources of total phenolic lignans (2.0 and 7.8 μg/g nut, respectively). Matairesinol, lariciresinol, pinoresinol, and secoisolariciresinol are all commonly found in nuts. They were identified after hydrolysis, so it is unclear whether they are glycosides or conjugates.

Brazil nuts contain the highest concentration of secoisolariciresinol (7.8 μg/g), which appears to be the primary compound in most cases. Almonds contain high concentrations of lariciresinol (up to 2.4 μg/g) [16].

Stilbene derivatives. The most common phenolic stilbene found in nuts is trans-resveratrol (3,5,4′-trihydroxystilbene). Pistachios are one of the most abundant sources of this compound. Ballistreri et al. [26] reported an average concentration of 12.0 μg/g of ripe kernels. It has been found in peanut skin (3.6 μg/g), along with trans-piceatannol. Trans-resveratrol concentrations vary significantly between genotypes. Tokusoglu et al. [32] found values ranging from 0.09 to 1.7 μg/g (average: 1.15 μg/g) and 0.03 to 1.9 μg/g (average of 0.84 μg/g for various pistachio and peanut cultivars). Almonds contain polydatin (resveratrol-3-β-glucoside) as the primary phenolic stilbene (7.2–8.5 μg/g). Resveratrol-3-O-glucoside is concentrated in almond skin. The variability of resveratrol content among 109 US peanut cultivars over 2 years was 0.003–0.026 mg/100 g peanut [33].

Alkylphenols. The phenolic chemical profiles of pistachios are of particular interest because they may contain some alkylphenols, including cardanols (3-akylphenols) and anacardic acid (6-alkylsalicylic acid) derivatives [34]. These phenolic compounds can also be found in other *Anacardiaceae* family members, including cashew nuts (*Anacardium occidentale* L.) [35]. Pistachio kernels contain predominantly monounsaturated pentadecenyl phenols, while anacardic acids have C13, C15, and C17 alkyl chain lengths that can be saturated, mono-, di-, or triunsaturated [36].

2.2 Proteins

Nuts contain an abundance of proteins and essential amino acids. Protein-rich foods include peanuts, almonds, and pistachios, while chestnuts have the lowest protein content. Chung et al. [37] found that some of these nuts had higher protein content than others, which can be attributed to differences in geography. Cultivars had a significant impact on protein content within nut species (12–15). Other factors, such as harvest year and post-harvest storage, and even the processing method, can affect the protein content of nuts. For example, Dodevbka et al. [38] found differences in raw, boiled, and roasted nut samples from Serbia. Nut allergies are primarily caused by seed storage proteins. The proteins involved in nut allergies belong to different families, especially 2S albumins, globulins (legumins and vicilins), non-specific lipid transfer proteins (nsLTP), plant pathogenesis-related proteins (PR-10), profilins, and oleosins [39].

The content of essential and non-essential amino acids varies significantly among nuts. Hydrophobic amino acids make up the majority of nut proteins, followed by acidic, basic, and hydrophilic amino acids [40]. Glutamic acid is the most important non-essential amino acid, with concentrations ranging from 0.02 to 6.21 g/100 g in chestnuts and almonds. Arginine, which ranges from 0.12 g/100 g in chestnuts to 3.08 g/100 g in peanuts, is the second most common non-essential amino acid, followed by aspartic acid (0.03 g/100 g in chestnuts to 3.15 g/100 g in peanuts). The most essential amino acid is leucine, followed by phenylalanine and valine. Chestnuts have the lowest levels of essential amino acids (0.10, 0.07, and 0.09 g/100 g for leucine, phenylalanine, and valine, respectively), while peanuts are the highest sources of leucine and phenylalanine, and pistachios are the highest sources of valine [41]. Nuts' taste, aroma, and color can be influenced by the ratio of essential and non-essential amino acids. This can be used to identify different almond cultivars [42].

The nutritional value of a food protein is determined by its essential amino acid composition and digestibility. Although nut proteins are commonly recognized as incomplete proteins (i.e., do not contain all essential amino acids) when compared to animal proteins, their consumption is strongly associated with cardiovascular health, if the intake of lysine is supplemented [43]. Combining various protein sources to provide adequate levels of all essential amino acids can boost the health benefits of nut consumption.

2.3 Fiber

Fiber is a health-promoting nut component. Epidemiological and clinical studies show an inverse relationship between dietary fiber intake and obesity, type 2 diabetes, cancer, and cardiovascular disease [44]. Among nuts, almonds have the highest fiber content, with genotype clearly influencing the amount recorded. Some studies have highlighted the influence of genotype on the fiber content found in almonds, which ranges from 6.88 to 9.74% in blanched almonds, demonstrating that almond skin is also responsible for the fiber content of this nut, as it contains approximately 60% fiber [45]. Chestnuts are considered a good source of dietary fiber [46], with values comparable to cashews. The fiber content of chestnuts has been studied, but no trend has emerged regarding the factors that contribute to their variation. Some authors point out the clear effect of cultivar on fiber content [47], area of production [48], and year [49]. The fiber content of hazelnuts is typically described as ranging from 6.5 to 9.7 g/100 g [50]. Researchers have found higher amounts of fiber in some cultivars, such as the Turkish

Tombul hazelnut (12.9 g/100 g) [50] or other cultivars, with fiber values ranging from 9.8 to 13.2 g/100 g (dry weight basis), being the lowest in Tonda di Giffoni and the highest in Campanica [51]. There is limited research on fiber content in pistachios. However, early data indicate a content of 1.1–2.0% [52], whereas more recent studies show significantly higher values. Dreher [53], Bulló et al. [54], and Terzo et al. [55] report fiber values of around 10%, with Rabadán et al. [56] claiming that the crop year and related weather conditions are the most important factors in determining variations.

2.4 Lipids and fatty acids

Nuts boast an array of nutrients, yet they exhibit notable discrepancies between types, alongside occasional but still significant variations within cultivars. Lipid content and fatty acid composition emerge as key parameters subject to considerable fluctuations when examining nut composition. In addition to the pronounced disparities among nut species, modifications in lipid content and profile can also arise from various other factors, with genotype being among the most influential in shaping nut composition. Recent studies underscore that both genotype and environmental factors are pivotal in altering several compositional parameters of specific nuts, particularly fat content [56].

The literature presents compelling examples to underscore this notion, and for conciseness, we will highlight only a few for each type of nut.

For almonds, Summo et al. [57], conducting research on samples from a germplasm collection under uniform growing conditions, documented lipid content variations, ranging from 42.4 to 56.2% (fresh weight), contingent upon the cultivar [58], and also noted a significant cultivar effect on lipid content in almonds. Furthermore, almonds are renowned for their intriguing fatty acid profile, primarily composed of monounsaturated (MUFA) (60%) and polyunsaturated (PUFA) (30%) fatty acids, with oleic, linoleic, palmitic, or stearic acids predominating [47, 49, 57, 59] research further highlights the impact of genotype on the fatty acid profile. Although major fatty acids remain consistent across studied cultivars, variations are observed in the individual amounts of each fatty acid, as well as in the sums of unsaturated (mono- or polyunsaturated) and saturated (SFA) fractions.

Regarding cashew nuts, recent studies reveal substantial variability in fat content and associated fatty acid profiles across different production regions. Rico et al. [60] analyzing 11 cashew origins demonstrate that fat content can range from 45.05 g/100 g in Vietnamese samples to 50.40 g/100 g in samples from Kenya. The predominant fatty acids in these profiles are oleic, linoleic, and palmitic acids. While monounsaturated fatty acids constitute the major fraction in all samples, followed by saturated fatty acids, in at least one sample, polyunsaturated fatty acids emerge as the second most significant fraction.

Chestnuts stand out for their low-fat content, contrasting with other nuts such as hazelnuts, macadamias, pecans, or almonds, where chestnuts exhibit the lowest fat content [33]. However, within this minor fraction, chestnuts contain higher quantities of fat-soluble bioactive compounds, such as tocols and phytosterols, compared to fat-rich nuts. They are rich in essential fatty acids, vital for health but not synthesized in the body, including saturated or unsaturated varieties, crucial for various health processes and mitigating chronic diseases [61]. Notably, linoleic and linolenic acids rank among the most critical unsaturated fatty acids [62]. Like other nuts, fat content and fatty acid profiles can vary significantly among chestnut cultivars. A comprehensive study of 17 chestnut cultivars produced in Portugal reveals significant variations in fat content, ranging from 1.67% to 3.50% [63]. Chestnut fat primarily comprises linoleic, oleic, and palmitic acids, with polyunsaturated fatty acids predominating. However, notable variations in these fractions are observed across samples, with some exhibiting nearly equal amounts of mono- and polyunsaturated fatty acids. Similarly, the quantity of saturated fatty acid displays significant variations among cultivars.

Among nuts, hazelnuts boast one of the highest fat contents, surpassing 60% [64], with some sources indicating levels exceeding 70%, contingent upon the cultivar [65], or even the canopy position of the fruits [66]. The fat in hazelnuts consists mainly of monounsaturated fatty acids (MUFA), constituting approximately 80% of the total fatty acid content, with oleic acid as the predominant individual monounsaturated fatty acid [67]. Polyunsaturated fatty acids represent the second significant fraction in hazelnut fat, primarily due to the presence of linoleic acid [68]. However, certain studies have found that saturated fatty acids can constitute the second most abundant group of fatty acids [57] influenced by the higher content of palmitic acid.

Like many other nuts, pistachios are rich in fat, with available research indicating values around 50% [69], although certain cultivars may have elevated fat content, reaching values as high as 74.15% [70]. Consistent with trends observed in other nuts, pistachio fat is abundant in unsaturated fatty acids, particularly monounsaturated fatty acids (MUFA). This fraction primarily comprises oleic acid, with a contribution from palmitoleic acid, while the second most significant fraction, polyunsaturated fatty acids (PUFA), is mainly composed of linoleic acid [56]. Regarding saturated fatty acids (SFA), the minor fraction consists almost entirely of palmitic acid [71].

Walnuts exhibit very high-fat content, with average values surpassed only by hazelnuts [67]. While fat content typically falls within the 60% range, significant variations have been observed among cultivars. Values have ranged between 49 [72] and 82% [73].

However, as previously mentioned, most studies report fat values around 60%, with some variability associated with the specific cultivar [74].

Walnut fat is predominantly composed of unsaturated fatty acids, particularly PUFA, while MUFA ranks as the second most prevalent type of fatty acid [75]. Linoleic and linolenic acids contribute significantly to the high PUFA content, with oleic acid as the major MUFA. In terms of SFA content, palmitic and stearic acids are the most abundant [76].

2.5 Vitamins

Vitamins are necessary for a balanced and healthy diet. Nuts contain water-soluble vitamins (ascorbic acid, B1, B2, B3, and B6) and antioxidants like α-tocopherol (vitamin E), which promote health, fight aging, improve brain function, and promote healthy skin [77]. Nuts are generally not significant sources of vitamin C: Walnuts: 1.3 mg: walnuts: 1.3 mg, cashews: 0.5 mg, almonds: 0.0 mg (negligible), pistachios: 5.6 mg, pecans: 1.1 mg, and Brazil nuts: 0.7 mg [78]. The nutritional value of a nut is determined by its chemical composition, which is influenced by the cultivar (genotype), meteorological factors such as temperature and radiation, and production practices.

2.6 Minerals

Nuts also contain high levels of minerals such as magnesium and potassium. In recent years, increased consumption of nuts has been considered beneficial to human health because it increases the intake of certain minerals, and they are considered heart-healthy snacks when consumed in moderation [56]. Nuts are an excellent source of minerals such as copper and magnesium. These two minerals may help prevent coronary heart disease. Pistachio and cashew nuts are particularly high in potassium. Most nuts contain adequate amounts of zinc and iron, but pine nuts, cashews, and almonds outperform the rest. In contrast, nuts do not have a high calcium content; however, some nuts, such as almonds, are higher in calcium content [46].

2.7 Aroma and flavor compounds

The aroma compound profile of nuts is determined by geographical origin, thermal processing, and the presence of microorganisms.

Aldehydes, particularly benzaldehyde [64, 79], contribute to the bitter almond flavor in almonds.

In addition to terpenoids and substances derived from amino acids, volatiles are usually present as a result of the oxidation of fatty acids [80]. Processing alters both the number of compounds and chemical classes present. Elmore et al. [81] found that Chinese and Ukrainian walnuts had higher levels of lipid-derived volatiles from linoleic acid breakdown (hexanal, pentanal, 1-hexanol, and 1-pentanol) and α-linolenic acid breakdown (1-penten-3-ol), while Chilean walnuts had higher levels of alkylbenzenes. Pyrazines are the most abundant group of aromatic compounds in peanuts. They are formed as a result of the thermally induced Maillard reaction. This also applies to other nuts, like pistachios and hazelnuts. The roasting process renders the fruit commercially viable and valuable, increasing the nut's sales and sensory qualities [71]. Kiefl and Schieberle [82] found that aroma-active compounds such as 2-acetyl-1-pyrroline, 2-propionyl-1-pyrroline, 5-methyl-(E)-2-hepten-4-one (filbertone), 2,3-diethyl-5-methyl pyrazine, 3,5-dimethyl-2-ethyl pyrazine, and 2 furfurylthiol can distinguish different hazelnut aromas. Roasted hazelnuts develop a nutty aroma when 5-methyl-(E)-2-hepten-4-one and 3-methyl-4-heptanone levels exceed 450 μg/kg. To avoid an over-roasted odor, the sum of two 2-acyl-1-pyrrolines and two pyrazines should not exceed 400 μg/kg. Specific temperatures, roasting techniques, and roasting times can be used to achieve the desired aroma for each cultivar.

One major quality concern for nuts is the development of off-flavors caused by oxidative degradation products. Off-flavor is caused by a variety of volatiles; the most important volatiles are 1-pentanol, 1-hexanol, and hexanal, and their presence at high levels indicates nut degradation [46].

3. The benefits of consuming nuts

The consumption patterns of nuts and seeds exhibit variations across different cultural contexts, encompassing both preferences for specific types of nuts, as well as the quantities consumed. Notably, Canada, certain African nations, certain regions of Europe, and the Middle East tend to report higher amounts of nuts consumption, whereas South America tends to have lower consumption [83]. Typically, these food items possess nutrients that are good for human health, including balanced levels of monounsaturated and polyunsaturated fatty acids, soluble and insoluble fibers, proteins, E and K vitamins, thiamine, folate, magnesium, potassium, copper, selenium, as well as substances like antioxidant compounds, and phytosterols [84–87].

Rajaram et al. [88] conducted a narrative review that analyzes the potential health advantages associated with the consumption of nuts, with a specific emphasis on their antioxidant and anti-inflammatory properties. This study emphasizes the antioxidant properties of nuts, which contribute to the reduction of inflammation and oxidative stress in the human body. Additionally, the study emphasizes research findings that demonstrate the potential of almonds, walnuts, Brazil nuts, and pistachios in regulating inflammation and mitigating oxidative stress. Evidence from systematic reviews and meta-analyses of cohort studies and randomized controlled trials (RCTs) suggest a modest protective effect of total nuts; however, the evidence is inconsistent for specific nut types [89–91]. Therefore, Rajamam et al. [88] highlight the necessity for a more comprehensive investigation, proposing the implementation of bigger randomized trials that should focus on various varieties of nuts, on the optimum dosages, and the duration of nut intake in the participants involved in the studies.

Excepting the antioxidant and anti-inflammatory properties of nuts, the weight loss benefits of nut consumption have been linked to their anti-obesity properties, which can be related to their high amount of polyunsaturated fatty acids, proteins, and polyphenols. The anti-obesity properties of walnut have been attributed to its ability to modify the intestinal microflora, namely by raising the abundance of Firmicutes while reducing the presence of Bacteroidetes. This mechanism has been documented in studies conducted on obese individuals [83, 92–94]. The regulation of gut bacteria is believed to be facilitated by the walnut kernel shell, which is believed to enhance the relative abundance of Bacteroides in comparison with Firmicutes.

Several clinical trials and cohort research studies have demonstrated that diets fortified with nuts do not result in an increase in body weight, body mass index, or the circumference of the waist [83, 92–94]. Instead, these diets tend to lead to a little decrease in all these measurements. In general, the consumption of nuts and seeds has been shown to have beneficial effects in enhancing fasting blood glucose levels, glycemic regulation, and sensitivity to insulin [95–98]. Moreover, research has shown that nuts have a beneficial effect on satiety and appetite reduction, potentially explaining why studies have not shown a connection between nuts and obesity [99, 100].

Increasing amounts of evidence suggest that a diet rich in nuts may have potential health benefits. Thus, it has been demonstrated that the consumption of phytochemicals derived from nuts has a beneficial impact on various disorders, including cancer, obesity, stroke, congestive heart failure, arterial hypertension, congenital disorders, cataracts, type 2 diabetes, and diverticulosis [10, 101]. According to Gonçalves et al. [10], nuts contain numerous phytochemicals that can contribute to their health-enhancing properties. The substances, including vitamins, phenolic acids, and flavonoids, have been extensively studied for their potential to mitigate specific types of cancer and cardiovascular disorders [102]. Additionally, phytoestrogens, organosulfur substances, fiber, and isothiocyanates have also been extensively examined by several authors [101, 103].

The systematic review conducted by Lockyer et al. [104] found a strong positive association between regular consumption of nuts and notable decreases in the likelihood of developing cardiovascular disease among the participants included in the review. Furthermore, the review also references the PREDIMED trial, which emphasizes that incorporating walnuts into a Mediterranean diet reduces the likelihood of experiencing myocardial infarction, stroke, and mortality caused by cardiovascular diseases [105]. Additional research in the field asserts that consistent consumption of nuts substantially reduces the likelihood of developing coronary heart disease and stroke. In these instances, the beneficial effects experienced by the human body can be attributed to the consistent intake of nuts, which enhance lipid profiles by reducing total cholesterol and low-density lipoprotein cholesterol levels, while also exerting positive impacts on several metabolic indicators.

According to Liu et al. [104], the efficacy of nuts consumption in reducing blood lipids, such as triglycerides, low-density lipoproteins, and total cholesterol, has been substantiated by a sequence of randomized controlled trials. Based on the conducted investigations, it has been observed that this phenomenon is particularly prominent among persons who exhibit elevated levels or possess cholesterol values that fall within the upper threshold. Walnuts are known to possess alpha-linolenic acid and various other bioactive components, which have the potential to enhance the lipid-lowering effect by promoting improved cholesterol management within the human body.

In recent years, there has been a growing body of research addressing the potential health benefits associated with the consumption of nuts. However, it appears that consumers may not have a comprehensive understanding of the multiple benefits that nuts might bring. Recent research has demonstrated that consumers link nuts with elevated levels of fat and protein, as well as their perceived health benefits. Nevertheless, there is a significant proportion of customers who lack awareness regarding the correlation between nuts and their impact on blood cholesterol levels, inflammation, and the likelihood of developing diabetes, obesity, cardiovascular disease, or cancer [87, 106, 107].

4. Uses in the food industry

Nuts are widely valued as agricultural and commercial commodities on a global scale. These foods provide a significant nutritional and fiber content, rendering them a commendable option for promoting healthy snacking, spreadable creams, ice cream, and nut-based culinary preparations. Various species of nuts are utilized in a diverse range of final products, and their high vitamin content and health benefits render them a preferred option among consumers who prioritize their well-being. Nevertheless, the processing of nuts can provide challenges owing to their rigid shells, hulls, and elevated moisture levels. The attainment of desired product attributes, including flavor, texture, minimum shelf life, and nutrient content, necessitates the implementation of appropriate processing techniques [80, 108].

4.1 Nut processing techniques and technologies

4.1.1 Hulling and kernel peeling

Hulling is the process of removing the outer shell, or hull, of a nut. This is done to expose the kernel for additional processing. The hulling technique varies depending on the type of nut and can be done mechanically or manually [109]. Subsequently, the nut kernel undergoes peeling, a process that involves eliminating the delicate, brown outer layer that envelops it. The removal of the skin is achieved by means of abrasive peeling, a process that entails rotating the kernels against an abrasive surface.

4.1.2 Drying technology

Drying is an important stage in nut processing because it reduces fiber content and extends the shelf life of nuts. There are numerous drying procedures accessible, including natural drying, artificial drying, and modern drying methods. To dry the nuts naturally, expose them to sunlight or air. However, this approach is inefficient, resulting in low quality and significant energy usage. Artificial drying technology uses a machine to dry the nuts using hot air. This procedure is more efficient than natural drying and can provide a higher-quality product. Current drying processes use novel techniques such as infrared and microwave drying to reduce energy usage and boost drying efficiency [110].

4.1.3 Roasting

This common way for processing nuts improves their flavor and texture. There are two sorts of roasting techniques: dry roasting and oil roasting. Dry roasting entails roasting the nuts without using any oil, whereas oil roasting includes applying oil to the nuts before roasting. For example, to roast cashew nuts, place them in a dry roaster for 20–25 minutes at 140–150°C. This produces a crispy nut with a deep, nutty flavor. Lucchetti et al. [65] investigated the role of the cultivar, pellicle, and the effect of roasting. As a result, the fatty acid composition, tocopherols, and total phenolic compounds of peeled/unpeeled and raw/toasted "Nocchione," "Tonda di Giffoni," "Tonda Gentile delle Langhe," and "Tonda Gentile Romana" hazelnuts were studied. The results show that all four cultivars have a significant proportion of mono- and polyunsaturated fatty acids, around 110–210 mg/kg of tocopherols, and, when unpeeled, 1250–2100 mg/kg of phenols.

4.1.4 Peeling

The process of removing the outer covering or coating from a nut. This improves the nut's look, texture, and flavor. There are numerous peeling techniques available, including kernel peeling, abrasive peeling, and air pressure peeling. For example, in the walnut peeling process, a machine delivers air pressure on the nut to remove its outer shell. The walnut kernel is then further processed for usage in final goods [111].

4.2 Food safety in nuts industry

Food safety is an essential concern in the food industry, and the processing of tree nuts is no different from one another. Nuts are subject to contamination from a variety of sources, including foreign debris and foodborne pathogens. Proper disinfection is required to ensure that the finished product is safe to consume. Foreign debris including rocks, sticks, and leaves is one of the most common sources of contamination in nut processing. Exogenous particles have the potential to cause harm to processing equipment and contaminate the final product. Adequate screening and cleaning procedures for nuts can effectively mitigate the occurrence of extraneous substances [112, 113]. Foodborne pathogens such as *Salmonella* and *Escherichia coli* provide a significant challenge in the context of nut processing. The ingestion of these microorganisms can lead to severe illness, and their elimination from the processing environment poses a challenge. Implementing appropriate sanitation and decontamination methods is essential in order to minimize the risk of contamination [114, 115].

4.3 Nut-containing foods

Nuts are a high-value-added product due to their excellent nutritional properties and the technologies used in their processing. They are marketed either whole, designed specifically for the foreign market, or fragmented and broken, used in the internal market industries of ice cream, cakes, and chocolates. It is a valuable delicacy that is mostly used in confectionary and as a dessert nut in cakes, pastries, candies, and chocolates to enhance their flavor and look. Cashew flour is commonly used in the preparation of cereal bars, biscuits, candies, and chocolates [116]. The detailed approaches are explained below (**Table 1**).

Crt. no	Industry	Product	Source	Results	Ref
1	Bakery and confectionery	Cookies	Nuts like almonds, walnuts, and pecans	Significantly enhanced wheat bulk density, water absorption capacity, oil absorption capacity, and swelling capacity, but lowered foam capacity and foam stability. Decreased moisture content, increased protein, fat, ash, and total dietary fiber content. Improved in physical characteristics such as hardness, weight, and thickness, while diameter and spread ratio decreased. After 28 days of storage, the total phenolic content and antioxidant capacity rose.	[117]
		Bread	Gluten-free bread—chickpea protein and tiger nut	Breads with darker crusts. Bread made with chickpea and tiger nut flour retained baking properties when shortening and/or emulsifiers were reduced or deleted. Apparently, interactions between chickpea protein and tiger nut lipids compensated for the effect of eliminating shortening and emulsifier on crumb texture.	[118]
		Cakes and pastries	Ground almonds or almond flour Peanut	Can be used in cakes, tarts, and pastries for a rich and moist texture. Better elasticity, chewability, and cohesiveness. Higher amount of phosphorus and magnesium.	[119, 120]
		Chocolate	Nuts such as hazelnuts, almonds, and peanuts Nuts oils	Used in chocolate bars, truffles, and pralines White chocolate has high notes of fruity and sweet flavors; milk chocolate has high notes of milky and sweet flavors; gold chocolate has dominant flavors of caramel and creamy/milky flavors; and white vanilla chocolate has sweet, milky, and vanilla flavors. Dark chocolate has higher notes of bitter/roasted and cocoa. Almond was the least perceived of the three, whereas hazelnut was the most prevalent, with the longest mean duration of perception. Fortification with peanut oil could improve the composition because peanut oil was rich in tocopherol, phytosterol, and monounsaturated fatty acids.	[121, 122]

Crt. no	Industry	Product	Source	Results	Ref
2	Snack foods	Roasted and salted nuts nut mixes	Peanuts, almonds, cashews, and pistachios or combination of different nut	Roasted and salted to make popular snack foods. Nuts typically include important elements that boost antioxidant activity and offer health advantages. However, these nutrients may be impacted by how nuts are prepared, consumed, and served. Indeed, depending on the type of nut, heat treatment (frying or roasting) significantly altered the positive and/or negative characteristics of the nut. In spite of their high-calorie content, we advise consuming a variety of nuts, both raw and heat-treated, as a substitute for foods high in calories but low in nutrients. This is because heat treatment of nuts may have a cumulative effect that cannot be disregarded.	[123]
3	Dairy and dairy alternatives	Nut milks:	Almond milk, cashew milk, and hazelnut milk	Significantly boosted fat, fiber, antioxidant, total phenolic content, and hardness in ice milk treatments, while decreasing ash content, overrun, and viscosity. The study found that tiger nut milk is high in total phenolic compounds, which are associated with effective antioxidant activity, making it a safe plant-based substitute for cow's skim milk for vegetarians and other consumers	[124]
		Nut-Based Cheeses	Cashews, macadamias, and almonds	Can be used to make dairy-free cheeses and spreads High-protein content. Increased melt, stretch, and mechanical sensory attributes	[125–127]
		Vegan cheese	Nuts and soy bean	Reduced the cheese yield, but increased the fat contents. Calcium and potassium were abundant in the cheese samples, but the iron content was generally low	[128, 129]
4	Cereals and granolas	Granola bars	Nuts and seeds: peanuts, cashew nuts, almonds, and walnuts	Increased crunch attributes and healthy nutrition. Increased nutritional value of the energy bar. Balance nutrition regarding protein, fat, carbohydrates, and minerals Increased iron, magnesium, phosphorus, and calcium content, good antioxidant activities.	[130, 131]
		Breakfast cereals	Nuts like almonds and walnuts	For added flavor and texture. Sources of lipids, proteins, and antioxidants.	[132]

Crt. no	Industry	Product	Source	Results	Ref
5	Salads and main dishes	Salads	Nuts such as pecans, walnuts, and almonds	Salads for crunch and flavor Source of phenolic compounds and antioxidant activity	[86]
		Main Dishes	Ground nuts	Can be used as a coating for fish or chicken, or as a thickening agent in sauces and stews.	[133]
6	Nut butters and spreads	Peanut butter	Ground peanuts.	To make various nut and seed butters or spreads, the nuts and seeds are first roasted, then ground and combined with sugar, salt, stabilizers, and emulsifiers. To achieve the best-tasting nut and seed butters, roasting conditions must be ideal. The amount and method of grinding have an impact on the butter's mouthfeel and smoothness. Optimizing the various amounts of salt, sugar, stabilizers, and emulsifiers is necessary to produce butter that is more flavorful, stabilized, and does not separate into sections while stored. Optimizing the methods for making low-fat spreads and butters based on nuts and seeds is necessary since consumers' preferences for low-fat butters are growing.	[134] [135]
		Almond butter	Ground almonds		
		Other nut butters	Cashew butter, hazelnut butter, and walnut butter		
7	Desserts and ice cream	Ice cream and desserts	Nuts like almonds, pecans, and pistachios	Toppings or mixed into ice cream. Can be used in pies, tarts, and other desserts for added flavor and texture. As stabilizers which thickens the ice cream, improve whip ability, bind free water, reduce meltdown, help avoiding wheying off and maintain structure.	[136]
8	Beverages	Nut Liqueurs	Nuts such as almonds, hazelnuts, and walnuts	Are used to make flavored liqueurs. Rich source of phenolic and volatile compounds. Presence of catechin, quercetin, and its sugar-conjugated derivatives	[137, 138]
		Nut-Based Drinks	Nut milks and smoothies	Ice milk—kefir and kombucha fermentation in cashew nut beverage: probiotic activity, lower sugar contents	[139]
9	Oils	Food industry	Nuts like almonds, pecans, and pistachios	Significant proportions of nutritionally and medicinally desirable fatty acids and nutraceutical compounds (sterols, tocopherols, and other phenolics)	[140, 141]

Table 1.
Nuts approaches in food industry.

5. Nuts-based spreads

Nuts are mainly consumed, roasted, and even grinded into fine pastes, for which the following definitions are present in Codex Alimentarius: plant butters for the spreads with 100% nuts as ingredients, without sugar in the composition or which contain at least 90% of the seed as ingredient, while to spreads with 20–40% sugar in the formulation and at least 40% of the seed in the composition [134]. Nuts and seeds, such as peanuts, hazelnuts, almonds, cashew, macadamia nuts, and pistachio, or their mixtures are currently used for manufacturing nut-based butters, but they are expensive ingredients because of their seasonal character and origin, which is mainly tropical or Mediterranean [134, 142]. While plant butter is rather consumed by a class of consumers which is more aware of nutrition and sustainability and appreciate food products with singular, natural ingredients, spreads are largely produced for direct consumption or to be further included as fillings in various confectionary products. For economic, technological, long-term storage, and sensory reasons, other ingredients are commonly added to the nut butters. Nut butters were also reported to present some oxidative or textural issues, since are mainly produced by subjected the raw ingredient to thermal treatments, removing teguments and skin, grinding, with exposure to air and light prior packaging, for which reason the inclusion of stabilizers, salt, and sugar is permitted up to 10%.

Spreads are complex semi-solid multi-phase dispersions where the continue phase is represented by fat, originating from the nuts, or purposely added, while the dispersed phase by solids such as sugars, teguments of the nuts, cocoa, and milk powder depending on the assortment. While the plant butters maintain the nutritional value of the nut, the commercially available nut-based spreads are high in saturated fats and sugar, have lower amounts of fibers in the composition, and might contain purposely added palm fat, because of its low price, oxidative stability, no odor and taste, and low cost, alternative spreads, which would be as healthy as possible being necessary to be developed [143]. Nuts, because of their high content of unsaturated fats, are susceptible to oxidation especially when thermally treatments were applied to them, or when exposed to oxygen and light, thus during storage and especially when they are transformed into butters or spreads.

Coconut oil or milk fat was explored as fat systems aiming to replace the palm fractions of a commercially available formulation of a hazelnut spread, coconut fat leading to a soft texture, and decrease of each evaluated textural parameters, while milk fat leading to increased adhesiveness [144]. Oleogels structures that aim to replace highly saturated or trans fats in foods, with oils reach in PUFA solidified due to their inclusion in some 3d interconnected structures developed by structuring agents, have the potential of replacing palm fat in hazelnut spreads. Glycerol monostearate (GMS-3-6%)/olive oil-based oleogels were included in a design of experiment (DoE) approach for manufacturing hazelnut spreads by Marra et al. [145]. All of the analyzed responses were significantly influenced by the presence of the oleogel, while the other parameters varied in the design were palm oil presence (0–75%). The decrease of palm fat in the formulations also leads to decrease of spreadability and hardness and increases in the adhesiveness, which are less desired for the textural attributes of a spread. According to the results of the desirability function, the authors report that an oleogel made of 95% olive oil and 5% glycerol monostearate, could totally replace palm oil in a hazelnut spread with good properties, but they hypothesis was not confirmed in their study, since they did not manufactured and analyzed the indicated sample [145]. Similarly, a 5.3% GMS-olive oil-based oleogel was used in obtaining a high protein pistachio spread, sweetened with stevia and with skimmed milk powder and whey protein concentrate as structural modifiers that aim to improve the attributes of the product [146]. A DoE approach was also explored in this study, but textural attributes were not improved, because of the non-fat solids, and the software of the design revealed that their concentrations and their interactions affect the structuration level of spread samples and thus their spreadability.

In spread formulation hazelnut is commonly associated with cocoa for obtaining products with high acceptance from the consumers. To increase the oxidative stability of cocoa and hazelnut spreads, inactive yeast cells (*Saccharomyces cerevisiae*) were used in the study of Gül Yiğit et al. The objective of the inclusion of the yeast was achieved, the TBARS values being half of the reference after 150 days storage, while the sensory analysis revealed that the inclusion in 5% is the maximum level accepted [147].

Spreads rich in polyunsaturated fatty acids, digestible proteins, vitamin E, minerals such as P, Ca, and Mg, but also polyphenols can be developed from roasted walnuts that are highly available in Romanian households, but grown also in orchards [148].

The main polyphenol in nuts belongs to the class of ellagitannins, namely the pedunculagin and might give to the food products formulated based on nuts prophylactic properties in neurodegenerative diseases, but also the most prevalent diseases of this era, cancer, and cardiovascular diseases, the effects being proved by some valuable long term interventional studies, as mentioned by Sultana et al. [149].

The stability and acceptability of a sugar free walnut butter, but also the consumption intention and market acceptability in Romania were studied by Leahu et al. Walnuts roasted at 120°C/for 30 min were grinded with a laboratory blender at a speed of 20,000 rpm for 1 min and sweetened with Jerusalem Artichoke Powder (5%) or maple syrup (3%), with the usage of xanthan gum as stabilizer in various amounts (max. 2%), while the sample containing the syrup showed the behavior of a non-Newtonian fluid, in the rheological evaluation, with reduced viscosity compared to the pure nut butter. For the other, a sinusoidal Lissajous curve with viscosity fluctuations was revealed. The second type of nut presented lower values for textural attributes, despite the more fluid character of the sample with syrup, the hardness being almost half in comparison with the walnut butter alone, with adhesiveness increasing three times. In sensory analysis, the texture of the other sample, the walnut butter with maple syrup had the highest overall texture scores, even if the adhesiveness of this sample was also increased, according to the textural analysis. The interest in the novel spread was higher for people under 40, and among them 30% consume peanut butter once in a month [150]. During the extraction of the kernel from the walnut shells, considerable amount of broken sample is generated, which should not be considered waste, since is suitable for plant-based butter production or spreads, possessing the same properties as the whole walnut, but with some adaptation of the thermal treatments and durations because of their size and separate processing from the whole walnuts.

Acorns are technically and botanically considered nuts [151]. They are the nut-like fruit of oak trees, consisting of a hard, woody and cuplike shell, and a seed. While the whole nut is not valorized in human consumption, the seeds of the genus *Quercus acorns*, from *Fagaceae* family, compete nowadays with conventional nuts in food product formulations because of their complex composition including high amounts of carbohydrates and fats, low allergenicity, and sustainable character.

In the study by Stiti et al. acorns were valorized in a dessert because of their availability, anti-diabetic properties and high biological value—antioxidant activity (37.73 ± 13.08% DM), and a high amount of polyphenols (433.4 mg GAE/ml) determined in the DPPH assay. Acorns were subjected to some treatments prior use in order to reduce their bitterness, by three means of which boiling and changing water until clarity was more efficient as thermal treatment at 180°C or soaking in baking soda [5]. Four dessert formulations—spreads, were prepared by boiling a considerable percentage of acorn paste from which tannins were removed (38–50%) in water, with sugar and cocoa powder and for one formulation with the inclusion of a sesame paste (11%). In the sensory analysis the formulation containing 43% acorns, and no sesame paste being highly scored for each tested parameters (texture, appearance, color, smell, and sweetness) [5].

Acorns are highly intended for oil extraction, because the fatty acids profile of the resulting oil resembles to olive oil [152], also possessing antioxidant compounds [153], thus resulting a flour rich in carbohydrates, but also biologically active substances, depending on the oil extraction methods [153]. Defatted acorn flour, as single ingredient or in mixture with other flours, was used in some bakery products formulation such as biscuits [154–156], cakes [157, 158], bread [159, 160], or chocolate [161].

In the work of Socaciu et al. Sessile oak acorn (SOA) was included in spreadable vegetable paste formulations manufactured from sunflower seeds, created as plant-based meat spread analogues (liver pates) but with reduced costs for the ingredients and sensory enrichment. Enrichment of the product with 10% SOA leads to a product with higher content of lipids and proteins, but because of the high starch content, was not very well scored in a sensory analysis.

6. Other uses of nuts

Nuts, being highly nutritious, are cultivated extensively in various climatic conditions and nations. They contain lipids, fibers, proteins, carbs, as well as various minerals and organic constituents. Nuts contain numerous phytochemicals that can contribute to their health-enhancing properties. Among these options, it is imperative to consider the presence of vitamins, phenolic acids, and flavonoids, along with phytoestrogens, fiber, organosulfur compounds, and isothiocyanates, and their potential to mitigate specific types of cancer and cardiovascular illnesses [101, 103]. Tédong et al. [162] showed that cashew kernels can mitigate functional and histological alterations in the kidneys caused by diabetes. The hypoglycemic effect of the cashew plant has primarily been documented in individuals with type I diabetes. The occurrence of diabetes in rats caused by streptozotocin is associated with changes in kidney function and morphology. The administration of varying doses of cashew plant extract (150 and 300 mg/kg/day) resulted in a noticeable decrease in blood glucose levels, total secreted protein, glycosuria, and urea in diabetic rats.

However, nut wastes, such as leaves, shells, hulls, and fruit disposed in landfills, are useless. Numerous value-added products derived from walnut shells and hulls have been utilized in various sectors, including the food industry. Various waste materials have been utilized in the production of catalytically active compounds to circumvent the need for expensive commercial chemicals in catalytic processes [163].

Nuts have the potential to serve as various agents, such as reducing, stabilizing, and tempting agents, surfactants, carbon precursors, and more, in the synthesis of heterogeneous catalysts that are both simple and efficient. Chemicals generated from nuts can be utilized to create diverse catalysts either on their own or in combination with other substances like nanoparticles, such as CuO NPs, Cu NPs, Ag NPs, TiO2 NPs, and so on. Metal nanoparticles can be synthesized using extracts derived from various components of nuts. The production of nanoparticles often involves the preparation of carbonaceous chemicals derived from nuts. Activated carbons have been utilized as effective, environmentally friendly, and economically viable substrates for the production of diverse carbon-based catalysts. Catalysts derived from nuts have the potential to be utilized in several environmental applications, including the degradation of organic contaminants [164].

There is a significant trend in the development of environmentally friendly catalysts due to the detrimental impact of metal-based catalysts on the environment. For instance, Wu et al. [165] conducted a study where they utilized walnut shell as the primary material to produce nitrogen-doped biochar. This nitrogen-doped biochar was then employed as an environmentally friendly catalyst for the chlorination of acetylene. The nitrogen source used in this process was the condensation product of dicycliamide or dicyandiamide-formaldehyde (DF). The 2.5 DF/biochar-850 catalyst has exceptional catalytic activity due to a significant amount of quaternary nitrogen serving as the active center. This leads to a remarkable acetylene conversion rate of 94.5% at a temperature of 220°C and a reaction time of 45 h^{-1}. The thermal stability of the metal-free nitrogen-doped biochar catalyst is enhanced by the inclusion of formaldehyde, effectively inhibiting carbon deposition during the catalytic reaction.

Walnut shell powder was employed to eliminate lead from an aqueous solution. When the initial Pb^{2+} level was 100 mg/L, it was used a natural walnut shell dose of 1 g/100 mL, and a yield above 90% was achieved within a time frame of fewer than 2 minutes. The adsorption capacity was determined to be 9.912 mg/g at room temperature using the Langmuir equation [166].

To mitigate the presence of Cu (II) in groundwater samples, a research investigation was conducted by Foroutan et al. [167] to develop an innovative magnetic nanocomposite utilizing walnut shell ash, starch, and Fe_3O_4. The study reported maximal Cu (II) sorption capacities of 29.0 and 45.4 mg/g using walnut shell ash and walnut shell ash/starch/Fe_3O_4. The composite adsorbent can be reused three times with sufficient efficiency, depending on the water quality, due to its ability to recover copper from three groundwater samples.

A key step in the development of lightweight, environmentally friendly bricks with enhanced thermal insulation capabilities involves the production of burned bricks infused with agricultural waste. Barnabas et al. [168] did research that employed walnut shell waste as an ingredient in the production of fire ceramics bricks using burnt clay. The results indicated a greater capability for water absorption and specific heat energy. An elevated walnut shell content exhibited a positive correlation with heightened porosity and enhanced water absorption characteristics. The increase in walnut content resulted in a decrease in linear shrinkage and heat conductivity at elevated temperatures, specifically 1100 and 950°C, respectively. The increase in fire temperature resulted in an improvement in the bricks' resistance to salt crystallization.

The antibacterial, antioxidant, and anticancer characteristics of copper nanoparticles (CuNPs) linked to cellulose walnut shell material were investigated. The antioxidant properties of CuNPs were significantly increased by increasing the concentration to 10%. CuNPs exhibit a cytotoxic effect on K562 cells that is depending on the dosage. The compound's IC50 value against peripheral blood mononuclear cells

(PBMCs) was significantly greater than the IC50 value of the synthesized nanoparticles (NPs) against K562 cancer cells (25.24 ± 5 g/mL) [169].

The combination of walnut green hull and chemicals such as sodium lignosulfonate exhibits a synergistic effect in inhibiting the corrosion of materials, particularly cold-rolled steel. This combination demonstrates a notable enhancement in inhibitory efficiency, reaching 97.2% [170].

Sanjeeva et al. [171] utilized distilled technological cashew nut shell liquid as an additive to transform triglycerides into biofuel, without the requirement of methyl esters production.

In the dyeing industry, walnut husk has the potential to function as a mordant. The utilization of alginate and walnut husk as mordants in the dyeing process of viscose rayon fabric with an anthocyanin solution derived from *Hibiscus sabdariffa* L. calyces resulted in enhanced color strength and fastness [172]. The antibacterial activity of wool yarn dyed with walnut husk was found to be up to 35%. Upon treatment with sodium salt nanoparticles, the colored wool yarns exhibited a remarkable antibacterial characteristic, as evidenced by their ability to retain 91% of their original state even after undergoing 10 consecutive washing. The researchers also observed favorable wash and light fastness characteristics [173, 174]. Additionally, they made an effort to print alpaca wool utilizing walnut husk and iron sulfate. The walnut husk-extracted pectin obtained through ultrasound-assisted extraction has been observed to possess favorable emulsifying properties [175].

The possibility of methanolic walnut husk extract as a sustainable and environmentally acceptable alternative to propyl gallate as an antioxidant for enhancing the oxidation stability index of biodiesels, such as waste cooking oil, has been suggested [176]. The life cycle assessment comparison between walnut husk extract and propyl gallate demonstrates the efficacy of walnut husk as an environmentally beneficial antioxidant for biodiesel fuels. Environmentally friendly absorbents of harmful dyes and metals from the environment have also been identified in walnut husk extracts. Titan yellow dye may be effectively eliminated utilizing walnut husks, achieving a removal rate of over 85.5% when administered at a dosage of 0.06 g at a dye concentration of 15 ppm. In the context of petroleum treatment, the utilization of nanocomposites consisting of walnut husk extract and silver (Ag) has demonstrated notable efficacy in the removal of heavy metals such as lead, chromium, and cadmium from wastewater. About 0.75 g of these nanoparticles have the ability to eliminate lead, chromium, and cadmium by up to 72.6, 81.3, and 88.1%, respectively, during a period of 5 hours.

The presence of insecticidal capabilities in walnut husk extracts indicates their possible application in agriculture as a substitute for pesticides that have negative impacts on both human health and the environment. The walnut extract has demonstrated insecticidal efficacy against *Pieris rapae* larvae and *Helicoverpa armigera* larvae, resulting in mortality through stomach toxicity of up to 50% [177].

The efficacy of walnut husk in combating malignant cells has been demonstrated. The human gastric cell line SCG7901 exhibited suppression of cancer cell growth upon treatment with walnut husk extract [178]. The administration of walnut husk has been observed to enhance lipid levels and the gut microbiome in obese rats that have been subjected to high-fat diets. It has been observed that the intervention enhances insulin resistance and glucose metabolism, while concurrently decreasing fat storage and adipose tissue hypertrophy in rats with obesity. The administration of walnut husk extract to the rats resulted in a reversal of gut microbiome diseases, specifically a reduction in Fuso bacteria, Firmicutes, and Peptostreptococcaceae, as well as an increase in Bacteroidetes at the phylum level [179]. The efficacy of walnut husk extract in inhibiting platelet aggregation has been observed. The acetone extract derived from walnut husk has exhibited a 50% increase in protein secretion, as well as the ability to prevent platelet aggregation. The extract stimulates caspase and inhibits the production of reactive oxygen species [179].

Almond by-products, such as almond shells, can be utilized for bioenergy production using thermochemical and biochemical conversion technologies. Almond woody biomass can be used as composite fillers and absorbents, and torrefied shells can be used as low-grade plastic enhancers. Almond shells can be utilized as feedstocks for thermochemical conversion processes such as gasification, pyrolysis, and torrefaction, making them valuable for bioenergy production.

Chestnut by-products can also be utilized in the leather industry, adhesives, and topical formulations for the prevention and treatment of skin oxidative stress-mediated diseases. The phenolic compounds present in chestnut leaf extracts have shown antibacterial properties, DNA protection, and the ability to prevent and treat oxidative stress-mediated diseases like photoaging. Chestnut shell extracts have been studied for their potential use as heavy metal adsorbents and as substitutes for phenol in adhesive formulation and chrome in leather tanning. The chestnut by-products can be used as bioactive substances in the pharmaceutical, food, and cosmetic industries due to their beneficial properties in diseases such as diabetes, cancer, cardiovascular diseases, and neurodegenerative diseases [180].

Pistachio shell waste can be used as a reinforcing material in composite structures for various industrial applications, including automotive, building and furniture, and medical products. It has the potential to be employed in the production of thermoplastic-based, thermoset-based, and bio-composites, offering exceptional mechanical characteristics and functioning as a viable substitute for conventional reinforcement materials. Pistachio shell waste can also be used in the production of carbon electrodes, which find applications in supercapacitors, electrical double-layer capacitors, and electrochemiluminescence systems. Pistachio shells possess a notable concentration of lignin and cellulose, making them well-suited for augmenting the thermal and mechanical properties of polymer composites. Additionally, pistachio shell waste can be converted into activated carbon, which has applications in various electrochemical systems and can help reduce the environmental impact of food packaging [181].

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Section 2

Chemical Composition, Nutrients and the Beneficial Effects of Using Nuts

Chapter 2

Almond Varieties: Nutritional and Chemical Composition and Health Benefits and Culinary Application

Mubeen Asad and Alveena Malik

Abstract

The main aim of this chapter is to present a short summary of different growing species of almond and their health benefits. "Almonds," which are cherished for their taste and nutritional value, are available in dozens of varieties, each possessing its own distinct character. The nutritional composition of almond is presented through our analysis, which highlights the macronutrient, micronutrient, fiber and phytochemical contents. Popular almond types, which include Nonpareil, Carmel, Mission, Sonora, and Independence, along with their freshest taste and implementation in cooking, are described. In addition, we provide information on the health benefits of almond, such as its benefits for heart health, weight management, blood sugar control, bone health and brain health. In human food preparation, almonds are not only combined with snacks but also in other simple mixed dishes, bakes, beverages and comprehensive options. The choice of almond variety depends on the nutritional value and culinary possibilities of distinct varieties of almond. Genetically and environmentally friendly, the nutritional quality of almond may vary slightly. It is known for several pharmacological properties, including antistress, antioxidant, immune stimulant, lipid strategizing and laxative properties. It is a highly useful tool for improving the health of our memory, ameliorating muscle function, prolonging life, and improving various other aspects of our health.

Keywords: almond varieties, antioxidant, vitamins, health benefits, phytochemicals

1. Introduction

Nuts are considered dry fruits with a single seed, and the wall of the ovary becomes hard to reach maturity. The most well-known famous trees with edible nuts include hazelnuts, walnuts, almonds and pistachios. Other nuts include nuts from cashews, pecans, macadamias, pine, peanuts and Brazil nuts [1]. Almonds have been admired as a quintessence of healthiness and as the most edible and broadly cultivated seed. The different almond species belong to the genus *Prunus* and the family Rosaceae. The almond fruit is called a drupe, in which the seed is enclosed in a rigid shell and covered by an external hull. It is mostly domesticated in the belt from Turkey to Pakistan, which is considered a Mediterranean climate zone of the Middle East. In 2016, the entire world production of almonds was 3.2 million tonnes, of which 63% stood apart from the United States, whereas the other chief producers were Iran, Morocco and Spain, collectively accounting for 14% of the world's entire production. In South Asia, almond varieties such as Jordonala, Non-Parral, Mission, and Utra from the Khyber Pakhtunkhwa district and Katha, Kaghzi, Quetta Determination, and Talwar from Balochistan are highlighted, highlighting diverse cultivation practices. Regardless of the best 20 countries in the developing countries of the world, Pakistan overdepends on exchanging almonds because of the absence of logical learning and research on the therapeutic estimations of Pakistani almond assortments.

Almonds are the richest source of many nutrients, the dominant of which are fats, which differ in various varieties. On average, it contains 50–60% fat [2]. The composition of fats indicates their dominance in monounsaturated fatty acids (MUFAs), which range from 66.7–69.7%. The suitable ratio of monounsaturated to polyunsaturated fatty acids (PUFAs) makes almond a healthy food for humans. The detailed fatty acid profile revealed that 0.62% palmitoleic acid, 66.7–72.47% oleic acid, 18.69–23% linoleic acid and α-linolenic acid below 1% oleic and linoleic acids are inversely correlated and together account for 91.16–94.29% of the total soluble lipids [1]. Up to 10% saturated fatty acids are present, and among them, palmitic and stearic acids are dominant [3]. Research suggests that coronary heart diseases and strokes can be prevented by the consumption of monounsaturated fatty acids, which support the development of a healthy serum lipid profile [4]. In accordance with Sallamander Concepts (Pty) Ltd., South Africa. Chemical analysis of sweet almond oils revealed that they contain 3.0–9.0% palmitic acid, 2.0% palmitoleic acid, 0.5–3.0% stearic acid, 60.0–70.0% oleic acid, 20.0–30.0% linoleic acid, 0.4% alpha-linoleic acid, 0.2% arachidic acid, 0.2% eicosenoic acid, 0.2% behenic acid and 1.0% erucic acid. Nuts provide 20 to 30 kJ/gm of energy because of their high fat content, which is as low as 46% in cashews and 76% in macadamia nuts. The fatty acid profile of nuts is considered beneficial, as half of the total fat is unsaturated, that is, MUFAs (monounsaturated fatty acids) and PUFAs (polyunsaturated fatty acids), while the proportion of saturated fatty acids is very low, at 4–16% [5]. In addition to fats, almond is also a good source of proteins, as 100 g of protein contains 22.7–29.5 g of protein and is considered a good source of amino acids of both types, that is, essential and nonessential. Different types of essential amino acids, such as tryptophan, histidine, lysine, leucine, isoleucine, threonine, valine, phenylalanine and methionine, exist in adequate amounts [4]. The proteins of almond are also rich in the amino acid arginine and exhibit adequate digestibility [6]. These have good amounts of carbohydrates: a 100 g serving contains 19.5–22 g, of which approximately 12.2 g is dietary fiber, 3.89 g is sugars, and 0.79 g is starch. Almonds have a compact foundation of minerals (3–4.6 g/100 g), including calcium (280–300 mg), copper (0.9–1.3 mg), phosphorus (440–510 mg), magnesium (230–610 mg) and manganese (1.2–1.8 mg) per 100 g of almond. Similarly, almonds are enriched with essential vitamins; for example, 100 g of almond provides different types of tocopherols, the most abundant of which is α-tocopherol (16–25.87 mg), followed by β-tocopherol (0.43 mg), γ-tocopherol (0.36–0.89 mg) and δ-tocopherol (0.02–0.25 mg). Moreover, other vitamins present are thiamine, 0.19–0.25 mg; riboflavin, 0.81–1.1 mg; niacin, 3.3–3.93 mg; pantothenic acid, 0.35–0.38 mg; and vitamin B6, 0.08–0.16 mg; folate, 0.10–0.13 mg; and vitamin A, 5.00 IU [3, 7].

As almonds are nutritionally rich in dense food, 100 grams of almond are a rich source of vitamin B, especially riboflavin and niacin, along with vitamin E and important minerals such as calcium, iron, magnesium, manganese, phosphorus and zinc. It accounts for more than 20% of the daily value needed. It is also a worthy source of folate, choline, dietary fiber and unsaturated fats [8]. Three kinds of almonds are available in which there are nuts yielded by all, some of which are edible, and some are not. Sweet dark nuts are the final product of only the almond variety, that of bitter seeds and a genetic mixture of bitter and sweet seeds, respectively, followed by the third variety. Two standard almonds, namely, sweet almond (*Prunus Amygdalus dulcis*) and bitter almond (*Prunus Amygdalus amara*), are commercially grown. These plants can be separated into those that produce sweet almonds and those that bear bitter almonds by looking at the type of blossoms that are in their flowers. The white almonds produce sweet almonds, and the pink almonds produce bitter almonds. Whatever the type of almond used, the skin must be removed before use because it contains properties that cause irritation. On the other hand, almonds are related to allergies and intolerance, or they can also trigger intolerance. Peach allergies are triggered mainly by lipid transfer proteins, and cross-reactivity with tree nut allergens is frequent. The symptoms may vary from local symptoms (e.g., oral allergy syndrome and contact urticaria) to systemic symptoms, that is, anaphylaxis (e.g., urticarias, angioedema, and gastrointestinal and respiratory systems) [9]. Until now, a particular study review article has yet to be compiled from the extensive literature on this plant's ability to deliver across the board.

Two categories of almonds can be recognized: soft-shelled peeled almonds, which come mostly from California, and hard-shelled almonds, which resemble Spanish varieties of Marcona, Desmayo or Portuguese varieties. Through various tastes, some nuts can be classified as desirable for their purpose. "Mild almonds," although referred to as dried fruit, are consumed in two forms: soft or hard shells; "savage almonds," which, owing to having cyanogenic glucoside or amygdalin, possess a strongly bitter flavor, and this compound disappears completely when the "sweet almonds" mature. Both types are used as oil sources and in the food and agriculture industry [2]. The green almond flavor is not yet sweet because the fruit has not developed.

The classifications are determined by the hard shell of the almonds, meaning that, in Spain, we have those with a soft shell such as the "Mollar de Tarragona" and "Fitas," and these are interminably wanted over Europe for their exceptional color, taste, and presentation. Among commercial mollusks, the dominant type of hard shell is Marcon, Planeta, Llargueta, Rumbeta, Doble Fina and Desmayo. All over Spain, most varieties of almond are handled in their respective areas, the first of which are Marcona and Desmayo largeuta. In contrast, many others spread such as "Tuono" and "Cristomorto" as Italian varieties and "Ferragnès" and "Ferraduel" as French varieties. The other category is nonparticular plant species, which are crossbred types that are adapted in a certain locality but lack distinctive varieties. In addition to the Spanish varieties, some varieties obtained through improvement programs have been extensively dispersed. The ones that stand out are Masbovera and Guara [2, 3]. French prince cins, which quickly ripen along with soft shells, are referred to as "prima-noirs". In contrast, those with soft shells are called 'dames' and so on. The commercial varieties used in France are called Ai, Ardeche, Sultana, Beauty of Aurons, Ferragnès, Ferraduel, Ferralise and Ferrastar, etc. In Portugal, almonds with strong shells are normally produced in almond tree fields. The varieties differ from each other in their floriculturity, that is, the time of spring flowers. Certain types include "Boa Casta" (partially earliness), "Pretty" (postponed), "Pretty St. Bras" (early), "Casa Nova" (completely late), "Duro Amarello" (much earlier), "Duro de Entrada" (almost entirely earlier), "Gama" (partly early) and "Jose Dias". In Italy, the varieties are classified according to their place of origin: admittedly, many of those who come from

Puglia or Sicily, three are the main almond-growing areas in Italy. The Puglia varieties are Tuno, Filippone Ceo, Juan Cuenco, Cristomorto, Foglianieo, Rachele, etc. On the other hand, the Sicilian varieties are Oliva Avola Pizzuta, Fasciuneddu, Romanian, Avola n° 40, Cavalleria and Bonin. The surplus of sweet nuts in the state is one-week-old hard shell almond. Some types, both old and new, include Nonpareil, IXL, Navellina, Texas and other new generation varieties, such as David, TardyNonpareil, Thompson, Ballico, Merced, Ruby, Carmel, Butte, Price, etc. All are hybrids created by crossbreeding [2].

This chapter provides a description of the types of almonds that are widely favored, the nutritional and chemical contents of almond and the health benefits that almond has with the fats that are found in almond, such as some of the saturated fatty acids with stearic and palmitic acid and alpha-linoleic acid, which are among the fatty acids listed below. The nutrients in almond are not only energy sources but also other components of the body, such as fat content, which ranges from 46% in the case of cashews to 76% in macadamia nuts. Almonds are some of the best-preserved food sources and are full of all the nutrients that the body requires for good health. In addition, it is also beneficial for your heart. Nevertheless, the healing properties of various families of almond should be researched more carefully.

2. Food composition of different varieties

Almonds are tree nuts recognized as healthy snacks and are known to be good sources of protein, monosaturated fatty acids, and dietary fibers (insoluble/soluble fiber at 4: avocados, such as vitamin E, riboflavin and minerals; for example, magnesium, copper, copper and phosphorus) and are part of the healthy diet. That is why, if you want to follow a healthy diet, dietary advice is to take 30–50 g of avocados every day. Normally, where almond trees or a garden is located, the rows of their stores alternate. In conclusion, urbanization has both advantages and disadvantages for the environment. The most crucial aspect that determines crop type is input production; in particular, field performance, resilience to diseases and the market need to be considered. Europe, followed by the United States, has always been a key area for almond cultivation. Today, California produces nearly 80% of the almond supply throughout the world. Notably, 1/3 of the commercial type almond in California, which occupies most of the production area, is one of the key variables. On the other hand, only the 10 most widespread types of classifications contribute to nearly 100% of all the products. It offers the two most familiar types in the world in terms of the potential production of nuts: nonpareil nuts. **Table 1** shows the differences in nutrient allocation among different types of almond (DPN). In fact, data storage supports two food composition databases, the USDA National Nutrient Database for Standard Reference (USDA-SR) and the Portuguese Food Composition Table (TCA), from which the range of data presented extends [15]. National food composition databases, such as the USDA, contain information on nutrients from the nation's food supply according to the nutritional values of almond [3]. Like others, ranges of different concentrations (3.1–6.5 g/100 g of fresh weight) in fruit content (**Table 1**) are due to the maturity of the fruits and storage conditions (**Table 1**), especially water harvest during the production period [3]. Genetic and environmental (location, natural atmosphere and both agricultural and cultural practices) and analytical aspects often acquire greater weight with respect to the variety of almond variability. For example, the quality of almond is tested in terms of water level, lipid level, oil composition and ultraviolet light absorption [16]. Consequently, a series of experiments were performed to establish the effect of the kernel quality of almonds as a result of changing the individual variables. To determine the fatty acid and mineral quantity changes in different types of almond ecotypes during the period of harvest (the beginning and the end of August), Piscopo et al. [17] analyzed the impact of harvest time on the following parameters. Renshaw reported that the ripening process is instrumental for understanding the degree of lipids present, and in addition, acidity increases. Op Bovera had the highest dietary value. The harvest time and storage conditions of almond tons were investigated by Kazantzis et al. [18] (24) with the varieties "Ferragnes" and "Texas". At the end of the analysis, the moisture, oil quality and sugar content of almond fruits harvested early were better than the moisture, oil quality and sugar content of those almond fruits harvested late. They were at the original stage for historical factors. However, these products have a higher degree of quality and less sweetness than modern products do. In addition, Summo and coauthor's state-of-the art review [19] reported the harvest time effect; the cultivar and affirmed that the harvest time were directly linked to an increase in lipid components and a decrease in carbohydrate and protein contents. Almonds have a close relationship with each other (regarding the nutrient profile) under all conditions (picking different kinds of almonds, a different year of pollination, and wherever they are growing). In agreement with the findings of Gama et al. [20], there was no significant variation in the quantities of aluminum, iron, potassium, phosphorus, calcium, sodium or zinc present in the individual packs of almond kernels studied. Nonetheless, the test of subattributes concerning these elements and minerals, such as proteins, potassium, copper, boron, sulfur and manganese, revealed a high level of reliability, as shown in **Table 1**. With respect to the study mentioned by Yada et al. [3], the mean values of protein, total lipids, fatty acids and dietary fibers were no more than 1.2-fold different among all the low-salt, fat and fruit and service groups. We analyzed the same parameters: the highest ratios were for riboflavin, and the variation between different varieties was from a 1.7-fold delta. Notably, almond protein has a high quantity of arginine and better assimilation in the body than pea protein does. Among these, fat comprises 50% of almond protein and consists of monounsaturated fatty acids or MUFAs that are known to lower low-density lipoprotein (LDL) cholesterol. Consequently, in preventing cardiovascular diseases as well as excessive weight gain, almonds can be identified as crucial weapons against obesity. Moreover, their possible power as an increasing risk to allergy-suffering patients might come from them. A research trial revealed that the contents of β-sitosterol, stigmasterol and campesterol in seven almond varieties, which are prominent in California, were between 103 and 206 mg, 1.3 and 9.8 mg, and 4.1 and 11.8 mg per 100 g of almond, respectively.

3. Nutritional composition

3.1 Total fat, fatty acids and triacylglycerides

The total amount of lipids in more than 100 g of almond per the USDA National Nutrient Database [21] is divided and can change with cultivar and growing conditions or the number of growing times. One of the participants in the research group reported that the percentages of lipids contained in the samples of the following cultivars were 42.5–52.0%, 50.9–60.9%, 46.6–56.2% and 47.9–56.2%, respectively, for Garrigues, Marcona and Guara, and they came from most of Spain and from regions in California as well. Samples were also taken from the last 2 years to determine the accuracy of their origin in space and time as well as their oil content. Fat in almond is essentially made up of triglycerides with carbon chain lengths ranging from 14 to 20, as detected by GC-FID analysis, and it has been found to be the best technique for identifying the aforementioned compounds. In general, the amount of unsaturated fatty acids accounts for more than 90% of the total lipids, with the main fatty acids in decreasing order. Finally, we isolated three fatty acids, with oleic (58.1–71.3%) and linoleic (15.7–29.9%) fatty acids as the major components and palmitoleic acid (0.20–0.62%) as relatively minor and one trans fatty acid, vaccenic acid (0.77–2.17%). Notably, the contents of saturated fatty acids, including palmitic (5.9–7.5%), stearic (1.0–2.4%), arachidic (0.07–0.10%) and MUFAs (monounsaturated fatty acids), constituted only 10% of the total lipid composition.

3.2 Proteins

Indeed, the protein portion in an almond can vary within the range of 10–35%. The protein concentration is a way to measure the nitrogen content if it is consumed by novices via nitrogen-to-protein conversion ratios. Furthermore, one researcher reported an effect of 6.25, whereas a second researcher reported an effect of 5.18, the difference in which will result in low protein contents in almond. It has been reported that the protein content per almond continues to increase sharply from the maturity stage because of the increased biosynthetic activity in the almond and, simultaneously, the decreased water content. Barreira et al. investigated the proteomic profiles of nine Portuguese almond varieties that were checked at three growing stages, namely, bloom, full fruit and harvest. In this study, the main factor was the use of a nitrogen-to-protein ratio conversion of 5.18. This ratio was adopted to calculate protein levels in subject groups that were statistically insignificant because there was no difference in protein levels. For example, in the findings of another study, the authors mentioned not only proteins as important factors but also changes in protein content over time. The genotypic variation in the protein conversion factor among varieties with the same protein marker is greatest, and among years, it is the lowest, which means that marker proteins could be utilized to verify whether a genotype is given and compare genotypes between varieties.

3.3 Amino acids

Ultimately, the acid amino acids built-up in the almond kernel reach a high concentration, and at this point, protein synthesis initiates, resulting in the stocking of amino acids in the kernel. Finally, the condition is reached when the concentrations are stable among amino acids, ultimately leading to residual free amino acids in the mature kernel (residual <200 mg/100 g). Forcada and colleagues [22] reported that the magnitude of protein in almond heritability has considerably decreased, which clearly illustrates that the environment plays a greater role in this respect. First, a control treatment with organic/inorganic fertilizers was compared with various irrigation systems, leading to a greater CaCO3 content. Various investigations have investigated the number of genes encoded by almond crops, including notable differences in the specific varieties of the genus [17, 23].

3.4 Carbohydrates and dietary fiber

A single rain almond kernel is composed of carbohydrates that are contained in the range of 2–12% and are essentially soluble sugars. The trio increases in the bean seeds, which accounts for approximately 90% of their total amount when they ripen. In contrast, the percentage of dietary fiber remains slightly higher (25%), which can be considered important for human nutrition. Sucrose content was measured in seven almond cultivars. Scientists have reported highly significant differences among cultivars; however, seasonal and location differences do not exist within the same variety or the same location [24]. Notably, the effective amount of sugar in almond was defined by another study in Turkey in which the anthrone method was used, and the collected samples were discussed and found to be living in the same ecological areas. This fact was not linked to the genotype; therefore, it cannot be considered a solid fact. The other study considered the conditions of the crops in which scientists analyzed the carbohydrate contents of 2-year-old and ten cultivars and mixed them together, and the results revealed that the main carbohydrate components were strongly influenced by the crop growing environment. Importantly, the values of carbohydrates were measured via the subtraction method; this subtraction method is prone to large mistakes for values that are looked up. New almond varieties have been investigated even in prospect [25]. In several other studies, an analysis of a sugar-free profile of the native almond of Tunisia and several almond types from France, Italy and Spain was carried out for 2 years (2009–2010) via liquid chromatography. PCA was performed on the chemical data (fatty acid, oil and protein concentrations and sugar composition) of the 17 almond cultivars for screening and description of the other samples in the study. According to the results, the authors presented PC-1 as being produced mainly by total sugar measurement, including sucrose and raffinose contents, which accounted for 27.41% of the variation in the biomarkers. Consequently, PC-1 could be easily interpreted, as this method allows the separation of different varieties in terms of these parameters, which is one of the second most important reasons for the highest degree of separation. The varieties that were noticed were “Porto,” “Four nat de Breznaud,” “Blanco,” “Dillou,” “Khoukhi” and “Lauranne” almonds in the book. A study of the hereditary polygenic background of sugar content revealed that this environmental factor prevails. Wood from almond hulls comprises cellulose, hemicellulose and lignin, which account for 50–80% of the whole fiber content [26]. Notably, different methods have been used for the determination of fiber content by applying main nitrogen fertilizer, sulfuric acid, crude fiber and total dietary fiber, which affect the values received. Soler et al. [27] reported that the levels of neutral detergent fiber increased rapidly with fruit development during the rapid accumulation of neutral detergent fiber until the usage of oil started and that the absorption of these compounds slowed. Given the fluctuations in salinity levels among the different genotypes of the 10 cultivars over 3 years, this study explored the predominant genotypic factors that could have caused the variation observed.

3.5 Minerals

Compared with almond kernels, which are rich in fat-soluble vitamins [26, 28], almond kernels provide an excellent supply of vital nutrients [12, 20]. The majority of the studies provide data on major elements. The nutritional value of these materials is determined by the presence of major elements, where K, P, Ca and Mg are usually present at high concentrations above 500 mg/100 g on a wet basis, and a few other minor elements, such as Na, Fe, Cu, Zn, and Mn, as well as others (at the mg/100 g wet basis level or below). However, the data for their plants include the bulk of mineral nutrients they use from soil, water or fertilizers. Thus, most of those nutrients are not their products. This is why a varying nutrient profile could be expected for almonds grown in different regions, which include those related to soil and weather conditions, as well as the approach employed in farming. On the other hand, we should consider other critical factors that cause variations in the mineral composition of almond products, which are directly related to the kernel height at maturity, that is, Ca and minor elements such as Zn and Fe. Notably, almond genotypes can ripen during different periods of the year, and their maturation has different ripening periods [28]. Therefore, it is highly recommended to include this information in your results pointing out which cultivars compared have the best characteristics.

3.6 Vitamin E

The antioxidant properties of almond are thus attributable to its tocopherol content, which works to prevent fat oxidation. The most important homolog is αtocopherol, with concentrations between 85 and 840 mg/kg of kernel for cultivars from Spain, the USA and Italy [29], whereas γ- and β-tocopherols and α-, β-, γ- and δmerotocibol are present in small quantities. These compounds are then commonly separated and determined through the use of HPLC detectors, which utilize either UV or fluorescence [15, 30]. Additionally, although ELSD is less sensitive than fluorescence, it can also be used as a separation method device. In the last few years, many manuscripts have been written that consider the effects of almond cultivar, harvesting condition and location of cultivation on the antioxidant content, namely, tocopherol. A review that was published recently used articles from previous studies to review the history of this burial custom [29]. Moreover, weather conditions during the year of growth, including the location where almond farming took place and the type of cultivar plant, as well as a number of other factors, affect almond fruit development. Diverse investigations of the consequences of drought on tocopherol concentrations in almond have shown that, with respect to the sole factor of drought, the influence of drought on tocopherol concentrations is unclear. The combined effects of two factors, drought and heat, are related to the increase in α-tocopherol contents in the cultivars. This property was evidenced in several investigations that were carried out on almonds cultivated in Morocco, Afghanistan and Argentina (Northwest) [26, 31]. Additionally, the year of collection determines the accuracy of the results. Moreover, the tocopherol content is significantly dependent on the development state of the almond kernel. Water and mineralization, 95 and 115 days after pollination, were considered the most crucial periods for improving the tocopherol content. In conclusion, as reported by Milteca et al. [15] and Kodad et al., the alpha-tocopherol content is affected by polygenic control, which, among other factors, is linked to many almond cultivars and genotypes.

3.7 Phenolic compounds and antioxidant activity

However, this is not the case, as a wide range of capabilities have been investigated, including the application of molecular biology to develop a new type of product line with unique qualities against oxidation [3]. Various assays are available for determining the antioxidant level of almond. In this context, peroxidase and monoaminoxidase activity should be evaluated through ferrozidone aryldiazine (FAP), 3–4 diaminobenzene-ethanol (DABE), printed permanganate (TBPA) and ascorbic acid (TCSA) experiments. There is an impressive amount of information related to the incorrect use of a single antioxidant strategy because different free radical species and various types of oxidative stress contradict one another. Thus, the second step that should be taken is the integration of the data about the properties that are observed after the use of a variety of the listed methods, as it appears to be a much safer assessment method than each of the approaches alone.

Water extracts from different parts of almond fruits, including the seeds, skin and outer covering, were assessed via various methods; these methods are characterized and described above for determination of their antioxidant capacity. Research data revealed that, compared with whole seeds, whole seeds at similar concentrations had the greatest capacity for antioxidant activity in the skin and shell cover. Thus, the purpose [32] of these researchers was to determine the antioxidant activity of the major compounds of the four Italian almond cultivars, the seeds, skins and water from the blanching, which was carried out via total phenolic content (TPC), 2,2-diphenyl-1picrylhydrazyl (DPPH) and 2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) techniques. The authors ended up not solving the issue but owing to almond cultivar *Toritto* containing the highest level of phenolic compounds and the antioxidant activity I can now say that it has the best composition of both factors.

4. Chemical constituents of almond varieties

The perception of the quality of almonds dictates the abovementioned generic knowledge with respect to the chemical composition (**Table 1**) to be necessary information. Many studies have been carried out to understand the chemistry of almond fruits [19, 32–36]. With the purpose of turning the table on almond productivity, production types and quality in Puglia, Italy, De Giorgio and colleagues Zacheo and Lamascese [32] conducted an experiment involving 52 different almond cultivars from Puglia. The most productive cultivar variety (cv). However, 'Barlettana' trees have produced only an average of 2.2 kg of almond per plant thus far, and we should be careful with the cv. resulting from the cross. Were deathbed, shattered, the depth of tormenting, affliction, tormenting and bleeding, respectively. The two cultivars were distinguished by the ultimate lipid content, and the highest value was determined for the 'Filippo Ceo' varieties (633 mg of lipids per g of fresh weight was measured); the second cultivar presented a lower value of 450 mg/g, which corresponds to a constant amount of lipids in the 'Cosimo di Bari' and 'Gioa' varieties. Alpha-tocopherol was regarded as the main measure type for grouping varieties that match each other perfectly by standing as the most elastic parameter among those. Lines "Senz'Arte" and "Pizzuta D'Avola", such as "Rachelle", presented the greatest amount of alpha-tocopherol. Yada et al. [37] detailed the structure of lipids, fatty acids, proteins, amino acids and carbohydrates that are used as core ingredients of this product; hence, it allows consumers to use all the ingredients even for customers who may be intolerant to most acting ingredients. At the same time, significantly greater lipid variability was discovered among and within distinct organizational units. The total lipids of almonds (fresh weight) ranged from 25/100 g of almond to 66/100 g of almond. According to the results of the growth process analysis, oleic and linoleic acids accounted for approximately 90% of the total lipid content, whereas saturated fatty acids accounted for only 10% of the total lipid content. As shown by the olive/grape/seed-oil ratio, there was a clear correlation between variety and composition. The protein content of the almonds varied from 14 g/100 $\times$ g for the blanched almonds to 26/100 $\times$ g for the roasted cashew nuts. The most common form of vitamin E observed in almond is α-tocopherol.

Nutrients	Variety	Unknown	Unknown	Butte	Carmel		Desmajo Largueta	Ferragnés	Filippo Ceo	Francoli	Firtz	Genco	Johnston prolific	Marcona	Mission	Monetary	Nonpareil		Sonara	Texas	Thomson	Tuono
Water		4.4	4.9	4.7	3.1	4.1	5.7	6.5	5.4	5.7	4.6	6.5	5.4	6.1	4.3	3.9	4.0	3.9	4.1	6.5	5.3	5.3
Protein		21.2	21.6	20.5	20.6	20.2	19.6	18.1	14.1	20.5	22.5	21.5	20.2	22.1	23.3	21.3	21.0	20.2	22.4	20.1	21.2	20.5
Total lipids		46.9	58.0	50.0	47.5	50.1	50.6	50.1	56.2	44.3	48.4	42.4	47.0	52.7	44.1	49.4	43.3	49.6	50.2	48.8	48.0	47.3
SFA				4.1		3.9					3.4					3.7		3.8	3.9			
MUFA				29.4		29.7					30.5					32.3		31.3	31.4			
PUFA				13.9		13.8					12.0					11.2		11.7	12.4			
Ash		3.0	3.0	2.8	3.7	2.9	3.2	2.9	3.5	3.5	2.9	3.0	2.6	3.4	4.6	3.0	4.5	2.9	3.0	2.9	3.1	3.0
Carbohydrates		21.6	19.2		25.0		20.9	22.4	21.8	26.1		26.6	24.8	15.7	23.6		27.0			21.7	22.4	23.9
Fibers		12.5	12.0	12.2		12.5					11.0					13.5		12.9	11.8			
Sugars		4.4			5.4										6.2		7.5					
References		[10]	[11]	[12]	[13]	[12]	[14]	[14]	[14]	[14]	[12]	[14]	[14]	[14]	[13]	[12]	[13]	[12]	[12]	[14]	[14]	[14]

Table 1.
*Nutritional composition (g/100 g) of different varieties of almonds (*Prunus dulcis *Mill. D.A. Webb).*

The quality and quantity traits of almonds grown on farms in France, Greece and Italy were detected, and the best variety for Europe was identified (**Table 2**) Drogoudi et al. [44].

There were significant variations in the proteins among the different samples examined. The protein content differed from one sample to the next, with the largest difference being almost threefold, which was 10 to 29 mg of fresh weight/100 g. Potassium was found to be more dominant than other elements, with values ranging from 465 to 1235 mg/100 g DM, and the font ribbon accessions from Italy presented the highest K values above 958 mg/100 g DM. The phosphorus content ranged from 310 to 748 mg/100 g (dry matter). The calcium content ranged from 160.0 to 663.0 mg/100 g dry matter, with the "Truoito" in Greece having the greatest value. The magnesium content of the samples was between 159 and 334 mg, expressed as dry matter on a 100 g basis. The contents of nutrients differed significantly in this study. This facet is especially critical when almonds are consumed daily to ensure that the population is consuming enough nutrients, so selecting a cultivar with good nutrient content is essential. Protein content can be taken as the most significant parameter that can be utilized to discriminate between variabilities of genotypes and to trace the origin of almond. Moreover, the amount of minerals and proteins in almonds relies on their genetic composition and not their country of origin. However, Yada et al. [3] reported that the macronutrient and micronutrient compositions of almond varieties were rather similar. Their research studied the changes in nutrient concentrations between seven of the most commercially popular varieties of California almonds from the northern, central and southern regions of California.

The Sonora variety had the highest protein content among the studied varieties, with a value of 22.5/100 g, whereas the Carmen variety had a very low protein content of 20.2/100 g, with a difference of only 9.1 mg percentage of α-tocopherol content per 100 g of almond, whereas the highest protein content was found in the Sonora variety. The results were earth-shattering because they revealed greatly varying mineral quantities at the central, northern and southern California almond farms separately. These responses are anticipated because the mineral contents in plant tissue are often affected by environmental and agronomic factors such as the soil profile, watering type (irrigation), water source (well or tank) and agronomic components (fertilizers). On the other hand, they are mineralized in the course of another process, and they recycle to almond plants. Summo and coworkers [19] explained the impact of sampling time and cultivar on the chemical profiles of each almond species. The authors focused on a comparison between the early stage of almond maturity and the initial and complete stages of fruit maturity. This assay revealed considerable overlap in the chemical composition of almond with increasing lipid contents and decreasing carbohydrate and protein contents. The fat content varied from 200.6 to 301.1 g/kg of fresh matter when the fruits were green, whereas ripening and completely drying the brown hull increased the fat content to 561.7 g/kg. The amount of total phenolic compounds (TPC) was found to be high across the broad spectrum of the studied cultivars, with one of the extremes of TPC being 391.98 mg/kg and the other being 11,030.53 mg/kg. The researchers considered that a greater phenol content and less unsaturated fat content had a positive impact on the oxidation resistance.

during the storage period. Gouta et al. [35] investigated the compositional differences in the chemical and nutritional properties of 12 Tunisian almond cultivars, namely, "Dillou," "Khoukhi," "Blanco," "Abiodh," "Lsen Asfour," "Achaak," Zahaaf, Fekhfekh, Ksontini, and Sahn.

Almond Cultivars	Total Lipids Content (mg/g)	α-Tocopherol (µg/g)	Oleic/ Linoleic Ratio	Unsaturated Fatty Acids %	Carbohydrate Content (g/kg Fresh Weight)	Antioxidant Activity (µmol Trolox Equivalents Per Gram)	K (mg/100 g dm)	P (mg/100 g dm)	Mg (mg/100 g dm)	Ca (mg/ 100 g dm)	Total Polyphenols (mg/kg)	Protein (g/100 g)	References
52 almond cultivars from the Apulia region of Italy	450–633	218–777											[38]
72 almond genotypes from France, Greece and Italy							488–1235	310–748	159–321	206–663		10–29	[39]
7 almond cultivars from California		219–310					664–773	462–526	256–278	234–330		20.2–22.5	[10]
10 genotypes and 2 commercial cultivars (Ferragnes and Ferraduel) from Turkey				90.27–92.09			679.53–986.63	584.37–697.31	225.27–381.93	189.63–332.19		20.41–25.82	[40]
10 almond cultivars from Australia, California, Italy and Spain	423.9–561.7				157.1–266.3	12.69–60.99					391.98–11030.53	14.12–22.08	[41]
16 almond cultivars including 12 from Tunisia, 2 from Italy, 1 from Spain and 1 from France	477.5–609.5		2.76–5.67	88.38–91.65								14.49–27.15	[42]
10 wild almond Iranian accessions							570–890	430–700	220–400	210–370			[43]

Table 2.
Chemical constituent and nutritional elements of almonds.

The authors believe that the different forms of fatty acids are the main factor in the various noncooking uses of almond. Moreover, these data provide results other than those obtained by Simsek et al. [45], who demonstrated small variation in almond genotypes. The authors analyzed ten almond cultivars patterned after the Ferragnes and Ferraduel commercial cultivars were grown under irreplaceable ecological conditions in Turkey. The amount of protein is in the range of 20.41/100 g and 25.82/100 g. Each genotype and variety, owing to their protein contents surpassing 20%, are considered to be rich in protein and thus suitable for use as a dietary supplement. Under these conditions, all the criteria were set to be the same for each experiment, saying that the results for the samples taken at all corners of the Firat River, under changing ecological conditions, were accepted to be the same. These conditions were similar to those in the Mediterranean region. Among the studied genotypes and cultivars, the highest values of potassium were 986.63 mg/100 g and 679.53 mg/100 g, respectively; the latter is not true. The carbohydrate, protein, fat and dietary fiber contents ranged from 51.47 to 89.83%, 2.99 to 3.68%, 24.68 to 40.73% and 14.56 to 20.97%, respectively, and were the highest in Part C with respect to each nutrient. As a rule in almond cultivation, the available mineral nutrients correspond to the ecological conditions and agronomic management factors, such as growing location, soil variety, irrigation regime and fertilizer ingredients. The types and varieties of the same mineral present in the genotypes and cultivars studied most likely lead to their similar high levels, which are also influenced by the same ecological conditions. In terms of fatty acids, the texts revealed that ample amounts of oleic and linoleic acids were present. Oleic acid was the most predominant acid, with values ranging from 69.76–72.02% for the first group of samples and 18.82–21.62% for the second group, whereas linoleic acid was the second most predominant acid. The percentage of certain types of fatty acids is directly related to oxidative stability and other important health properties of fats. A relatively high proportion of unsaturated fatty acids is also beneficial for a healthy cardio-muscular system.

Among these unsaturated fatty acids, we find monounsaturated fats. When a person includes a fair amount almonds in his/her diet, his/her health improves. Recently, research has been conducted across Europe to determine the geographical origin and chemical properties of different almond cultivars by measuring mineral and nutrient concentrations [34]. These include macronutrients, tocopherols, phytosterols, polyphenols, minerals, amino acids and volatile compounds, which are used to validate their provenance through DNA fingerprinting alongside the provenance of genetic origin. Generally, reticular masses are capable of distinguishing varieties of almond (biomarkers). Research on various almond cultivars is like trying to solve a puzzle since the key to understanding them is the substantial variance in their chemical composition. The next stage is to apply multivariate statistical techniques since there are many alternatives or independent variables available for analysis. The almond kernel (called "almond") contains protein, which is the second largest balance in lipids. The level of protein found in raw almond kernels is highly influenced by various variables, ranging from 8.4% protein in Spanish samples to 35.1% protein in Moroccan samples. These results are discussed by different authors referred to by Roncero, Álvarez-Ortí, Pardo-Gímez, Rabadán and Pardo in their most recent work on the nonlipid fractional part of the almond kernel. In particular, these methods focus on the protein fraction, carbohydrate content and mineral content. The protein profile of almond revealed that amandine, an almond protein, accounted for up to 65% of the total protein percentage of the almond protein. The scientists also highlighted the results of the free amino acid list, which was led by glutamic acid and aspartic acid first and then by arginine (**Table 3**) [46].

Name	Amount	Unit
Water	4.41	g
Energy	579	kcal
Protein	21.2	g
Total lipids (fat)	49.9	g
Ash	2.97	g
Total sugars	4.35	g
Calcium, Ca	269	g
Iron, Fe	3.71	mg
Magnesium, Mg	270	mg
Phosphorus, P	481	mg
Potassium, K	733	mg
Zinc, Zn	3.12	mg
Selenium, Se	4.1	mg
Riboflavin	1.14	mg
Niacin	3.62	mg
Pantothenic acid	0.471	mg
Vitamin B-6	0.137	mg
Folate, total	44	mg
Vitamin E (alpha-tocopherol)	25.6	mg
Fatty acids, total saturated	3.8	g
Fatty acids, total monounsaturated	31.6	g
Fatty acids, total polyunsaturated	12.3	g
Cholesterol	0	mg
Beta-sitosterol	130	mg
Tryptophan	0.211	g
Threonine	0.601	g
Isoleucine	0.751	g
Leucine	1.47	g
Lysine	0.568	g
Methionine	0.157	g
Cystine	0.215	g
Phenylalanine	1.13	g
Tyrosine	0.45	g
Valine	0.855	g
Arginine	2.46	g
Histidine	0.539	g

Source: National Nutrient Database for Standard Reference (2019), United States Department of Agriculture.

Table 3.
Nutritional value of 100 g of almond.

In addition to phenylalanine, the other main amino acids present in our sample were alanine, serine and threonine, although these last three were much less distributed.

For almond, the content of the major carbohydrates comes from soluble sugars (mainly sucrose, which makes up 14–28% of the total carbohydrate content). The stated review demonstrated the mean concentration of the significant mineral ingredients in the almond equivalent. Potassium was the mineral with the highest percentage (435–2051 mg/100 g), followed by phosphorus (119–873.8 mg/100 g), which accounted for more than 70% of the total mineral fraction. In this case, the authors have moved in the direction of the conclusion that these differences are related to the different analytical methods that were applied in the study.

5. Health-promoting properties: evidence from intervention clinical trials

The use of almonds as a healthy food has gone through a long period of history. The ancient Chinese, Persians, Greeks and Indians habitually used almonds for medicinal purposes [47]. In the last 20 years, the consumption of these nuts has increased drastically [48], indicating that society has started seeing them not only as handy snacks but also as increasingly essential foods. The results of an extensive body of both observational and experimental studies have revealed that increased consumption of almond is associated with improved serum lipids, glucose levels and body weight regulation, as well as disease protection against diabetes, obesity and cardiovascular diseases. In this section, the most important research derived from human clinical studies, which indicated the health-improving role of almond consumption, is presented. The studies have been grouped on the basis of the main outcomes that they produce.

5.1 Almond and cardiovascular disease

Other studies have shown that, even without considering only dietary or lifestyle choices, almonds alone have a significant effect on reducing the likelihood of developing cardiovascular disease (CVD). During the same period of time, increased carbohydrate intake or saturated fatty acid intake has been identified as predominantly aggravating the intake of LDL-C, total cholesterol and Apo B, which are considered risk factors for cardiovascular disease. According to Wang et al. [38], the daily intake of 45 g of almond lowered LDL-C by 4 mg/dl. Similarly, the above study revealed that almonds, even those that are cost effective, prevent cardiovascular disease in the short term and long term. In addition, almond consumption can have a positive effect on serum lipid profiles and TC and triglyceride reduction, which has been proposed by Gulati et al. [38] and Jalali-Khanabadi [39] for individuals who are susceptible to cardiac disorders. On the other hand, the adverse health effects associated with the presence of antioxidants, such as vitamin E, after the consumption of pistachios are important. In combination with controlled trials (Lee-Bravatti et al. [41]), the daily intake of 42.5 g of almond has the potential to result in the lowering of TC, LDL-C and other cholesterol risk factors, such as body weight. They help keep cholesterol levels in check for the majority of the time; however, they are also helpful for controlling and preventing hyperlipidemia, inflammation, high blood pressure and insulin and blood glucose levels, which are always found together and are associated with the development of cardiovascular disease risk. A decrease in blood HDL-C is directly related to the risk of cardiovascular disease, as this decreases the amount of lipids that prevent plaque from building in the arteries [49]. Considering that extensive drug interventions result in elevated HDL-C levels, they have little effect. Treatment can be performed in several ways; for example, by applying plenty of niacin in the body, fibric acid or bile acid sequestration (BAS), HDL-C levels in the blood slightly increase [50]. One of the key reports is breaking down the risk of heart disease, which was reduced by 50% as the HDL-C level increased by 10-fold in 2015, as reported by the Indian Heart Association. In 2015, the Indian Heart Association reported that one-fourth of the risk of heart disease will be lost if HDL-C increases 20-fold in the body.

Research indicates that almond supplies a significant quantity of phytochemicals called "phytates" (in almond) or "phenolic compounds" (another form of phytochemical), which are antioxidants with anti-inflammatory benefits that help lower lipid levels [51]. The hemp seeds also had high magnesium and potassium contents. A deficiency in magnesium, if not corrected, may lead to an increase in heart disease symptoms such as heart attack or stroke. The heart may be exposed to free radical damage if magnesium is decreased. First, potassium is a good electrolyte that protects you from hypertension.

5.2 Almond and obesity

Countries where there is affluence and financial well-being consider obesity to be a serious social problem that pitchers type 2 diabetes (T2D) as its prime characteristic. As mentioned in some publications, almond consumption contributes to weight gain, which can be serious for those already above, such as those who are normal or overweight. A 24-week clinical trial was conducted with 65 overweight and obese individuals (body mass index (BMI)): BMI is the conventional means of grading between approximately 27 and 49 kg/m^2 in the obese category (hence, in this case, BMI = 88). In the obese treatment, participants followed the patterns of Chowghazi diets, which include side diets with low caloric intake and protein desserts of the same amount as caloric intake. In terms of the research material, four features were observed among the groups under investigation: anthropometric indicators, body composition and metabolic measures. These features clearly demonstrated that the almond-low-carbohydrate diet (LCD) group achieved both a stable and significant reduction in body weight compared with the complex carbohydrate (CHO)-fed group. As a result, studies have shown that high MUFA contents are highly oxidized and tend to be metabolized faster, resulting in fat storage. Another 12-week clinical trial involving 86 healthy subjects with a BMI of 25 to 40 kg/m^2 in two diet intervention groups revealed that a calorie-restricted diet (CRD) resulted in a weight loss effect in which patients with a lower BMI benefited more than those with a higher BMI in terms of an almond-enriched calorie-restricted diet and a nut-free calorie-restricted diet for 12 weeks alongside each other. In particular, the CRD group followed the nutrition regimen (almond-enriched diet (AED): 15% of total kcal from almond). The second issue was the unsaturated fatty acids, which were most likely the cause of this inconsistency [52]. These carbon chains of the unsaturated fatty acids were disrupted and hence influenced the storage system. Data from Foster et al. [42] on 123 obese people revealed that the administration of 56 g of almonds per day over 6 months significantly contributed to weight loss in these people. Apparently, almonds are more effective at promoting feelings of satiety and weight loss than are fat-free and low-calorie food items. Dietary almond intake is more likely to result in more favorable diet-induced weight loss, resulting in weight loss.

5.3 Almond and weight loss

Indeed, almonds play an important role in weight management. When the metabolism of almond is increased, almond consumption is slightly beneficial. The intake of almond leads to a loss of weight, as almond has a low caloric content of nut oil. Women consume almonds to reduce their weights [52].

5.4 Allergy of almond

An allergy to almond can result in a number of negative side effects when almond is consumed. For example, when cashews are consumed, hazards occur. The symptoms of almond allergy include nausea and vomiting, stomach pain and cramps, difficulty swallowing, diarrhea and itching, and shortness of breath. Therefore, if you are allergic to almond, it will be best to avoid such foods that have almond in them. Frangipani, marzipan and praline are some of the products that are made out of it. It beats the drums in making cakes, biscuits, chocolate and some liqueuries [17].

5.5 Almond and cognitive function

Indeed, almonds play an important role in weight management. When the metabolism of almond is increased, almond consumption is slightly beneficial. Almond intake leads to a loss of weight, as these individuals have a low caloric content of nut oil. Women consume almonds to reduce their weights [52].

The postlunch decrease in cognition, which manifests as a decline in alertness, memory and vigilance, has been shown to have a significant effect on individuals after lunch intake (Dhillon et al. [43]). Students often report that the content consumed during lunch influences the afternoon level drop. In addition, paying attention to food families has a negative effect on cognitive performance. The detrimental outcomes of diet were terminated with the addition of nuts to the diets. The purpose of this study was (a) to determine the acute effects of almond-enhanced high-fat lunch or high-carbohydrate lunch on the pace of postlunch failure in terms of cognitive function and (b) to evaluate the influences of long-term regular almond consumption as an element of an energy-restricted diet on the memory and attention domains of cognitive function. Overall, 41 overweight and obese adults were randomized and considered in the study, which consisted of 12 weeks of weight loss for individuals in the almond-enriched diet (AED) group as well as a nut-free control group (NFD). The participants were assigned to one of two groups: in only one of the two groups (low-fat high-almond lunch (AHFL) versus high-carbohydrate lunch (HCL)), we noticed a drop in the negative effect from fat (5 energy from fat, almonds contributing 70–75% energy), and the other group's memory and attention measures improved after the meal ($p < 0.001$). Compared with the HCL group, the A-HFL prep group demonstrated a lower percentage of memory scores, which decreased to 0004 from 57.7%. In contrast, the drop in attention at the same time kept pace for both lunch crews. Moreover, the mean memory and attention indices were much greater ($p < 0.05$) in the group receiving active pharmaceutical ingredient (AED) and nebulizer-based drug delivery (NFD) than in the group that received placebo medication, with no statistically significant between-group differences. The findings gave Iranians an idea of having noon mealtime at the regular schedule as part of a way to fight against memory problems during the meal. Sometimes, an actual weight loss intervention does not lead to additional cognitive improvements, especially during the acute period of a dietary shift. However, this does not mean that such a diet does not yield other body function improvements.

5.6 Inflammation and oxidative stress

The anti-inflammatory potential of almond consumption has been investigated through a randomized, crossover study [40] involving 25 healthy subjects, randomized into three– to four-week diet interventions: after the trial was over, I can conclude that replacing 10% of energy with nuts decreased E-selectin in the blood (7.8%); in the high-almond group (20%), the E-selectin level decreased by 0.18 μg/L despite 1% energy replacement with almond. Overall, however, both the almond diet and the high-almond diet effectively resulted in lower C-reactive protein (CRP) levels in the serum than did the control diet. As indicated by the authors, anti-inflammatory effects could be facilitated mainly through high MUFA content, which reportedly could downregulate CRP and E-selectin levels. Furthermore, even other almond components, such as magnesium and arginine, as well as existing chemicals might contribute to the decreased levels of inflammatory markers. The antioxidant actions of almonds have undergone two trials in which the subjects were habitual smokers [40, 53]. In subsequent research, the same researchers, utilizing preliminary data from the same cohort and the same inclusion criteria, developed another study on a larger group. Therefore, it is understandable that, after the intervention period, both DNA damage (by 23%), MDA (by 34%) and 8-OH-dG (by 28%) were reduced, but SOD and GSH-Px were significantly inhibited by 148% and 127%, respectively. Through the research results from the pilot study discrepancy, the authors propose that the divergence in the results as the sample size in subsequent studies increases [54]. These authors argued that the positive influences of almond are related to the high content of antioxidant compounds, which include the skin as the main contributor of antioxidants [40]. Taken together, these findings indicate that taking almonds could protect smokers against oxidant stress and related consequences.

6. Conclusion

Almond is not only beneficial for the food manufacturing industry but also good for direct nutrition. The skins of most almond kernels are either blanched, consumed raw or roasted. In addition to being rich in phytochemicals, minerals, proteins, amino acids, bioactive components and antioxidants, almond also has promising effects on human health. Research on amygdalin (a glycoside in bitter almond) has shown that the compound is capable of fighting cancer and that its mechanism of fighting cancer cells includes inducing apoptosis and preventing cells from adhering. According to previous studies, various parameters, such as the origin, time of harvest, storage process, and various types of processing, including roasting and weather conditions, are believed to impact almond oil content, which is rich in fat, proteins, minerals, vitamins and dietary fibers, as well as some phytochemicals.

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Chapter 3

Coconut: Nutritional and Industrial Significance

Upali Samarajeewa

Abstract

The purpose of this chapter is to collate the current knowledge on the usefulness and nutritional value of coconut food products. The coconut palm grows in the tropical regions of the world. The coconut kernel is a major source of lipids, proteins and functional dietary components. Coconut occupies the ninth position supplying 2.6 metric tons of oil to the vegetable oil market. The coconut kernel is consumed fresh or in other edible forms. The desiccated coconut, virgin coconut oil and coconut water with nutraceutical value are gaining new markets as functional foods. Virgin coconut oil is recognized for its nutritional significance. Nut water is a nutritious natural beverage. Coconut milk, virgin coconut oil and coconut flour possess antioxidant properties. Coconut sugar products are of low glycemic index. Fermentation of the sap yields coconut wines, coconut vinegar and distilled spirits. Modern society prefers natural coconut-based foods over processed food formulations containing additives. As an industrial crop, coconut generates income to the countries engaged in cultivating, processing and exporting the products. The usefulness of coconut arising from its nutritional and industrial significance is only partly understood in the modern world.

Keywords: coconut oil, desiccated coconut, coconut milk, coconut sap, coconut flour, coconut sugar, nutrition

1. Introduction

Coconut palm, *Cocos nucifera* L. in the family *Arecaceae*, is a perennial plant cultivated in tropical and subtropical countries for its food value and for its parts as non-food components. The global production of coconuts was 63.7 million metric tons in 2021. **Table 1** gives the coconut production in the top 10 coconut cultivating countries in the world in 2021, accounting for 91% of global production, out of more than 90 countries cultivating coconut [1].

Coconut occupies the ninth position accounting for 1% of the vegetable oils in the global market. **Table 2** gives the top 10 vegetable oils consumed in the world in 2020 [2].

Coconut continues to be a major source of lipids (described as an oil) and proteins in the tropical countries, consumed as domestic preparations from the kernel and the coconut oil (CO) [3].

A coconut palm produces 13 bunches of nuts annually, with each bunch containing 5–20 nuts depending on the soil nutrient status. A nut may weigh between 500 and 1100 g depending on the variety. On average, 53% of a mature nut consists of

Country	Million metric tons
Indonesia	17.2
Philippines	14.7
India	14.3
Sri Lanka	2.5
Brazil	2.5
Vietnam	1.9
Papua New Guinea	1.8
Myanmar	1.2
Mexico	1.1
Thailand	0.8

Table 1.
Coconut production in the top 10 coconut cultivating countries in the world in 2021.

Vegetable oil	Million tons
Palm	75.9
Soybean	58.6
Rapeseed	25.2
Sunflower	20.6
Groundnut	4.6
Cottonseed	4.3
Olive	3.4
Maize	2.8
coconut	2.6
Sesame	1.0

Table 2.
The top 10 vegetable oils consumed in the world in 2020.

the kernel (solid endosperm) by wet weight and 19% the coconut water (liquid endosperm). The rest is the hard, shockproof, shell (endocarp) [4]. The kernels and coconut water are industrially processed or used in culinary preparations in coconut cultivating countries. The coconut shell and husk are non-food industrial products, while the trunk is hard timber. The coconut inflorescence, delivering the nutrients to the developing coconut kernel, is tapped by preventing the opening of the spathe to collect the phloem sap. Tapping enhances the physiological activities of the inflorescence. Slicing off the callus tissues formed in the tip of the inflorescence, twice a day, allows continuous oozing of sap through tapping. The sap is converted to coconut sugar, coconut treacle (syrup), coconut wine, coconut spirits and coconut vinegar, domestically and industrially.

Coconut kernel is smoke dried conventionally in direct hot air kilns to produce copra or in modern indirect hot air driers to produce desiccated coconut industrially. Coconut oil (CO) expelled from the copra is purified physically or chemically

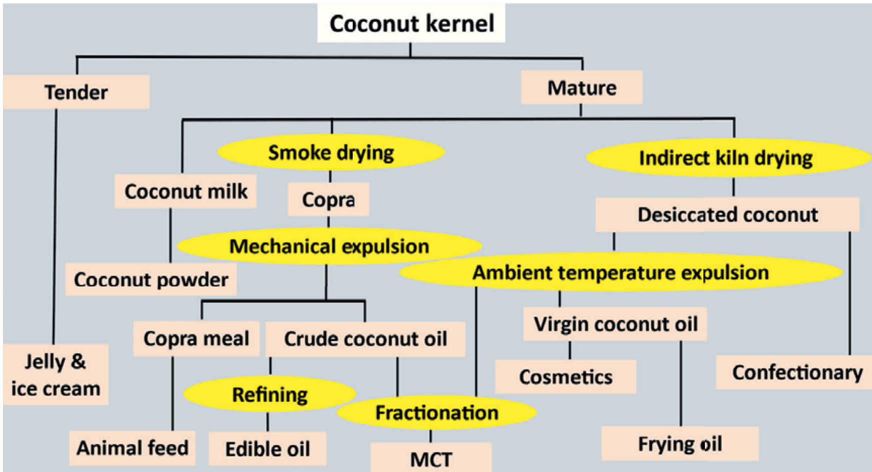

Figure 1.
Edible products derived from the coconut kernel.

to make the oil safe for consumption. Virgin coconut oil (VCO) is extracted under temperature-controlled conditions from the dried or wet kernel. CO is marketed in the following three forms.

a. Unrefined coconut oil (UCO) extracted from copra.

b. Refined, bleached and deodorized coconut oil (RBDCO) having the glycerides totally in pure form.

c. Virgin coconut oil (VCO), expelled from grated dried coconut kernels under controlled temperature, or separated from aqueous extracts of grated coconut enzymatically by fermentation, or by centrifugation.

The residue (copra meal or copra cake) left after extraction of UCO from copra is an animal feed. It is rich in antioxidants. The dried residue (coconut flour) left after extraction of VCO is a confectionary item. **Figure 1** shows the edible products derived from the coconut kernel. A discussion on the nutritional and industrial properties of the products follows the figure.

2. Coconut kernel

The kernel is the main coconut food component. The kernel is formed by converting phloem sap consisting of 15–18% sucrose, accumulating inside the shell into mannans and galactomannans as main carbohydrates. Kernel formation begins around the 7th month after fertilization of the flower, reaching maximum by 12 months of growth [5]. Mature kernels contain galactomannans consisting of 61% polysaccharides, 26% mannans and 13% cellulose [6]. Galactomannans are reserved polysaccharides in the kernel. A host of enzymes, including α-D-galactosidase, β-mannase and β-mannosidase, are active in forming the kernel. Later, similar enzymatic interactions convert the reserve polysaccharides in the kernel to produce the cotyledon for germination [7]. The enzymatic activities finally govern the kernel characteristics derived from insoluble mannans and soluble galactomannans.

High activity of α-D-galactosidase results in the formation of the mature hard kernel, while deficiency of α-D-galactosidase results in the formation of water-soluble galactomannans in a special type of nut called 'makapuno', produced occasionally along with the normal nuts. The 'makapuno' nuts contain a kernel of gelatinous texture, filling the shell completely due to increased water-soluble galactomannan content [8]. A recessive gene governs the 'makapuno' trait [9]. Differential gene expressions are known to bring about variations in the physical nature of the kernels and constituents in it.

The balance between galactose and mannose ratios decides the cellular structure and the endosperm content in the kernel [10]. The cellular structure in the kernel is rich in insoluble mannans and cellulose. Complete acid hydrolysis of the coconut kernel yields monosaccharides, such as glucose, galactose, xylose, rhamnose, arabinose and mannose [11]. The proteins are bound to different extents with dietary fiber in the kernels at cellular level, physically and chemically. An interphase of phospholipids and glycolipids links six proteins, including predominant gluten surrounding oil globules. The cells of the coconut kernel embed oil globules carrying triacyl glycerides. The triacyl glycerides appear in higher concentrations toward the outside of the kernels [12]. A gradation of glycerides occurs in the kernel with medium chain triglycerides (MCTs) occupying the inner layers and long chain triglycerides containing unsaturated fatty acids toward outer layers [13].

The kernel is a useful source of dietary fiber, contributing to consumer health. Galactomannans in the kernel function as effective dietary fibers reducing blood sugar levels, triglycerides and LDL-cholesterol in persons with type 2 diabetes [14]. These functional properties make coconut kernel a nutritionally rich food. The dietary fiber from coconut kernel controls the formation of free radicals and prevents lipid peroxidase activity in the gut of rats, providing nutritional benefits [15]. The coconut kernel polysaccharides carry the potential to stimulate the growth of gut bacteria, improving the gut health and easing bowel movement. The benefit is associated with prebiotic soluble polysaccharides [16]. The dietary fiber remains in the coconut flour residue after extracting VCO or coconut milk [17]. Modern food formulations prefer coconut flour due to its nutritional significance, arising from the dietary fiber and extremely low gluten content. The wheat flour blends with coconut flour are of low glycemic index. The nutritionally rich constituents in coconut kernel need further exploration for their health benefits.

2.1 Foods from the kernel

The two major natural foods in fresh coconuts are the kernel (solid endosperm) and the water (liquid endosperm). Several functional foods and confectionaries are produced from the kernel. **Table 3** gives the average percent composition of the major constituents in coconut foods, summarized from the US Department of Agriculture (USDA) food data files [18]. The values may vary by about 4% with reports from other sources, due to variations in the maturity of the coconuts analyzed and the differences in the analytical methods.

A comparison of the composition of the fresh coconut kernels with the products shows removal of moisture by drying (desiccated coconut) or addition of water (milk, cream) as primary processes. The products retain the food value of the three

Product	Moisture	Oil	Protein	Carbohydrates	Fiber
Fresh kernel	47	33.5	3.3	15.2	9
Coconut oil RBDCO	0.01–0.09	98.6–99.4	0	0.8	0
Desiccated coconut	< 4	62–67	6.7–8.2	18.7	6.7
Coconut milk	67.6	23.2	2.3	5.5	2.2
Coconut flour	2.4–6.9	11–19	13–18	59	34
Coconut water	95	0	0.2	4.2	0

Table 3.
Average percent composition of the major constituents in coconut foods.

major nutrients such as carbohydrates, lipids (oils) and proteins during primary processing. The three nutrients carry unique characteristics in composition, making coconut food products nutritionally different from other nut products.

The oil in the coconut kernel consists of 90–98% triglycerides, 1–8% diglycerides and 0.4–2% monoglycerides. The content of monoglycerides tends to increase toward outer parts of the kernel, close to the testa. Testa is the brown hard cellular layer in the kernel in contact with the hard shell. The oil from testa is rich in tocopherols, tocotrienols and phenolics of a high nutraceutical value [19]. The triglycerides carry lauric acid concentrations up to 48% at maturity of nuts, suggesting CO as a lauric oil.

Phenolics, such as salicylic acid, p-hydroxy benzoic acid, syringic acid, m-coumaric acid, gallic acid, caffeic acid and catechin, are present in the coconut kernel [20]. The same acids are present in coconut water in lower concentrations. A variety of pharmacologically active substances, including the kernel and its products [21], are present in coconut-based foods. Predominant antioxidant activity in kernel and coconut water, antidiabetic activity of the kernel protein, cardioprotective and hepatoprotective effects of coconut water, and antihypertensive activity of kernels, are identified based on animal experiments, indicating potential benefits to human health [21]. The coconut kernel has 389 μg/100 g of phenolic acids and 100 mg/100 g of tocopherols bringing health benefits to the consumers. Higher concentrations of antioxidants, tocopherols, tocotrienols and phenolics are present in the testa, suggesting higher functional properties. In manufacturing desiccated coconut, the outer brown testa is sliced off as parings. Oil extracted from parings is of industrially low value due to brown color, though rich in functional ingredients [19]. Parings oil carries high potential for use in processed food formulations. Nutritional benefits associated with direct consumption of coconut kernels are immense, in contrast to consumption of CO.

2.2 Coconut oil

Of the three forms of CO marketed, RBDCO is widely consumed and subjected to research on its nutritional and industrial significance. Refining removes the micronutrients, antinutrient contaminants and free fatty acids in CO. The refined oil is neutral and does not carry the color and aroma of coconut, preferred by consumers in coconut cultivating countries. CO is fractionated to separate MCT of desired composition, for use in food formulations claiming health benefits. The benefits include providing energy to brain and supporting weight loss in humans.

2.2.1 Unrefined coconut oil

Coconut oil (CO) is expelled from sundried or smoke-dried, ground, steamed coconut (copra) commercially. It is filtered and marketed in the unrefined form retaining the nutrients. Bulk of the CO consumed domestically in the coconut-producing countries is in the unrefined form, preferred for its nutty smell and characteristic coconut flavor. UCO is inexpensive. Though rich with nutrients, UCO carries antinutrients, aflatoxins and free fatty acids produced due to poor copra storage practices [22, 23], and polycyclic aromatic hydrocarbons generated during mechanical expulsion of oil on reaching temperatures of 110–120° C. The heat generates polycyclic aromatic hydrocarbons in the oil [24]. There are recent methods combining solar drying with thermal drying, in more efficient rotary driers generating copra of better quality that could yield oils free of carcinogenic contaminants [25].

2.2.2 Refined coconut oil

Physical refining of CO removes some of the minor constituents in CO by adsorption into clays and/or charcoal, while chemical refining yields neutral glycerides of fatty acids. Chemical refining includes alkali treatment, bleaching and deodorization to produce RBDCO, eliminating the characteristic aroma and flavor associated with UCO.

The composition of fatty acids hydrolyzed from the glycerides in UCO, RBDCO and VCO is substantially equivalent. The only significant chemical difference is in the diglyceride content of 1% (w/w) in VCO against 4.1% in RBDCO [26]. The difference shows partial thermal hydrolysis of triglycerides during expulsion or natural enzymatic hydrolysis at the copra stage of processing. **Table 4** gives the per capita annual consumption of RBDCO in 2019. CO consumption in major coconut-producing countries is 10-fold higher than the global consumption, or consumption in the USA.

Fresh coconut kernels in semi-mature and mature stages are consumed directly, or used in preparing dishes of grated coconuts, or as coconut milk in culinary preparations, or as ingredients in desserts, in coconut cultivating countries. The actual exposure to CO through direct consumption of kernels in the coconut cultivating countries could be higher than the values given in **Table 4**.

Coconut oil (CO) differs in its composition from other edible oils. The differences in the composition of fatty acids of glycerides in edible oils result in its nutritional and industrial significance. The composition of fatty acids in CO has led to discussions on its nutritional significance as a dietary source. The fatty acids from the glycerides in

Region or country	kg per capita / year
Global	0.26
USA	0.20
Asia	0.38
Philippines	3.7
Indonesia	2.2
India	0.17
Sri Lanka	1.4

Table 4.
Per capita annual consumption of RBDCO in 2019 [27].

Fatty acid	Property	Coconut	Palm	Olive	Peanut
Caproic	C6:0	0.52	nd	nd	nd
Caprylic	C8:0	7.6	nd	nd	nd
Capric	C10:0	5.5	nd	nd	nd
Lauric	C12:0	47.7	0.2	nd	nd
Myristic	C14:0	19.9	1.1	nd	0.04
Palmitic	C16:0	8	44	16.5	7.5
Stearic	C18:0	2.7	4.5	2.3	2.1
Arachidic	C20:0	nd	0.1	0.43	1.01
Behenic	C22:0	nd	nd	0.15	nd
Palmitoleic	C16:1 (n-7)	nd	nd	1.8	0.07
Oleic	C18:1 cis (n-9)	nd	39.2	66.4	71.1
Oleic	C18:1trans (n-9)	nd	nd	nd	nd
Gadoleic	C20:1(n-9)	nd	nd	0.30	nd
Linoleic	C18:2 cis (n-6)	1.6	10.1	16.4	18.2
Linolenic	C18:3 (n-3)	nd	0.4	1.6	nd
Medium chain	C6 to C12 acids	61		0	0
Long chain	C13 to C21 acids	31		106	100
Saturated fatty acids		91.9	49	19	1.6
Unsaturated fatty acids		1.8	49	86	89.4
Monounsaturated fatty acids		0	40	68.5	71.2
Polyunsaturated fatty acids		1.6	9	18	18.2

nd = not detectable.

Table 5.
Percent composition of major fatty acids in glycerides of coconut, palm, olive and peanut oils [28, 29].

vegetable oils are converted to methyl esters to quantify them, for scientific discussion of their properties. **Table 5** gives percent composition of major fatty acids in glycerides of coconut, palm, olive and peanut oils.

Fatty acid compositions of the glycerides of the vegetable oils reported in different studies may vary by about 3% from the values given in **Table 5**, due to natural variations associated with maturity of the raw materials and the differences in quantification methods. The comparisons are therefore based on major differences in types and proportions of fatty acids.

Vegetable oils and animal fats contribute to the human diet, providing energy and constituents with bearings on human health. The lipids (oils or fats) of different origin are compared for their nutritional benefits or possible detrimental effects on human nutrition. CO with a high concentration of saturated C6 to C12 fatty acids grouped as medium chain fatty acids, arising from MCT, differ from other oils functionally. The short chain and MCT fractions account together for 61% of the total fatty acids in CO. A scientific view exists in identifying the high MCT percentage in CO as nutritionally positive, arising from differences in metabolic pathways taken by fatty acids in the human body.

Current guidelines of the World Health Organization (WHO) recommend limiting energy from total lipids to less than 30%, and energy from saturated fatty acids to less than 10% of the total energy derived from the diet [30]. There is low consensus in interpreting the WHO guideline for CO among the scientists. While some scientists apply the guideline equally to all edible lipids, others consider CO-derived lipids to be different, being largely of MCT origin, against glycerides of long chain fatty acids in most vegetable oils. Lauric acid, a saturated medium chain acid, is the predominant fatty acid in CO. Medium chain fatty acids are commercially defined as having 6 to 10 carbons (C6–C10), while the physiological and metabolic definitions identify medium chain fatty acids as those with C6–C12 [31]. The commercial definition does not consider lauric acid as a medium chain fatty acid. Lauric acid appears to behave both as a medium chain and as a long chain fatty acid in human metabolism. The lauric acid in CO appears to take two metabolic pathways, with 67% of it following the portal passage, not contributing to the formation of chylomicrons and HDL- or LDL-cholesterol, in contrast to the pathway taken by saturated long chain saturated fatty acids [32]. On a theoretical basis, two-thirds of the lauric acid and the C6 to C10 acids consisting of 13.6% making a total of 45% in CO may be following portal pathway through the liver without reaching chylomicrons. The two views on metabolic mechanisms have led to low consensus on the nutritional significance of CO. Clinical trials from different angles attempt to understand the actual effects of CO on human health. **Table 6** summarizes the conclusions suggested in Meta-studies, after assessing clinical research publications on the effect of CO on human health by scientists.

YEAR: Conclusions [Ref]
2023: "The current evidence from shorter term randomized controlled trials suggests that replacement of coconut oil with cis-unsaturated oils lowers total and LDL-cholesterol, whereas for the association between coconut oil intake and cardiovascular disease, less evidence is available" [33]
2022: "Coconut oil intake revealed no clinically relevant improvement in lipid profile and body composition compared to other oils/fats. Strategies to advise the public on the consumption of other oils, not coconut oil, due to proven cardiometabolic benefits should be implemented" [34]
2020: "In summary, consistent, and strong evidence shows that coconut oil has an adverse effect on lipid parameters associated with cardio-metabolic health, with limited studies to conclude the effects of atopic dermatitis and oil pulling" [35]
2020: "While the evidence related to the connection between saturated fat intake and heart disease may be inconclusive and thus not be in full support of reversing suggestion to avoid saturated fats, certainly a revision is justified. A more in-depth investigation of the connection between different types of saturated fat and disease is warranted" [36]
2020: "Compared with animal oils, coconut oil demonstrated a better lipid profile. In comparison with plant oils, coconut oil significantly increased HDL-C and LDL-C. Better lipid profiles were reported with VCO" [37]
2020: "Coconut oil consumption results in significantly higher LDL-cholesterol than nontropical vegetable oils. This should inform choices about coconut oil consumption" [38]
2016: "Observational evidence suggests that consumption of coconut flesh or squeezed coconut in the context of traditional dietary patterns does not lead to adverse cardiovascular outcomes. However, due to large differences in dietary and lifestyle patterns, these findings cannot be applied to a typical Western diet. Overall, the weight of the evidence from intervention studies to date suggests that replacing coconut oil with cis unsaturated fats would alter blood lipid profiles in a manner consistent with a reduction in risk factors for cardiovascular disease" [39]

Table 6.
Conclusions suggested in Meta-studies, after assessing clinical research publications on the effect of CO on human health by scientists.

The range of information summarized in **Table 6** indicates the difficulty in concluding CO as a nutritionally unhealthy or healthy vegetable oil based on the high lauric acid content in the coconut glycerides. Evidence clearly shows CO to be nutritionally better than edible animal fats. Though studies have attempted to recognize the relationship between saturated fatty acids in diet and heart disease, a direct and clear correlation has not been evident as fatty acids are only one factor leading to heart diseases [28]. Lifestyles, relationships between individual fatty acids, the functions of each fatty acid and the biochemical pathways taken by acids in human body appear to lead to health effects, rather than straight relationship between structures of fatty acids and human health, as established through multifactorial effects applying Spearman's correlation. Excessive energy consumption together with inadequate exercise is one of the causes of heart diseases. All fats and oils contribute to heart disease by supplying high energy when consumed in excess [28]. At least half the calories from CO arise from the saturated MCT. Metabolism of CO occurs through mechanisms different from metabolism of other vegetable oils, at least partly. As a strategy to substitute saturated fatty acids in CO by polyunsaturated fatty acids partly, and work out a formula that may be healthier, blending CO with other oils appears to be a practical choice. The aim would be to shift toward the globally accepted guideline of 10% saturated fats in the diet. **Table 7** gives percent fatty acid composition of a proposed coconut (C'nut) and palm oil blend (1:1), compared with three vegetable oils as an improved health option. The proposed blend may reduce the burden on the liver to manage excessive amounts of saturated fatty acids, meeting modern expectations on contributions from edible oils.

The proposed blend is industrially possible, less costly and offers an improved nutrient balance toward the recommended energy intake limit from saturated vegetable oils, and beneficial suggestions described for unsaturated fatty acids. The usefulness of coconut oil would increase as a blend to keep up with the needs of the modern world.

2.2.3 Virgin coconut oil

Virgin coconut oil exhibits health benefits and better nutritious properties than CO. Non-thermal methods extract VCO in the natural form, from the kernels. The fresh mature kernel is grated or cut into small pieces in the same way as for processing desiccated coconut and dried using indirect heat, under mild conditions, to extract VCO. The oil is expelled at a temperature below 50° C, to prevent the formation of polycyclic aromatic hydrocarbons. Alternately, grated fresh kernel is blended with water to extract

Fatty acid type	Peanut	Olive	Palm kernel	Palm	C'nut	1:1
Saturated (SFA)	10.7	19.4	82.1	49.9	92.1	71
Monounsaturated (MUSF)	71.1	68.2	15.4	39.2	6.2	23
Polyunsaturated (PUSF)	18.2	18.0	2.4	10.5	1.6	6
Medium chain	0	0	54.8	0.2	61.3	27
Long chain	100	100	30	99.4	39.7	65

Table 7.
Percent fatty acid composition of a proposed coconut (C'nut) and palm oil blend (1:1), compared with three vegetable oils as an improved health option.

the milk or the cream. The filtered extract is allowed to ferment naturally or treated with enzymes to destabilize the oil-in-water emulsion, releasing the oil. Centrifugation separates oil from the water. Freezing and thawing are practiced in separating water from VCO in the emulsion in certain processes. The dry extraction of VCO from desiccated coconuts carries the advantage of providing less water globules in oil, which may serve as enclosures for spoilage bacteria to grow, reducing product quality. The nutraceuticals from the kernel retained in VCO make it a healthy food component. VCO is rich in antioxidants, vitamins and phytosterols originating from the fresh kernel [40].

There are no significant differences in the composition of triacyl glyceryl esters of fatty acids among VCO and RBDCO other than due to the degree of maturity of coconuts or natural variations in coconut varieties. The quality parameters tested to recognize VCO from CO, namely iodine value, saponification value, peroxide value, anisidine value and free fatty acid, show comparable figures indicating their similarity in the main fatty acid components [40].

The VCO and UCO possess better inherent nutritional characteristics due to phenolic and other minor constituents than RBDCO. The total phenolic content expressed as mg gallic acid equivalents (GAE)/ 100 g was 2- to 4-fold higher in VCO and UCO than in RBDCO. The total antioxidant activity is 1.5-fold higher in VCO and UCO than in RBDCO [41]. The high heat of processing and refining of RBDCO destroys phenolics partly, while the phenolics remain stable in the preparation of VCO. Rangana et al. [42] reported up to 8.3 mg GAE/100 ml of VCO. The VCO is gaining recognition as a modern version of CO in the markets due to its antioxidant activity and phenolic content, recognized as healthy characteristics. The VCO also carries modest concentrations of tocopherol and tocotrienol [43]. The main phenolic acids in the VCO consist of caffeic acid, syringic acid, p-coumaric acid, vanillic acid and ferulic acid [44, 45]. The total phenolics extracted into VCO from the kernels vary with the extraction methods. The distribution of phenols in the kernel is not homogeneous; high concentrations of phenols are in the outer areas of the kernel, close to the testa. However, testa is removed from rest of the kernel by paring, reducing the appearance of phenolics in desiccated coconut, and VCO. The VCO carries potential as a raw material to extract bioactive compounds carrying anti-inflammatory effects [46–48]. VCO having phenolics and added sweeteners possess market value as ingredients in chocolates with health claims.

In an exposure study of middle-aged humans to VCO and olive oil, no differences were observed in the synthesis of HDL-cholesterol between the two groups; VCO did not increase the LDL-cholesterol significantly compared to olive oil. The nutritional effects of VCO are proven to be different from those of RBDCO in several studies. The relevance of examining total dietary contributions from the VCO, rather than properties of individual components in oil, is a better approach against the current background of consuming heavily processed foods, formulated from highly purified constituents [49]. VCO is in demand for the cosmetic industry as a base for skin care and hair care products.

Though with limited research, there is evidence showing the benefits of the VCO on Alzheimer's disease. The benefits arise from the ketone bodies released in the liver due to rapid metabolism of MCT in VCO, providing an alternate energy source for the brain, and helping in neuronal viability. The antioxidants in VCO contribute beneficially, relieving oxidative stress on the brains providing protection [50]. The results of the study need to be complemented with more research, though positive effects are reported with consumption of VCO in persons with Alzheimer's disease. Modern World is recognizing the usefulness of VCO with emerging new knowledge.

2.3 Desiccated coconut

Shredded coconut kernels are thermally dehydrated under relatively mild heat to manufacture desiccated coconut, following certified food safety management practices. Desiccated coconut carries the total complement of constituents in the fresh kernels including MCT in higher concentrations, due to the removal of water (**Table 3**). Desiccated coconut is rich in carbohydrates including dietary fiber, proteins, vitamins, minerals and antioxidants. The desiccated coconut provides a healthy balance of constituents as a food ingredient than RBDCO. The dietary fiber from coconut kernel protects the colon in rats, preventing the formation of unwanted free radicals, which may otherwise act on the mucosa of the lining in the lower gastrointestinal tract. The observation suggests health benefits on the consumption of desiccated coconuts [15]. Dietary fiber regulates fat absorption and food intake, lowers digestion, absorption and metabolism, reducing the energy intake. Consumption of coconut in the form of desiccated coconut may ameliorate the unhealthy effects described for the consumption of RBDCO. Desiccated coconut forms a minor component in desserts and culinary preparations for consumers. Modern commercial food formulations incorporate desiccated coconut to provide functional properties. The desiccated coconut is used in baking, adding sweetness, giving nutty flavor to cakes, cookies and muffins, in smoothies, in energy bars and in ice cream toppings.

2.4 Coconut milk and cream

Liquid from the comminuted coconut kernels is squeezed, after blending with or without water, to obtain coconut milk. The milk is separated from the solid by filtration. The milk may contain 15–35% lipids, 4–6% carbohydrates and 2–3.5% protein as an emulsion, varying with the method of extraction. Codex standard for coconut milk stipulates 10% lipids, 2.7% non-fat solids and 12.7–25.3% total solids as minimum requirements. The standard recognizes coconut cream by stipulating double the amounts of lipids, non-fat solids and higher total solids compared to coconut milk, in line with extraction with minimal water or no water [51]. Coconut milk is the most widely used form of coconut in the coconut cultivating countries for culinary preparations. In the Philippines, 60% of the coconut harvest end up in culinary preparations. The corresponding figure in Sri Lanka is 75%. The global figure is 25%. Coconut milk is canned as milk or in concentrated form as cream, with stabilizers to prevent separation of water from oil. Canning protects milk from microbial spoilage. Coconut milk carries a mean antioxidant activity of 575 mg EGA/100 g, which is higher than that of cow milk. Coconut milk contains albumins, globulins, prolamins and gluten as the main protein components [52]. The proteins in the extracted coconut milk serve as natural emulsifiers for several hours, preventing immediate separation of the oil from the water.

Coconut milk is spray dried to a powder for preservation. A study on consumption of a porridge prepared using coconut milk powder was shown to increase the HDL-cholesterol and decrease LDL-cholesterol in 60 volunteers, suggesting that coconut milk behaves differently to CO in human metabolism [53]. Most arguments associated with detrimental effects of the RBDCO toward health do not appear to be valid, with the coconut milk consumed daily in the coconut cultivating countries. The nutritional benefit of coconut is associated with its way of consumption, natural or refined. The questionable health properties identified with coconut consumption are associated with highly refined CO, while the beneficial properties are associated with natural forms of coconut products. Natural coconut products consist of a mix of carbohydrates, lipids, proteins and nutraceuticals. The constituents bound together as a mixed source of nutrients and energy appear to behave nutritionally differently from the purified RBDCO. The observation on the mixed source of nutrients in coconut milk supports the 'Polynesian paradox' on food patterns, with the existence of populations physically isolated from the rest of the world consuming coconuts as the chief source of calories, mostly with fish in the diet. The reported total lipid consumption in them is less than 35% and the isolated populations are free of atherosclerosis [54].

The consumption of coconut in the form of milk, cream or kernels by populations in Pacific Islands does not appear to cause cardiovascular problems against CO consumption in other countries. CO is researched intensely for its detrimental effects in the populations already on lipid- and carbohydrate-rich diets, which is different from the consumption of coconut in unprocessed forms having dietary fiber, proteins and antioxidants in Pacific Islands. The nutritional difference in the two types of exposures, refined and unrefined forms, is yet to be fully supported by rigorous research with controls for wide scientific acceptance leaving out biases [33].

2.5 Coconut flour

Coconut flour (coconut meal) is the residue left on extraction of the coconut milk or the VCO. The residue is dried and ground to a fine powder. The carbohydrates associated with the soluble dietary fiber in the coconut flour contain predominantly mannose and galactose, retained in the kernel during extraction of the VCO. The coconut cell wall polysaccharides are rich sources of total fiber, carrying high water holding, oil holding and swelling capacities, contributing excellent nutritional characteristics to foods [17]. The nutraceutical property in the soluble dietary fiber is associated with its antioxidant activity, low glycemic index *in vitro*, and high oil holding and water holding capacities, qualifying the coconut flour for its potential as a functional food [55]. The coconut flour exhibits biofunctions such as absorption of bile salts and toxic ions in the digestive system. It is a low-cost product with high nutritional significance. Coconut flour is a potential ingredient in biscuit manufacture [56]. New food formulations harnessing the nutritional benefits arising from the dietary fiber in the coconut flour are appearing in markets of developed countries [57]. With rapid recognition of the VCO as a healthy oil leading to increased industrial production, coconut flour would find new markets as a nutritionally rich byproduct to be used in new food formulations, and in recipes for soups, pancakes, etc., substituting up to 20% wheat flour.

2.6 Coconut water

Coconut water forms the medium for transfer of phloem sap into the coconut kernel. The reverse transfer of nutrients from the kernel into haustoria (cotyledon) during germination of coconut seed too occurs through the coconut water. The coconut water of cytoplasmic origin is in equilibrium with the soluble constituents in the kernel and provides the venue for biochemical reactions. Coconut water from nuts at the age of 5–7 months is a refreshing beverage containing 2.4–5.6% sucrose, 0.6–1.5% reducing sugars and up to 0.5% protein, depending on the variety of the coconut palm. Coconut water is a rich source of minerals containing 150–350 mg potassium per 100 ml, 18–46 mg calcium per 100 ml, 4–45 mg sodium per 100 ml and 7–15 mg magnesium per 100 ml along with several minerals in trace quantities. The water is rich with B and

C vitamins, though in lesser amounts than in most fruits. It contains a variety of sugar alcohols, amino acids, enzymes and phytohormones [58]. The combined properties of low acidity compared to those of fruit juices, isotonic mineral composition, low-calorie content, the traces of amino acids and phytohormones provide valuable nutritional and rehydration properties to coconut water as a natural beverage. It is an excellent sports nutrition drink. Its aroma is due to the combination of about 30 known volatiles and trace constituents. Coconut water shows notable polyphenol oxidase activity and peroxidase activity making it a nutraceutical drink [59]. Chang and Wu [60] reported (+) catechin and (−) epicatechin concentrations of 0.344 and 0.242 μg/ml, respectively, in coconut water adding to its nutraceutical value.

Coconut water is a fresh natural beverage consumed directly or preserved in tetra-packs. It has also found application for intravenous rehydration, substituting saline solutions due to its isotonic electrolyte composition [61]. The tender coconut water shows notable antioxidant activity and free radical scavenging capacity due to the ability of the metalloenzymes or minerals to release electrons, quenching the free radicals in the human body [58, 62]. Coconut water is gaining consumer acceptance as a base for smoothies, blend for fruit juices, lemonades and a cooking ingredient.

2.7 Coconut cotyledon

During germination of the coconut into seeds, the nutrient reserves in the kernels move into cotyledons (haustoria) to produce the sprouts, which end up as coconut seedlings. The cotyledons, possessing a sweet soft texture, are a delicacy. The cotyledons contain 10–13 mg/g carbohydrates, 1–2 mg/g proteins and 13–15 mg/g lipids. The cotyledons carry total phenols, tannins and alkaloids in amounts equivalent to the concentrations in the kernel. The cotyledons are rich in cardiac glycosides indicating strong health benefits [63]. The cotyledon is yet to be explored for its health benefits and marketing as a canned product industrially.

2.8 Copra meal

Copra meal (copra cake) is the residue of mechanical extraction of CO from copra. Copra meal is caramelized due to high heat of expulsion. It is an inexpensive nutritious feed, preferred for farm animals due to the residual oil, proteins and cellulose that could be digested by the ruminants. The proteins in copra meal contain glutelin predominantly [64]. There is the possibility of improving the digestibility of copra meal as a chicken feed, by enzymatic degradation of the cellulose [65]. Use of thermostable phenolic extracts of antioxidants from the copra meal, as alternatives to synthetic antioxidants in preventing lipid peroxidation in food systems, is suggested, based on *in vivo* experiments [66, 67]. Copra meal is a useful component in animal feeds and with potential to be used in extracting ingredients for human foods.

3. Inflorescence sap products

Phloem sap flowing through the inflorescence to produce the nuts is tapped to obtain the sweet sap. The inflorescence is sliced daily and tapped to artificially simulate the flow of sap. Slicing is done 2 to 4 times a day. The inflorescence tied to prevent opening is 'tapped' mildly using a wooden mallet to enhance the oozing of the sap through the 'wound', created by slicing off the callus tissues regularly [68, 69].

The clear oozing sap contains 15–18% sucrose at pH of 7. The sap collects into plastic bottles or earthenware pots hung on to the inflorescence and tied down in a semi-horizontal position. The sweetness of the sap attracts bees. The microorganisms naturally adhering to the body surfaces of bees contaminate the collecting sap, starting natural fermentation. A plant yields about 0.6 to 3 liters of sap per day, averaging 1.5 liters.

The natural fermentation of sap is arrested by applying slaked lime on inner wall of the collecting vessel to provide an alkaline pH [70], or by adding predetermined amounts of sodium metabisulfite solutions [71] or placing the powdered bark of *Vateria acuminata* plant in the sap collecting pots [72]. There are reports of using different preservatives for the same purpose [73]. The anti-ferments serve as microbial stats, suppressing natural fermentation during accumulation of the sap in the collecting equipment. Collection of sap into chilled boxes minimizes fermentation of the sap [74]. **Figure 2** summarizes the foods and beverages developed from coconut phloem sap.

The unfermented sap is a sweet beverage consumed fresh. It is marketed in tetra-packs as a natural drink. The sap is nutritious [75]. Coconut syrup (treacle), coconut jaggery (a hard brown sweet mass) or crystalline coconut sugar is produced by concentrating the sap as cottage industries in coconut cultivating countries. Concentrating the sap by boiling down to one-sixth of its volume produces treacle, which is similar in properties to golden syrup. Concentration of the sap in open pans over direct flame causes high caramelization. The treacle is self-preserving due to sugar content of more than 67%. The partial hydrolysis of sucrose in the sap during boiling results in a mixture of sugars in the treacle, consisting of sucrose, glucose and fructose in varying concentrations. On further concentration of treacle and cooling, it crystallizes the coconut sugar. Continued concentration of treacle results in a hard sugary mass called jaggery [72]. The glycemic index of coconut sugar is 55 or low, identifying it as healthy, compared to cane sugar of glycemic index 60. The low glycemic index is due to presence of the prebiotic fiber, inulin, in the coconut sap. Although coconut sugar contains potassium, calcium, iron and zinc, their nutritional contribution is insignificant. The coconut sugar carries the same number of calories and amount of carbohydrates as the table sugar. There is increasing

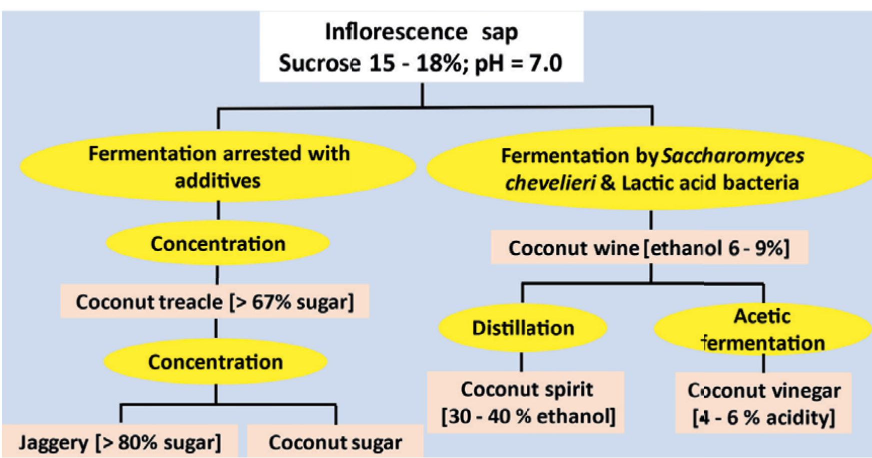

Figure 2.
Foods and beverages developed from coconut phloem sap.

recognition on the usefulness of coconut sugar as a natural sweetener in unrefined form, with potential health benefits [76].

The coconut sap ferments naturally to alcoholic beverage toddy (coconut wine). Toddy is distilled to arrack (spirit) industrially. A variety of yeasts and bacteria ferment the phloem sap during collection. The initial fermentation is caused by lactic acid bacteria, lowering the pH from 7 to 4.5, thereby providing a conducive environment for alcoholic fermentation by the yeasts. Seventeen species of yeasts belonging to eight genera and bacteria belonging to seven genera have been recognized among 200 cultures isolated from fermenting coconut sap. Of the yeasts, the predominant genus *Saccharomyces chevalieri* (35%) is the main ethanol producer [77]. Varying fermentation capacities of yeasts and ability to use them in industrial fermentations in continuous cultures have been explored for the 200 isolates of toddy yeasts [78]. The coconut wine containing 6–7% ethanol is consumed fresh or preserved by pasteurization. Among the microorganisms fermenting coconut sap naturally, there are hydrogen sulfide producers, giving obnoxious flavor at times to the coconut wine.

Distillate from the coconut wine is blended in the same way as other alcoholic spirits, to 30–40% ethanol for sale as a hard liquor. The coconut spirit contains a variety of characteristic congeners including higher alcohols, esters and traces of methanol. The lactic acid produced during initial fermentation generates high concentrations of ethyl lactate in the coconut spirits in the same way as in heavy whiskeys [79].

When coconut wine is left stored for months, it gets converted by the acetic acid bacteria, *Acetobacter suboxydans* and *Acetobacter overoxydans*, to vinegar containing 4–6% acetic acid. The conversion is enhanced industrially by setting up the bacterial cultures on surfaces of wood shavings or corn cobs and circulating the fermenting alcoholic sap on bacterial surfaces to allow aerated reactions, in wooden vats [80]. Coconut vinegar, being a natural product rich in potassium and sodium, is preferred in the modern world over synthetic vinegar for use in food preparations.

Coconut-producing countries have developed appropriate technologies to operate medium and large-scale industries to generate products from the coconut inflorescence sap. Sugars and alcoholic beverages from coconut palm have appeared in markets in developed countries. Coconut sugar is becoming a natural product of demand due to its low glycemic index compared to cane sugar.

4. Conclusions

Coconut plays a significant role in the diet of the populations in the coconut cultivating countries as a source of calories from oil. The proteins and nutraceuticals in the kernels benefit human health. Refined coconut oil produced industrially by conventional processes has raised research interest due to high concentration of medium chain fatty acids and high volume of saturated fatty acid glycerides in it, in contrast to the composition of other vegetable oils. Discussions on health benefits and detrimental effects associated with RBDCO continue. There is new evidence on the nutritional benefits of desiccated coconut, VCO, coconut milk, coconut flour, coconut water and coconut sugar as natural foods that have not undergone chemical refining. The antioxidant activities of the coconut foods and the dietary fiber in them, other than in RBDCO, have gained nutritional attention. With increased consumer demand for natural foods, coconut in unrefined forms may gain higher global recognition as useful and healthy nutritious modern foods.

Conflict of interest

The author declares no conflict of interest.

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Chapter 4

Macadamia Nuts as a Supplement to Cereal-Based Diets in Malawi

Emmanuel Junior Zuza, Abdulmumin Opeyemi Muhammed, Andrew Emmott, Rick L. Brandenburg and Yoseph N. Araya

Abstract

Macadamia is a high value tree crop with rising global demand. As a leading producer, Malawi has seen rapid expansion of macadamia orchards, indicating the crop's growing economic and nutritional importance. Macadamia nuts serve as a means of income generation and provision of high-quality nutrition among producers and consumers. As a consequence of these benefits, macadamia nut production is rising within the country. Rising domestic and international demand suggests macadamia production will help in economic growth in production areas. Integrating macadamia nuts into local diets could also provide nutritional benefits, allowing Malawi to simultaneously improve well-being and prosperity. To fully utilize this potential, Malawi needs strategic expansion plans for the crop. A comprehensive assessment of current and future suitable production areas is necessary. By matching production capacity to area's ecological conditions, yields can be optimized within sustainable limits. With mindful, coordinated support for the nascent macadamia industry, Malawi can leverage this crop for healthier, more resilient communities.

Keywords: macadamia, Malawi, livelihoods, diets, economic

1. Introduction

Addressing global food security is a significant challenge that we face today. The world's population continues to grow, driving changes in food consumption patterns. Food security is simultaneously threatened by land degradation and the negative impacts of climate change. Through the sustainable development goals (SDGs), the international community has committed to ending hunger, food insecurity, and all forms of malnutrition by 2030 [1]. However, the FAO [2] argues that the world is falling behind in achieving these goals, especially in Africa, where roughly one in four people face hunger.

Agriculture plays a crucial role in Africa, contributing to both food security and economic growth. The sector employs approximately 65–70% of the continent's labor force and accounts for 30–40% of gross domestic product (GDP) [3]. Smallholder production dominates and provides up to 80% of the food consumed across Africa [4]. Furthermore, over 75% of Africa's poorest people live in rural areas where smallholder agriculture is the primary economic activity.

Considering smallholder agriculture's centrality to Africa's economy and food systems, improving productivity and sustainability of the sector is critical. Enhanced and adaptive smallholder farming systems can simultaneously help in achieving SDGs including poverty reduction, food and nutrition security, and climate action. For example, increasing smallholder efficiency and climate resiliency can boost yields, reducing hunger and raising farmer incomes. Scaling up climate-smart agricultural (CSA) practices can also help to transform smallholder agriculture systems into a more sustainable and profitable sector in response to climate change while diversifying sources of household nutrition [5–7].

2. Background on Malawi

Malawi is a country in southern Africa, bordered by Mozambique to the south and east, Tanzania to the north and northeast, and Zambia to the northwest (**Figure 1a**). The country's terrain is highly varied, featuring the lows of the Great Rift Valley, which contains Lake Malawi and the Shire River valley, as well as plateaus, rift escarpments, and mountains with elevations ranging from 1000 to 1500 meters above the sea level (m.a.s.l.) and peaks as high as 3000 m.a.s.l. The country has a total area of 118,484 km^2, with 80% (94,449 km^2) dedicated to settlement and agricultural production (**Figure 1b**). Water bodies cover the remaining area, particularly Lake Malawi.

Malawi's population has been rapidly growing and is estimated to be over 22.8 million (www.imf.org/en/Countries/MWI). Nearly 83% of the population lives in rural areas [8]. Agriculture remains the core source of income for the majority of Malawians, accounting for over 90% of the population and contributing to approximately 82.5% of the country's foreign exchange earnings [9, 10]. The economy of Malawi is valued at over $12.6 billion by GDP (**Figure 2**).

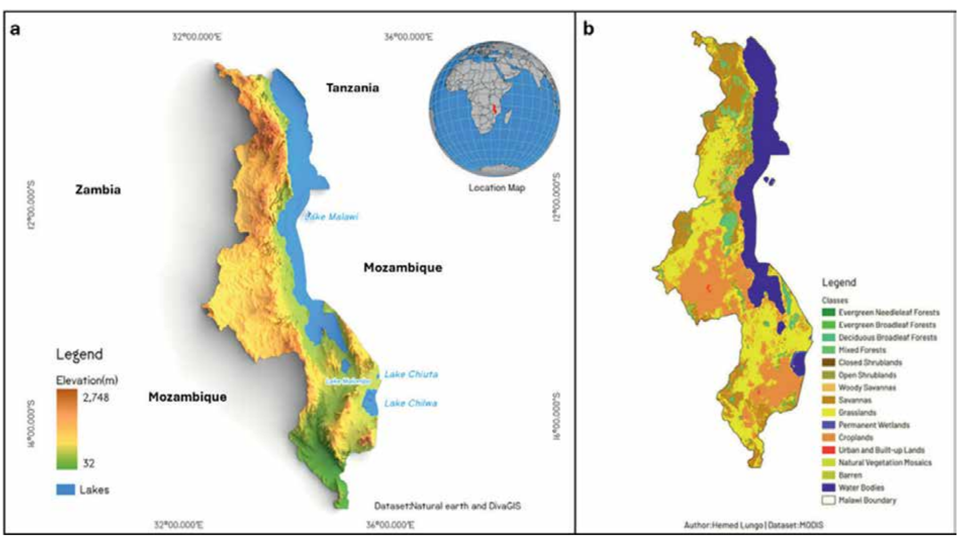

Figure 1.
(a) Geographic location and topography of Malawi. (b) Landcover/land use classification.

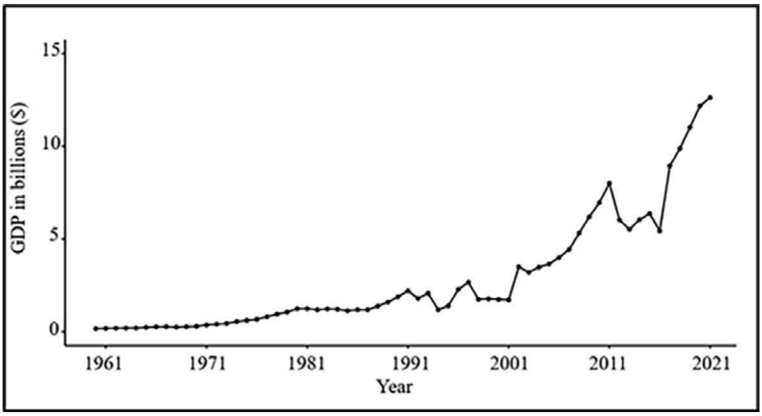

Figure 2.
Malawi GDP performance (data sourced from the World Bank).

2.1 The role and structure of the agriculture sector in Malawi

Agriculture forms the backbone of the economy and society of Malawi. Approximately 85% of households, across the country, are dependent on agricultural activities for their livelihoods and survival, especially rural communities [11, 12]. In addition to driving food security and rural incomes, the sector contributes over 30% to Malawi's total GDP. As such, a thriving and sustainable agricultural sector is critical for realizing Malawi's long-term economic development and reaching several SDGs, especially those on food security and climate action.

Malawi's agricultural sector comprises two distinct subsectors: commercial estate and smallholder producers. The distinction is principally reflected in the tenure systems under which land is cultivated [13, 14]. The commercial estate subsector encompasses medium and large-scale commercial estates ranging from 100 to over 10,000 ha, with land tenure systems primarily based on leasehold or freehold. Commercial estate producers are engaged in the multiplication of certified seed and cash crop production for domestic and export markets and are classified as having high input and high productivity [15–17]. Tobacco has been Malawi's main cash and export crop since the 1800s, falling under the commercial estate subsector [18].

Smallholder farmers, estimated to be two million farm families, cultivate about 4.5 million hectares of land in the country [14, 19–21]. The subsector is characterized by small-scale, subsistent farming, with the average smallholder farm size being less than 0.8 hectare (ha) [22, 23]. Smallholders collectively occupy 80% of the agricultural land in the country. Furthermore, smallholder production contributes approximately 25% of the country's GDP, 95% of the total agricultural labour force, and nearly 70% of agricultural produce, especially common beans, groundnuts, maize, soybeans, sunflower, and tobacco [24].

Despite the important contributions of the smallholder subsector to Malawi's food security and economy, production volumes from each farmer are small, and many are food insecure annually [25, 26]. This is attributed to three key factors. First is the utilization of traditional crop production practices, such as the use of handheld implements for farming and over-reliance on seasonal precipitation. Secondly, limited access to inputs and finance for the farming venture leads to low use of fertilizers and chemicals such as pesticides and herbicides. Lastly is the lack of crop diversification among the smallholders. These factors make Malawi's smallholder farmers increasingly vulnerable to natural and economic shocks, with climate change expected to worsen the situation [12, 27]. Therefore, the subsector must prepare and adapt for sustainable food security and economic development in the country.

2.1.1 Common crops grown in Malawi

Malawi's agricultural production is mainly oriented toward maize for food and tobacco for exports. Maize accounts for over 54% of the national caloric intake [28] and is extensively cultivated across Malawi. The crop thrives in various agroecological zones, from low-lying plains to highland areas [29–31]. Cassava is another vital food staple, providing around 15% of calories [32], and is commonly grown along Lakeshore plains and Upper Shire valley agroecological zones (AEZ) where its drought tolerance is beneficial. AEZs are geographical areas (**Figure 3**) with similar climatic conditions that can support rainfed agriculture [33].

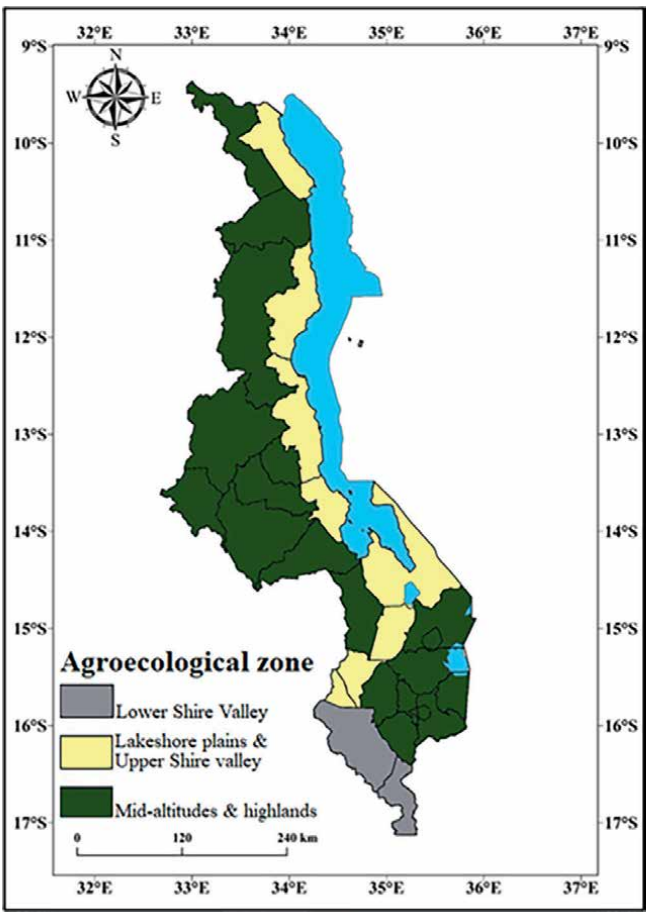

Figure 3.
Agroecological zones in Malawi.

Rice is also primarily produced in wetland regions near Lake Malawi and along the Shire River, taking advantage of abundant water access [34]. Sorghum and millet constitute traditional cereal crops in Malawi, occupying around 5% of cropland, generally in low-lying regions where moisture retention in soils enables reliable harvests [11, 35]. These food crops are essential sources of calories, nutrition, and resilience for smallholder farmers across the country. Their capacity to tolerate various marginal conditions makes them important components of diverse, sustainable cropping systems.

Until recently, the main cash crop in Malawi has been tobacco, and currently, 95% of the production output of the crop is by smallholders [18]. Moreover, tobacco has been one of the country's main agricultural exports for several decades [36, 37]. However, with the declining global demand for tobacco products and increasing international pressure to reduce tobacco usage, smallholders in the country require alternative cash crops for their survival [36, 38].

Recognizing the need for crop diversification, the Malawian government and other stakeholders are advocating for crops such as coffee, groundnuts, macadamia nuts, soybeans, and sunflower as suitable supplements to the smallholder maize-based diets and as alternative cash crops to tobacco and tea. Macadamia nuts have been highly recommended as they are nutrient-dense, require minimal maintenance, and fetch high market prices [39]. Moreover, the first harvest of the crop is in the lean period (January to February) when annual staple crops are not matured, and, thus, macadamia is an essential resource for improving food security when other food is in short supply and expensive.

2.2 Climate change and agriculture in Malawi

Climate change, caused by human activities, has become an undeniable reality. Evidence shows that agricultural production is already being affected by climate change. This is especially true in many parts of Africa, particularly among smallholder farming households [40, 41]. Malawi is particularly vulnerable to climate change due to high poverty levels, limited finances and technology, and a heavy reliance on a predominantly rainfed agricultural sector [7, 42].

Climate change threatens Malawi's economic growth, long-term prosperity, and the livelihoods of an already vulnerable population [43]. Localized droughts and floods reduce crop yields or result in total crop failure, worsening Malawi's food security [44, 45]. Furthermore, there has been a significant increase in extreme weather events, such as heatwaves, droughts, flash floods, and tropical cyclones in the country, from just one during the 1970s to over 40, dominated by floods between 2000 and 2022 [46, 47]. Climate change projections for Malawi suggest possible yield losses of 50% of maize, 45% of tobacco, 12% of groundnuts, 22% of soybeans, and 9% of potatoes by the 2050s, with adverse implications on food security [12, 48].

Malawi's temperatures have already risen by ~0.9°C from 1960 to 2021 (**Figure 4**). Results of 34 climate models provide with higher certainty that temperatures in Malawi will likely increase by 1.5, 2, and 2.3°C by 2030, 2050, and 2070, respectively, above the temperatures of the pre-industrial periods [49]. Such warming will likely have detrimental effects on the agricultural sector if there is low policy implementation effectiveness by the government. Some detrimental impacts may include crop failure, increases in crop pests and diseases, and a reduction in suitable areas for various crops [50]. For example, every degree day above 30°C results in a 1 to 1.7% reduction in maize yields [51].

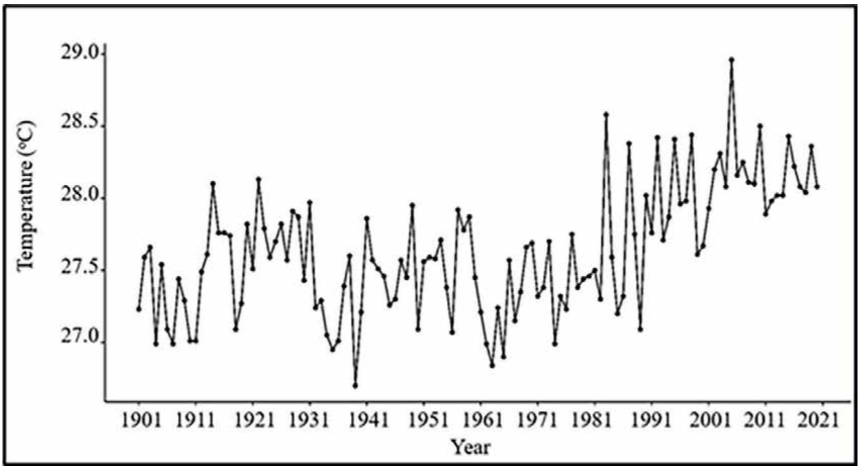

Figure 4.
Historical average annual temperatures for Malawi (World Bank Group climate change knowledge portal).

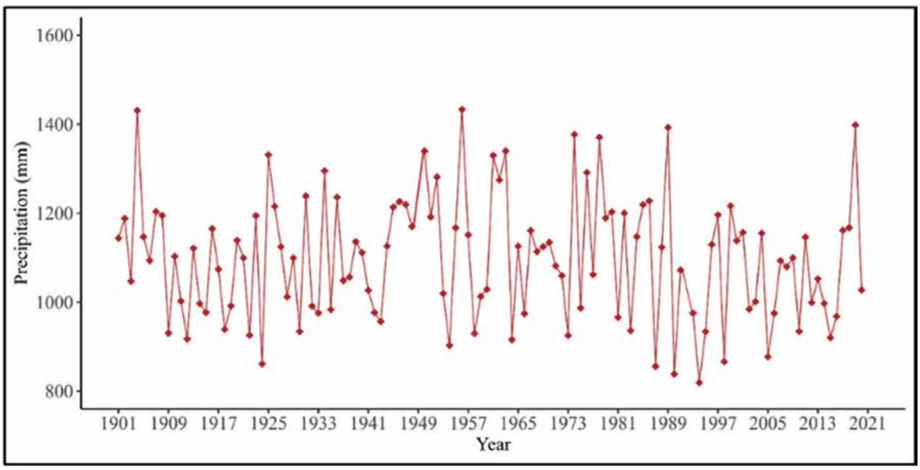

Figure 5.
Historical annual average precipitation for Malawi (data sourced from: World Bank group climate change knowledge portal).

> *"The past decade has witnessed a significant increase in temperature compared to my youth in the 1950s. Unfortunately, these climatic variations have had an adverse impact on my crop yields. In the 2018–19 growing season, we faced the challenges posed by cyclone Idai, and this year (2022), we have encountered the impact of cyclone Ana, both of which have resulted in flooding, leading to the loss of my crops especially annuals and damage to property." (EJZ_01).*

Malawi's rain-fed smallholder agriculture is highly vulnerable to shifts in precipitation and increased frequency of droughts and floods [52, 53]. Historical data show declining rainfall since 1960 (**Figure 5**), especially in southern and northern regions [43]. Decreases are evident for annual and seasonal precipitation (March to December), while slight increases are evident for the highest precipitation months of January and February [43, 54].

Extreme weather events like tropical storms Ana, Idai, Kenneth, and Freddy have caused massive flooding and crop destruction in recent years, leaving many homeless and food insecure, as well as loss of life. The El Niño dry period in early 2024 has also led to failed maize crops and replanting. Despite these climatic shocks, farmers who have diversified into several crops, particularly perennial crops, have reported being somewhat resilient (HIMACUL manager, pers. comm).

> *"Macadamia smallholders were better off in terms of resilience to cyclones Ana and Idai. This is because the macadamia trees and crops under the tree were not severely affected by the cyclones. Farmers were able to harvest some of their field crops, in addition to macadamia. The staples were used for food, and macadamia was sold for income. On the other hand, non-macadamia smallholders lost half or all of their entire crop, which rendered them food insecure." (EJZ_03).*

Climate projections indicate that Malawi will experience a decrease in the average number of precipitation days and an increase in the duration and intensity of precipitation by the 2050s [44, 45]. Seasonal distribution of precipitation will become stronger, with the rainy season receiving a higher proportion of rain and the dry season receiving less. It is projected that the reduction in precipitation will be more pronounced in the southern region of the country (−5.1%) than in the central (−2.8%) and northern (−1.8%) regions.

2.3 Status of food security in Malawi

Food security is defined as the condition where "all people, at all times, have physical and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life [55]." This definition describes the "Four Pillars" of food security: availability, access, utilization, and stability.

Food insecurity is a serious challenge in Malawi, as most agricultural production falls short of its potential due to climate change, soil fertility, and management practices [56]. Maize is a critical aspect of food security among Malawians, with access to and sufficient output of this staple being vital determinants [57]. This is reflected in a common Malawian saying:

> *"Ngati sunadye nsima ndiye kuti siunadye tsiku limenelo," (if you have not eaten maize porridge for a day, you are starving). This quote highlights the significant role that maize plays in the daily lives and overall welfare of Malawians.*

Many smallholders in Malawi struggle to meet their daily subsistence needs due to climatic shocks, primarily unpredictable precipitation patterns, and heatwaves. A less predictable rainy season for smallholders makes planning challenging. This is because farmers rely on knowing when the wet season will begin to sow their crops, apply fertilizers, and harvest during dry periods. Thus, less predictability makes crop yields more variable and vulnerable to post-harvest losses with farmers becoming food insecure.

Nearly 80% of rural individuals, particularly smallholder farmers, in Malawi are net buyers of maize, but their ability to buy adequate food is hindered by high market prices and limited household purchasing power [58]. Consequently, smallholders are the most vulnerable to chronic and transitory food insecurity due to their limited capacity to cope with climatic and economic shocks. For instance, the 2017–2018 growing season saw a 22.1% decline in maize production. This was attributed to severe droughts and flooding coupled with fall armyworm (*Spodoptera frugiperda*) damage [59]. As a result, over a million rural Malawians required humanitarian assistance to meet their food and nutritional needs.

To achieve food security among smallholders, agri-food systems in Malawi must become more efficient, inclusive, resilient, and sustainable. This can be made possible by implementing climate-smart agriculture (CSA) practices [60]. CSA practices support the FAO Strategic Framework 2022–2031, which considers the interlinkages in agricultural productivity, environmental impact, and social sustainability. Thus, CSA practices are a viable option for achieving food security and resilience to climate change at the community level. Some of the CSA strategies include agroecology, agroforestry, conservation agriculture, crop diversification, and regenerative agriculture [60].

3. Nutritional challenges in Malawi

Malawi faces significant nutritional challenges that originate from a combination of factors. These challenges include poverty, limited agricultural productivity, inadequate access to healthcare, and environmental stressors [19, 46]. Malnutrition remains a pervasive issue affecting all age groups, with children under five and pregnant women being particularly vulnerable [21]. Malnutrition contributes to high rates of stunting, wasting, and underweight [61]. Insufficient dietary diversity, poor infant and young child feeding practices, and lack of access to clean water and sanitation exacerbate the problem.

Central to addressing Malawi's nutritional needs is the diversification of the cereal-based diets prevalent in the nation. Cereals especially maize form the staple food for the majority of the population, but they lack essential micronutrients crucial for health and development [62]. While maize provides energy, it is deficient in key nutrients like vitamin A, iron, and zinc [63]. The prolonged consumption of cereal-dominated diets contributes to micronutrient deficiencies, leading to adverse health outcomes such as anemia, impaired immune function, and impaired cognitive development [64].

The predominance of cereal-based diets reflects dietary habits, socio-economic factors, and agricultural practices. Limited access and utilization of a diverse range of foods, particularly fruits, vegetables, fish, and animal-source foods, further compounds the challenge of meeting nutritional requirements. Moreover, poor soil health and fertility which are widespread in Malawi contribute to poor nutrient content of crops [55], exacerbating the deficiency in essential micronutrients.

To address these challenges, integrating nutrient-rich alternatives like macadamia nuts in the Malawian diet remains a viable solution. Macadamia nuts are rich in essential nutrients such healthy fats, proteins, dietary fiber, vitamin E, magnesium, phosphorus, and potassium [65, 66]. Consequently, incorporating macadamia nuts into the diet diversifies nutrient intake and provides a sustainable source of essential nutrients. Furthermore, promoting the production and consumption of macadamia nuts aligns with efforts to address malnutrition, improving food security and climate resilience in Malawi [67]. By leveraging the nutritional benefits of macadamia nuts, Malawi can mitigate the nutritional challenges and enhance the overall health and well-being of its population.

3.1 Macadamia

Macadamia species are native to Australia and were named by Ferdinand von Mueller in 1857 as a dedication to Dr. John Macadam, who was the Secretary of the Philosophical Institute of Victoria at the time [68]. Though originating in Australia, large-scale commercial cultivation of macadamia nuts first happened in Hawai'i in the 1880s [69, 70]. Since then, macadamia cultivation has spread globally, with major producers now including Australia, Brazil, China, Colombia, Costa Rica, Guatemala, Hawai'i, Kenya, Malawi, and South Africa. There are also expanding industries in Argentina, Fiji, Jamaica, Mexico, Mozambique, Myanmar, Nepal, New Zealand, Swaziland, Tanzania, Venezuela, Vietnam, Zambia, and Zimbabwe (**Figure 6**).

3.2 Botanical classification

Macadamia belongs to the *Proteaceae* family, subfamily *Grevilleoideae*, and tribe *Macadamieae* [71]. Eight macadamia species have been described, six of which are native to Australia and two to the Indonesian island of Sulawesi [68, 71]. *Macadamia tetraphylla* and *Macadamia integrifolia*, indigenous to Australia's east coastal rainforests, produce edible kernels [72]. Hybridization between the two species occurs freely, which is an essential source of variability for macadamia cultivar selection [73]. The other macadamia species (*ternifolia, jansenii, claudieana, grandis* [Australian], *whelanii,* and *hildebrandii* [Sulawesi]) are inedible due to high concentrations of cyanogenic glucosides, which are toxic to humans and livestock [74].

3.3 Structure of macadamia trees

Commercial macadamia varieties grown under ideal management conditions may attain a height of over 20 metres (m) with a spread of 15 m at 20 years [70]. Mature leaves are sclerophyllous, which allows them to resist collapse after turgidity loss caused by moisture stress; thus, macadamia leaves do not display stress until it is excessive and irreversible [75]. The proteiod root system of macadamia trees with

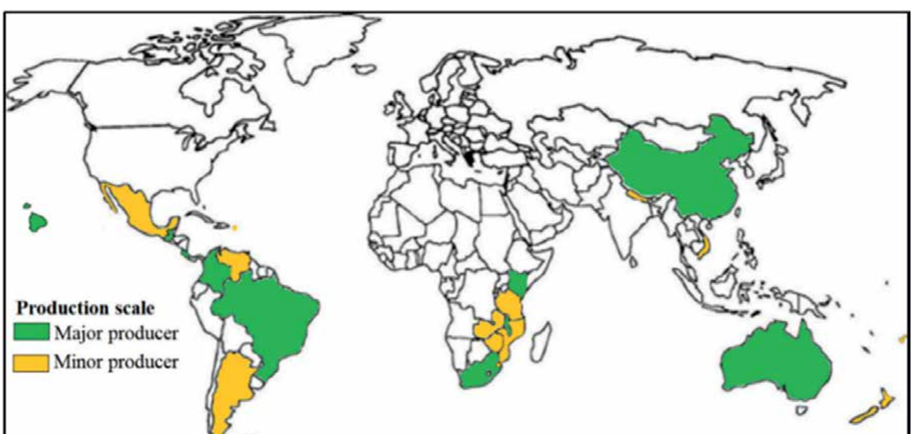

Figure 6.
Global macadamia growing areas.

clusters of feeder roots near the soil surface also helps the tree cope with extreme weather and reduces soil erosion [75].

3.3.1 Macadamia flowers and fruit

Macadamia trees produce large amounts of flowers. However, only a small proportion, approximately 30%, develop into mature nuts [76]. Macadamia flowers are borne in clusters on pendant racemes (**Figure 7**). The macadamia fruit ranges in size from 1.2 to 2.5 cm and comprises an embryo (nut or kernel), testa (shell), and a pericarp (husk).

3.3.2 Nutritional content of macadamia nuts

Macadamia nuts have an exceptional nutritional profile, rich in healthy fats, plant-based protein, and essential micronutrients [65, 77]. Nevertheless, the content of various chemicals and nutrients in macadamia nuts can vary considerably depending on the variety, seed maturity, growing locations, and growing conditions [66, 78, 79]. Thus, the results of proximate analysis of macadamia nuts carried out in different places and at different times can produce different results. For example, of all the nuts, macadamia nuts have the highest total fat content (≥75%), owing to their high amounts of monounsaturated fatty acid (MUFA) [74]. Nuts are also rich in carbohydrates, proteins, and dietary fibers (**Table 1**).

3.4 Healthy benefits associated with macadamia nuts

Regular nut consumption (a handful every day) is associated with many health benefits. Macadamia nuts contain an array of beneficial nutrients and bioactive compounds that promote human health and help prevent chronic diseases when consumed regularly. Despite their high fat content, studies have shown macadamia nuts have positive health effects attributed to their rich composition monounsaturated

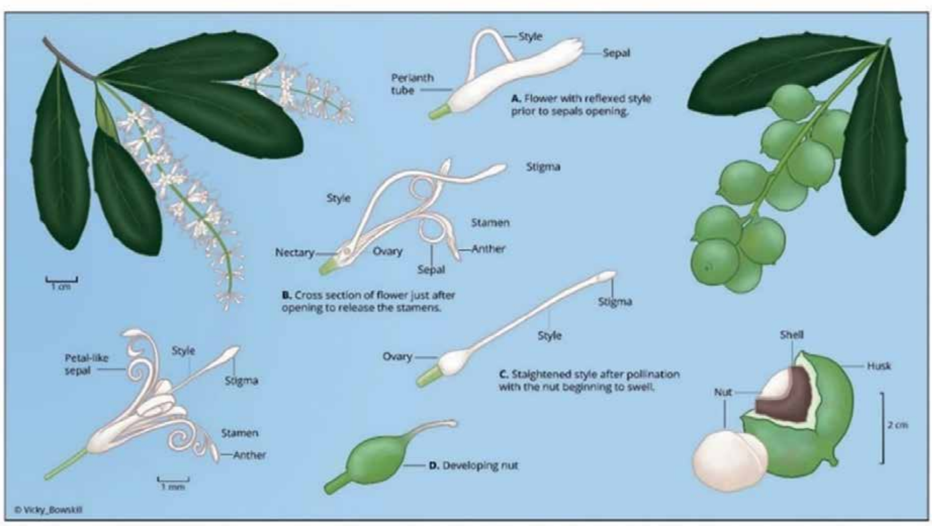

Figure 7.
Schematic diagram of macadamia floral parts.

Content per 100 g	AMS	USDA	SAMAC
Protein	9.2	7.9	9.4
Fat (total oil)	• 74.0	• 75.8	• 75.0
• Monounsaturated	• 60.0	• 59.3	• 84.0
• Polyunsaturated	• 4.0	• 4.0	• 3.5
• Saturated	• 10.0	• 12.1	• 12.5
Ash	1.3	1.3	1.6
Carbohydrate (total)	• 7.9	• 13.8	• -
• Sugar	• 4.6	• 4.1	• 4.8
Dietary fibers	6.4	8.6	7.7

Table 1.
Nutrient content of macadamia nuts (%).

fatty acids (MUFA), proteins, fibers, vitamins, minerals, antioxidants, and other phytochemicals.

Documented effects of macadamia nuts include improved markers of metabolic health, such as weight management, insulin sensitivity, blood lipid levels, and heart disease prevention. Eating macadamia can also regulate good gut health because they are high in fiber, therefore aiding in digestion and boosting healthy gut flora. Hence, their incorporation into diets is essential.

3.4.1 Macadamia nuts and heart disease

Consumption of macadamia nuts has been linked with some potential benefits for heart health. Multiple nutrients found in macadamia nuts, including vitamin B_6, iron, and manganese have been associated with improvements in lipid profiles by reducing levels of "bad" cholesterol (low-density lipoprotein cholesterol/LDL), while maintaining or even increasing levels of "good" cholesterol (high-density cholesterol/HDL).

High levels of HDL lipoprotein cholesterol are associated with a lower risk of heart disease and other cardiovascular problems. For example, consuming macadamia nuts for 5 weeks, compared to a similar diet without nuts, reduced arterial stiffness and wave velocity – two indicators of cardiovascular health risk [80]. One way macadamia nut consumption (as part of a healthy diet) helps persons with hypercholesterolemia is through favorable modification of the plasma lipid profile. For example, 4 weeks of intervention resulted in 3% reduction of total plasma cholesterol concentrations in humans [81].

Bioactive compounds present in macadamia nuts like tocotrienols and flavonoids also contribute to cardioprotective effects. These compounds exhibit antioxidant and anti-inflammatory properties, which help reduce oxidative stress and inflammation, two key factors responsible for the development of heart disease. Overall, the evidence from recent studies suggests that incorporating macadamia nuts into the diet may be a simple yet effective dietary strategy for reducing the risk of heart disease and improving heart health outcomes.

3.4.2 Macadamia nuts and body weight

The nutritional profile of macadamia nuts, especially their high monounsaturated fat content, has significant impacts on how they can affect body weight and composition. Several human trials have shown that including macadamia nuts in diets does not result in weight gain compared to different control diets, even when the total calories and fat intake are the same across groups for several weeks. This highlights the potential benefits of macadamia nuts in promoting fat oxidation and influencing metabolism, due to their unique fatty acid composition and bioactive compounds like palmitoleic acid.

3.4.3 Macadamia nuts and platelet aggregation

Macadamia nuts contain high levels of oleic acid, magnesium, and phytosterols which reduce platelet aggregation, a crucial factor in cardiovascular health. Platelet aggregation is the formation of a blood clot (thrombus) within a blood vessel or the heart. Thrombus formation is normal and an essential part of the body's response to injury. However, thrombus formation occurring inappropriately within blood vessels can lead to blockages, disrupting blood flow, leading to serious health problems. In a randomized controlled trial, Garg et al. [81] found that incorporating macadamia nuts into diet results in a significant reduction in platelet aggregation among individuals with elevated cardiovascular risk factors.

3.4.4 Macadamia nuts and oxidative stress

Oxidative damage occurs when there is an imbalance between free radicals and antioxidants in the body. Free radicals interact with and damage various cellular components, including proteins, lipids, and DNA. Studies have shown that regular consumption of macadamia nuts significantly increases the amounts of antioxidants in the body, thereby reducing the risk of oxidative damage. Antioxidants are molecules that neutralize free radicals by donating electrons, thereby preventing them from causing damage to cells and tissues.

Oxidative damage results in the development of various chronic diseases, including cardiovascular disease, cancer, neurodegenerative disorders (such as Alzheimer's and Parkinson's diseases), and aging. As a result, regular consumption of macadamia nuts helps in the prevention of these chronic diseases.

3.4.5 Macadamia nuts and inflammation

Inflammation is the body's natural response to injury, infection, or irritation. Acute inflammation is a short-term response that helps the body defend against harmful stimuli and promote tissue repair. In contrast, chronic inflammation is a persistent and prolonged inflammatory response that can occur when the immune system is activated for an extended period. Subsequently, chronic inflammation can result in pathogenesis of many diseases, including cardiovascular disease, diabetes, rheumatoid arthritis, inflammatory bowel disease, and certain types of cancer. It can also lead to tissue damage, dysfunction, and the progression of underlying health conditions.

However, the monounsaturated fats and omega-3 fatty acids found in macadamia nuts have been reported to contribute to anti-inflammatory properties in human cells. These fatty acids help modulate inflammatory pathways and reduce the production of pro-inflammatory cytokines, thus reducing inflammation in the body. A study by Xiao et al. [82] found that macadamia nut consumption resulted in decreased levels of inflammatory markers, such as C-reactive protein, in individuals with hypercholesterolemia, further supporting the anti-inflammatory effects of macadamia nuts. Moreover, an unusual omega-7 monounsaturated fatty acid (palmitoleic acid), to which macadamia nuts have a natural abundance, has been reported to generate numerous beneficial biological functions, especially its ability to increase insulin sensitivity and to reduce the risk of diabetes [83].

3.4.6 Macadamia nuts and gut heath

Macadamia nuts are rich in dietary fibers, which play a crucial role in promoting healthy digestion and maintaining optimal gut function. Dietary fiber provides nourishment for beneficial bacteria in the gut microbiota. This leads to the production of short-chain fatty acids (SCFAs), which are essential for gut health. Diets rich in fiber promote the growth of beneficial bacteria such as *Bifidobacterium* and *Lactobacillus* while inhibiting the growth of harmful bacteria. Creedon et al. found that consumption of macadamia nuts increases the production of SCFAs in the gut, leading to improved gut microbiota composition and function.

Fiber content in macadamia nuts also helps regulate bowel movements and prevent constipation, promoting overall gut motility and health. Additionally, the fiber in macadamia nuts contributes to a feeling of fullness and satiety, which may aid in weight management and promote overall digestive well-being.

3.5 History of macadamia production in Malawi

The origins of Malawi's macadamia production are not well documented. Researchers believe the crop was first introduced in the country in the early 1950s [84]. At the time, commercial estate producers, particularly, Naming'omba Tea Estate Limited (NTEL) in Thyolo district and Kawalazi Estate (KE) in Nkhata Bay district primarily used macadamia trees as boundary markers to prevent neighboring communities from encroaching on estate lands.

The decline of the tung oil industry in the mid-1950 to 1970s led to the growth of the macadamia nut subsector in Malawi [68, 85]. By the beginning of the 1980s, three commercial estates in the country were operational, and the first macadamia factory was established on NTEL [86]. Smallholder macadamia production started around the same time as the commercial estate sector, but significant growth was observed in the 1990s [68, 85, 87]. These smallholder farmers obtained their seedlings from either commercial estate producers or the research stations. Nevertheless, production by smallholders remained small and insignificant.

Realizing the potential of smallholder macadamia production to Malawi's economy and food security, the government of Malawi began the promotion of the crop in the central (Ntchisi and Dowa) and northern (Mzimba, Nkhata bay and Rumphi) districts of the country [88] from 2001 under the Macadamia Smallholder Development Project (MSDP). Smallholder macadamia in Neno and Mwanza districts started in 1992.

3.6 Current trends in macadamia production in Malawi

Although initiated and established by the estate sector, the macadamia nut industry in Malawi is currently thriving in both commercial and smallholder sectors. Currently, Malawi is the world's seventh largest macadamia nut producer [89]. The country has the potential to become a top macadamia producer in the next decade [89]. This is attributed to the availability of suitable land for production, particularly among smallholders. Zuza et al. [50] found that 57% (53,925 km^2) of Malawi's land area is climatically suitable for macadamia production.

Currently, there are eight major commercial producers of macadamia nuts in Malawi who also facilitate with processing and marketing of the crop (Gala Macs, Conforzi Estate, NTEL, Eastern Produce, Plantation General International, KE, Sable Farming, and Tropha Estates), alongside some medium-scale and smallholder farmers spread across the country [39]. Moreover, the country's macadamia industry is expected to continue expanding, with farms previously used for tobacco production being converted or diversified to macadamia production [58].

3.7 Macadamia cropping systems in Malawi

Macadamia production in Malawi is divided into three main types: large-scale commercial estates, medium-scale, and smallholder producers [27, 67]. Commercial estate and medium-scale producers typically establish extensive monoculture plantations of macadamia orchards across hundreds of hectares. Their production is highly intensive, often irrigated and mechanized aimed at global exports.

Medium scale and smallholder macadamia farmers use a mixture of cropping systems, including monocultures and agroforestry. The agroforestry systems consist of macadamia trees intercropped with either fruit trees (e.g., bananas, citrus, and mangoes) or fertilizer trees, along with understory crops. Smallholder farmers have different reasons for such diverse cropping systems, like improving soil fertility, increasing yield, diversifying income sources, and resilience to climatic shocks.

> *"One advantage of macadamia agroforestry is the year-round crop harvest. I am preparing to harvest the cabbages, and I already had my first macadamia nut harvest last December. I find the prices for macadamia to be highly competitive compared to other cash crops like groundnuts and soybeans. Additionally, I have a reliable market through HIMACUL." (EJZ_04).*

3.8 Uses of macadamia in Malawi

Malawi's macadamia producers benefit from the versatile uses of macadamia nuts, contributing to their economic prosperity and food security. Commercial estate and medium-scale farmers capitalize on the lucrative global demand for the nuts, primarily using them for export markets. The nuts are aggregated, shelled, packaged, and exported especially to South Africa and Europe, fetching premium prices due to their high nutritional value and distinct flavor profile.

Macadamia nuts play a vital role in the livelihoods of smallholder farmers across Malawi. These smallholders use macadamia nuts for income generation and to supplement their maize-based diets [39, 84]. The crop is harvested during the lean period (January to February) when annual staple crops are not matured, and thus, it is an essential resource for improving food security, both as a source of food when other food is in short supply and expensive and as a cash crop in the country.

Macadamia production is also a means for smallholder farmers to adapt and build resilience to climate change. Despite facing challenges such as flooding and droughts, farmers find dependency on macadamia nuts during difficult times. As such smallholders rely on the crop for both sustenance and income, even when other crops fail.

> *"Despite the flooding that destroyed my maize field, I can still depend on my macadamia trees. I already harvested the first batch of macadamia nuts, keeping some for consumption and selling the surplus for income while I wait for the second and third harvests. This means I have an additional crop that provides both food and income for my family. This comes in handy during the month of January where I have to pay school fees for my children, buy fertilizers for the maize crop and buy extra maize to last till April." (EJZ_05).*

Moreover, farmers view macadamia cultivation as a long-term investment. Farmers receive incentives for environmental stewardship, such as carbon sequestration by macadamia trees, motivating them to continue cultivation and pass on knowledge to future generations.

> *"When I initially began growing macadamia with the Macadamia Smallholder Development Project, it was merely an experimental venture. However, I now view macadamia as my retirement crop. In addition to being a source of food and income, I receive incentive payments for the carbon sequestration my macadamia trees accomplish." (EJZ_06).*

Additionally, the dried husks and shells of macadamia nuts are a sustainable source of fuelwood, offering longer lasting and more efficient fire than traditional alternatives like firewood and charcoal. By using macadamia husks and shells, farmers reduce pressure on natural forests for fuelwood, contributing to efforts in reducing deforestation. Lastly, by intercropping macadamia trees with other crops, smallholders optimize land use efficiency and diversify their agricultural portfolios, ensuring sustainable and resilient farming practices.

3.8.1 Consumption of macadamia nuts in Malawi

Macadamia nuts are an essential source of food and nutrition among smallholders and consumers in Malawi. The nuts are consumed both in raw and roasted form (**Figure 8**). Elsewhere, they are also used as additives in the confectionary sector

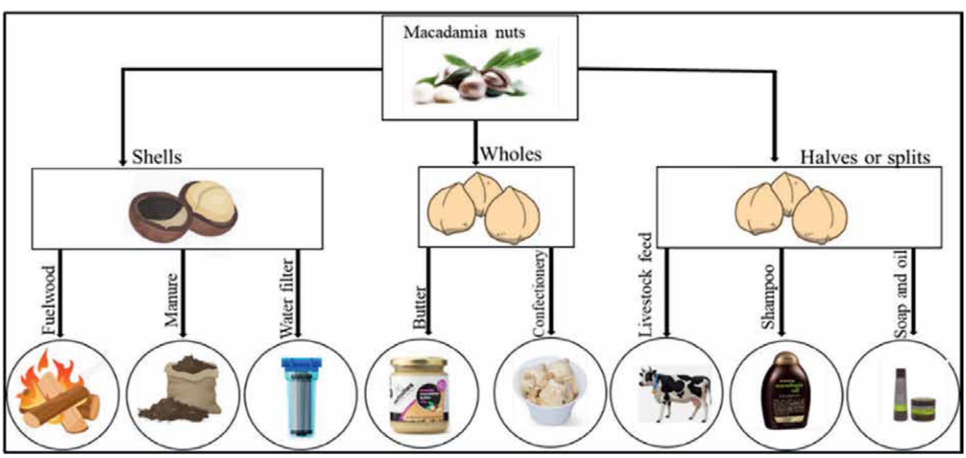

Figure 8.
General uses of macadamia nuts and shells in Malawi.

for cakes, ice cream, and macadamia butter. Macadamia halves are mostly used to produce cooking oil and cosmetics such as shampoo, soap, and sunscreens. The cake is used as animal feed.

Smallholder farmers and consumers in Malawi have cited multiple benefits associated with macadamia nut consumption. The predominant reason driving consumption is the nutritional benefits of nuts. For example, findings from a study conducted by Zuza [90] revealed that a significant majority, approximately 61% out of 144 participants, consumed macadamia nuts primarily for their health and dietary value. This emphasizes the nuts' potential to nutritionally complement the country's cereal-heavy diets. Therefore, there exists a pressing need for broader promotion of macadamia production to meet the growing demand for these nutritious nuts and to enhance dietary diversity nationwide.

> *"I consume macadamia nuts because they have many medicinal benefits, including lowering blood pressure." (EJZ_07).*

Beyond nutrients, macadamia accessibility facilitates consumption, especially for communities situated near production areas. This underscores that easy access and affordability motivates the use of nuts to supplement other foods. Therefore, in addition to nutritional merits, convenient availability makes locally harvested macadamias an important dietary component. As one farmer testified

> *"Meat and fish are quite costly in this area. So, I get most proteins and other nutrients from macadamias instead." (EJZ_08).*

3.9 Preparation methods of macadamia nuts in Malawi

Macadamia nuts are an important food source in Malawi [27, 39]. As production and availability of the nuts has increased locally, consumers have developed a variety of preparation methods to incorporate the nuts into traditional dishes and meals. These innovative techniques allow consumers to capitalize on the nuts' nutritional benefits while fitting them into local culinary culture.

Understanding macadamia usage is vital and can inform efforts to promote nuts for food security and nutrition goals. Moreover, documenting the preparation methods preserves valuable cultural knowledge on adapting the formerly exotic nuts into indigenous cuisines. This information could help nutrition programming and interventions to apply appropriate processing methods when utilizing macadamia nuts to combat malnutrition. Below is a summary on how macadamia is incorporated into Malawian diets.

3.9.1 Macadamia flour

Macadamia flour is a popular nutritious supplement made by households milling nuts with their maize. The resulting fortified flour is used to cook enriched traditional staples like "nsima," porridge, and relishes. Thus, the addition of macadamia flour boosts the nutritional value of these regular dishes by increasing healthy fats, vitamins (especially B_6), minerals (manganese, iron, and magnesium), carbohydrates, and dietary fibers [80, 83]. Macadamia also acts as a flavor enhancer [65]. The accessibility of milling allows farmers and consumers to easily produce this beneficial supplement for both health and taste improvements. Consequently, incorporating more macadamia nutrients through flour represents a valuable usage that can expand with rising production, especially increasing nutrition security for rural communities in the country.

> *"One common dish I love to prepare is boiling pumpkin leaves in combination with a half cup of macadamia flour and a touch of salt, which is eaten with nsima or potatoes and red beans." (EJZ_08).*

3.9.2 Macadamia oil

Macadamia nuts have the highest fat content of any nut, which is advantageous for the production of macadamia oil [91]. Communities in close proximity with the Highlands Macadamia Cooperative Union Limited have access to an oil press, enabling them to extract oil from harvested macadamia nuts. This oil is used as a healthy cooking base, further diversifying their culinary applications. Pressing oil reduces purchases of other vegetable oils, saving households money for other needs. The byproduct of oil production is defatted macadamia meal, which is then used to bake traditional "chigumu," bread, and as animal feed.

3.9.3 Macadamia nut snacks

Macadamia nuts are an important snack among Malawian consumers, especially children. While raw nuts are a popular choice, they can also undergo various flavor enhancements. Dry roasting is a common method used to intensify their flavor profile. Recently, individuals have the option to purchase macadamia nuts already roasted and seasoned, including varieties such as salted, smoked, and barbecue flavor. While, macadamia nuts are predominantly consumed roasted, the roasting process is highly likely to induce chemical changes in the lipids, and the consequential flavor modification is often rated well [92]. In fact, unsaturated fatty acid and mineral content was significantly increased rather than when eaten raw or boiling [93].

3.9.4 Macadamia butter

Macadamia nuts are providing Malawian smallholder farmers an opportunity to diversify the prevalent peanut-based butter diets with macadamia nut butter. The high oil content of macadamia nuts allows farmers to transform their harvest into butter through a simple yet value-adding grinding process [94]. Compared to mainstream groundnut butter, macadamia nut butter delivers superior health properties due to a richer composition of heart-healthy MUFA and antioxidants [91, 94]. It also provides a richer, creamier base, and mild, buttery taste profile that complements multiple uses like spreading on bread and baking.

Through the use of traditional mortals and in some cases small-scale grinding mills, enterprising smallholders are able to manufacture their own macadamia nut butter, generating extra income while meeting urban consumer demand for specialty spreads. The emerging niche product simultaneously diversifies ground-nut-dominated markets and farmers' income streams. Production can expand through cooperative partnerships and value chain support. Hence, the promising local manufacture and sales of macadamia nut butter illustrates the crop's opportunities to drive agricultural and food product diversity in Malawi.

4. Conclusion

Macadamia is a highly valuable crop in Malawi. The nuts contribute to local diets by providing a rich source of healthy fats, vitamins, proteins, and micronutrients, as well as diversifying farm incomes. As both domestic and international demand for nuts rises, its production has the potential of driving economic growth in rural areas across the country. However, to fully realize the potential of macadamia production, Malawi must undertake strategic efforts to promote its expansion. Careful consideration must be given to the current and projected suitable areas for production in light of environmental and socio-economic factors. By promoting the production of the nuts in areas where they are adapted, Malawi can maximize productivity while ensuring sustainable agricultural practices. Therefore, integrating macadamia nuts into Malawian diets as a cereal-based supplement has the potential to enhance the well-being of the people, while fostering economic growth.

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Conflict of interest

The authors declare no conflict of interest.

Additional information

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Section 3

The Use of Nuts for Medicinal Purposes

Chapter 5

Pistacia atlantica as Anti-Inflammatory Agent in Medicinal Uses

Chahrazad Bakka

Abstract

Pistacia atlantica, a plant native to the Mediterranean region, holds significant traditional medicinal value for various health conditions, notably those associated with inflammation. This study aims to review the existing literature regarding the anti-inflammatory properties of *P. atlantica* and discuss its potential as an alternative treatment option. An extensive search was conducted using PubMed, Scopus, Web of Science, and Google Scholar databases to identify relevant articles published up until January 2024. Articles were selected based on their relevance to the topic, quality, and credibility. *Pistacia atlantica* exhibits anti-inflammatory properties, as evidenced by its traditional use in treating conditions like stomach diseases, renal disorders, wounds, coughs, gastrointestinal disorders, and inflammatory diseases. Numerous scientific studies support these claims, demonstrating that *P. atlantica* possesses antioxidant, anti-inflammatory, and antimicrobial activities. Specifically, it has been observed to alleviate bowel inflammation, inhibit protein denaturation, and exert protective effects against oxidative stress. The strong correlation between the traditional uses of *P. atlantica* and its proven anti-inflammatory properties suggests that it may serve as an effective natural remedy for inflammatory conditions. However, additional research and clinical trials are required to fully understand its mechanism of action and optimize its therapeutic applications. By exploring the synergy between traditional knowledge and contemporary pharmacological understanding, we hope to contribute to the development of novel treatments for inflammatory diseases.

Keywords: *Pistacia atlantica*, anti-inflammatory, traditional medicinal, medicinal uses, pharmaceutical effect

1. Introduction

Belonging to the Anacardiaceae family, the *Pistacia* genus includes numerous species, with *Pistacia atlantica* being a prominent one known for its rich history in traditional medicine. This species is widely distributed across the Mediterranean and Middle Eastern regions alongside other notable species like *P. vera*, *P. terebinthus*, *P. khinjuk*, and *P. lentiscus*. Iran stands out as a significant producer of *Pistacia* spp., with a cultivation history spanning thousands of years and diverse culinary and medicinal applications for this herb. Wild pistachio (*P. atlantica*) is particularly economically important in Iran and can also be found in countries such as Pakistan, Greece, Turkey, and North Africa [1, 2].

Plants have played a significant role in traditional medicine for centuries, offering remedies for a wide range of health issues. Medicinal herbs have been utilized to alleviate pain and address various ailments throughout history. One such plant, *Pistacia atlantica*, has gained recognition for its potential as an anti-inflammatory agent, drawing from both traditional uses and scientific research. The traditional medicinal applications of *Pistacia atlantica* are diverse, encompassing treatments for stomach diseases, renal disorders, wounds, coughs, gastrointestinal issues, and inflammatory conditions [3, 4].

Pistacia atlantica is recognized for its diverse medicinal properties, including antioxidant, antidiabetic, antihyperlipidemic, antimicrobial, antiviral, antitumoral, gastroduodenal protective, diuretic, emmenagogue, wound healing, and analgesic effects [5, 6]. These therapeutic actions are attributed to the active compounds present in *Pistacia atlantica* that interact with biological systems through mechanisms such as modulating inflammatory responses, reducing oxidative stress, regulating glucose metabolism, lowering lipid levels, enhancing immune functions, and promoting cellular regeneration during wound healing [7–11].

In this research, we highlighted the study of research reports on the uses of the plant *Pistacia atlantica* as an anti-inflammatory in popular uses, as well as the scientific research carried out. As evidenced by its rich history of traditional usage and extensive scientific validation, *Pistacia atlantica* presents a compelling opportunity for advancing innovative therapies aimed at addressing a broad spectrum of diseases and conditions. Future research endeavors must concentrate on refining extraction techniques, discovering novel bioactive compounds, and examining synergistic interactions among these compounds to fully realize the therapeutic potential of *Pistacia atlantica*.

2. *Pistacia atlantica* Desf. as anti-inflammatory agent

2.1 Medicinal uses of *P. atlantica* in folk medicine

In Persian, *Pistacia atlantica* is known as *Baneh*. In English, it is commonly referred to as the *Mt. Atlas* mastic tree. In Arabic, it is called *Butm*, and in the Canary Islands, it is known as *Almacigo*. The resin of wild pistachio, called *Saqez*, is used for various industrial and traditional purposes. *Vanoshak* is the name of the fruit of the tree that has a thin green shell with a hard rind and a nutritious marrow [12].

Atlantic pistachios are traditionally used in Persian medicine to treat various conditions such as pain, discomfort in the upper abdomen, indigestion, and peptic ulcers [13]. It is also used topically for joint pain and in treating diseases related to cancer, digestive system disorders, wounds, and injuries that are difficult to treat [13]. Additionally, research suggests that Atlantic pistachios have antioxidant properties and may be beneficial for preventing or treating inflammatory bowel disease [14].

Kidney tonic and aphrodisiac: In Iranian folk medicine, *Pistacia atlantica* (also known as Anjir) is traditionally used to treat kidney stones and improve overall renal function. It is also believed to enhance sexual performance [15].

Dermatological benefits: This plant has long been utilized for skin conditions such as wounds, scabies, lip fissures, and hair loss. Its use in wound healing is supported by modern scientific research [15].

Miscellaneous: Resins derived from *Pistacia atlantica* are employed as a gum tissue strengthener and for bone fracture treatment. The fruit is applied topically for back pain relief due to its analgesic properties [15].

2.2 Biological effect as anti-inflammatory agent

Several studies have investigated the anti-inflammatory activities of *P. atlantica*. A methanolic extract from *Pistacia atlantica* Desf. leaves demonstrate anti-inflammatory activity, confirmed through experiments involving the reduction of carrageenan-induced hind paw edema in mice [16]. Flavonoid compounds within the extract contribute to its anti-inflammatory effects [17]. Additionally, studies have reported the presence of anti-inflammatory activities when evaluating the unripe fruit extracts of *Pistacia atlantica* [17], indicating that multiple plant components possess anti-inflammatory properties.

Bakka et al. [18] evaluated the phytochemical screening and *in vitro* anti-inflammatory activities of *Pistacia atlantica* Desf. extracts through protein denaturation inhibition by egg albumin and bovine serum method. The plant, belonging to the Anacardiaceae family, has been traditionally used for various medicinal purposes such as anti-inflammatory effects. The leaves and fruits were macerated and extracted with chloroform, ethyl acetate, and n-butanol. The extracts showed significant anti-inflammatory activity *in vitro*, suggesting their potential as a potent anti-inflammatory agent for various applications.

Moreover, other studies have highlighted the anti-inflammatory properties of *Pistacia atlantica*. The unripe fruit extracts of *Pistacia atlantica* demonstrated significant anti-inflammatory activities *in vitro*, along with antioxidant, antibacterial, and enzyme inhibitory activities. These findings suggest that *Pistacia atlantica* extracts have the potential to be utilized as a natural remedy for various physiological diseases [17].

The leaf buds of *Pistacia atlantica* exhibit high anti-inflammatory properties, among other bioactivities. Studies have demonstrated that the leaf-bud extract significantly reduces carrageenan-induced hind paw edema in mice, confirming its anti-inflammatory action [19]. Additionally, the plant samples show effective antioxidant activity, with low EC50 values for 2,2-diphenyl 1-picrylhydrazyl (DPPH), total antioxidant capacity (TAC), and reduced power tests. These findings highlight the potential of *Pistacia atlantica* leaf-bud extracts as a valuable source of bioactive molecules with multiple pharmaceutical benefits [19].

The aqueous extract of *Pistacia atlantica* Desf. from Morocco demonstrates *in vivo* analgesic and anti-inflammatory properties. The study conducted by Ghizlane Hajjaj and colleagues revealed that the aqueous extract reduced carrageenan-induced paw edema in mice and displayed analgesic activity in animal models [20]. These findings support the traditional use of *Pistacia atlantica* in the treatment of pain and inflammation. Other research also confirms the anti-inflammatory and analgesic effects of *Pistacia atlantica* extracts, further validating its potential as a natural therapeutic option [18–20].

The essential oil extracted from galls formed on the leaves of *Pistacia atlantica* Desf. exhibits new *in vitro* and *in silico* studies demonstrating anti-inflammatory activities. This essential oil has shown promising anti-inflammatory properties in various studies, indicating its potential therapeutic value in managing inflammation [21]. Additionally, the methanolic extract from *Pistacia atlantica* Desf. leaves have been reported to possess anti-inflammatory and antioxidant activities, further supporting the plant's potential as a source of bioactive compounds with anti-inflammatory properties [21]. These findings highlight the diverse pharmacological benefits of *Pistacia atlantica* and its potential applications in inflammatory conditions.

Research on the inflammation-lowering property of *Pistacia atlantica* in cotton pellet granuloma involves testing various doses (100, 200, 400, and 600 mg/kg body weight) in Swiss albino rats. The study assesses the anti-inflammatory potential of *Pistacia atlantica* through its effects on cotton pellet-induced granuloma formation. The results indicate that all tested doses of *Pistacia atlantica* significantly reduce inflammatory exudates and granuloma mass formations compared to the control group [21]. This research provides valuable insights into the anti-inflammatory properties of *Pistacia atlantica*, suggesting its potential as a natural remedy for inflammation-related conditions.

The combination of *Pistacia atlantica* oleo-gum-resin and honey has shown a protective effect in an experimental model of acetic acid-induced colitis in rats. The formulation containing *Pistacia atlantica* oleo-gum-resin and honey reduced inflammation of the bowel and colonic ulcer severity, as evidenced by the downregulation of inflammatory markers [22]. This study suggests that the combination of *Pistacia atlantica* oleo-gum-resin and honey could be a potential therapeutic option for colitis, offering physiological and pathological improvements in a rat model. The anti-inflammatory effect of *Pistacia atlantica* subsp. *kurdica* volatile oil and gum on acetic acid-induced acute colitis in rats has been studied. The research shows that oral administration of *Pistacia atlantica* subsp. kurdica volatile oil and gum improve colitis symptoms in rats. Specifically, the study highlights the protective effect of oral administration of essential oil derived from *Pistacia atlantica* gum on ulcerative colitis in rats. However, unlike the oral form of gum, its rectal administration did not prove to be significantly effective in improving colitis [23]. This research supports the idea that *Pistacia atlantica* subsp. *kurdica* contains active components capable of modulating inflammation in the context of colitis, providing evidence for the potential use of this species in the management of inflammatory bowel disorders. The healing effect of *Pistacia atlantica* fruit oil extract in acetic acid-induced colitis in rats has been investigated. The study demonstrates that the administration of *Pistacia atlantica* fruit oil extract exhibits a significant healing effect on acetic acid-induced colitis in rats. The extract effectively reduces inflammation, promotes tissue repair, and improves colonic damage caused by acetic acid. These findings suggest that *Pistacia atlantica* fruit oil extract may have therapeutic potential in the treatment of colitis and related inflammatory conditions [14].

The evaluation of the effect of a topical gel form of *Pistacia atlantica* on induced oral mucositis in male golden hamsters has shown promising results. The study assessed the stereological, anti-inflammatory, and antioxidant markers of a hydroalcoholic extract of *Pistacia atlantica* leaves and their combination on induced oral mucositis in hamsters. The findings suggest that the mixture of *Pistacia atlantica* could be effective in the treatment of oral mucositis, indicating its potential therapeutic value in managing this inflammatory condition [24].

The study on the healing effect of *Pistacia atlantica* as a remedy for induced oral mucositis in male golden hamsters has shown promising results. The research evaluated the effects of a mixed gel containing 10% *Pistacia atlantica* and 10% *Hypericum perforatum* on induced oral mucositis in male golden hamsters. The findings suggest that this combination could serve as a healing accelerator remedy for oral mucositis, indicating its potential therapeutic value in managing this inflammatory condition [25]. Moreover, research has shown that the methanolic extract from *Pistacia atlantica* leaves possesses anti-inflammatory activity. Additionally, the fruit oil of *Pistacia* *atlantica* has been found to alleviate inflammation and facilitate wound healing. These findings support the traditional uses of *Pistacia atlantica* in treating inflammation.

The investigation of *Pistacia atlantica* subsp. *kurdica*'s anti-inflammatory activities focused on evaluating the effects of various fractions of baneh gum and volatile oil in an experimental rat model of ulcerative colitis. The results revealed the following: Constituents analysis: Alpha-pinene was identified as the primary component of baneh volatile oil, accounting for approximately 41.23%.

Treatment efficacy: Both oral gum and volatile oil reduced all indices of colitis and myeloperoxidase activity when administered at appropriate doses (100, 200, and 400 mg/kg for gum; 100, 200, and 400 μL/kg for volatile oil).

Route comparison: While oral administration of gum displayed significant improvements in colitis, rectal application did not show similar effectiveness.

Comparison with reference drugs: The anti-inflammatory effects of baneh gum and volatile oil were comparable to those of oral prednisolone and hydrocortisone enema [23].

Pistachio oil has been recognized for its anti-inflammatory properties due to its composition of linoleic acid, oleic acid, and stearic acid. These major components have shown significant wound healing and anti-inflammatory effects when applied to oil-absorbed bacterial cellulose in a burn wound model. This oil has the potential to serve as a safe and effective dressing for wound management. Furthermore, *P. atlantica* fruit oil has demonstrated promise in treating ulcerative colitis, with studies indicating that high doses of the oil can reduce colonic injury by mitigating oxidative damage in rats through oral and rectal administration.

Research suggests that wild pistachio oil may also play a role in modulating hypothyroidism, impacting serum lipid profiles and leptin concentrations. In a study conducted by Hamidi et al. in 2017, the topical application of gel formulations containing 5 and 10% *P. atlantica* oil showed positive effects on cutaneous wound healing in rat models. The results revealed enhanced re-epithelialization, formation of mature granulation tissue, and the presence of adnexa such as hair follicles and sweat glands with the use of Atlas pistachio oil gels, particularly the Bene 10% formulation, at 21 days post-injury. Interestingly, rural populations have long utilized fixed oils extracted from Atlas pistachio fruits for managing conditions like rheumatoid arthritis and joint pain. The oil is commonly applied directly to the affected area with a gentle massage to enhance absorption and promote relief [26].

2.3 Relation between pharmacological and folk medicine uses of *P. atlantica* as anti-inflammatory agent

The relationship between traditional uses and pharmacological effects of *Pistacia atlantica* regarding inflammation can be elaborated upon using the following studies.

2.3.1 Wound healing properties

According to traditional medicine [5], *Pistacia atlantica* is used for wound inflammation. A recent study confirmed the *in vivo* effect of *Pistacia atlantica* hulls extract, showing improved wound healing. The experimental evidence supporting the wound-healing properties of *P. atlantica* comes primarily from the following sources:

Hydromethanolic *P. atlantica* hulls extract: A study demonstrated the improvement of wound healing when treated with hydromethanolic *P. atlantica* hulls extract. Histopathological examination revealed enhanced collagen deposition and reduced inflammation in wounded rats receiving *Pistacia atlantica* hulls extract compared to control animals. The mechanism underlying the wound healing effect may involve increased expression of transforming growth factor beta (TGF-β), fibronectin, and type III procollagen, leading to accelerated granulation tissue formation.

2.3.2 Anti-inflammatory activities of leaves

Pistacia atlantica leaves have been identified to possess anti-inflammatory properties [16]. Studies have shown that the methanolic extract derived from *Pistacia atlantica* leaves exhibits significant anti-inflammatory effects. Histopathological studies revealed a notable reduction in lymphocyte infiltration in groups treated with *Pistacia atlantica* leaf hydroethanolic extract, indicating its anti-inflammatory potential. The leaf hydroethanolic extract of *Pistacia atlantica* demonstrated protective effects against gentamicin-induced nephrotoxicity, further supporting its anti-inflammatory properties. The anti-inflammatory effects of *Pistacia atlantica* leaf extract might be attributed to its ability to suppress the production of pro-inflammatory cytokines, such as tumor necrosis factor-alpha (TNF-α). The extract may also help regulate the balance between pro-inflammatory and anti-inflammatory molecules, thereby preventing excessive immune responses.

2.3.3 Effect against ulcerative colitis

Pistacia atlantica volatile oil and gum demonstrate therapeutic effects in reducing colitis indices and myeloperoxidase activity [27]. Studies have demonstrated the therapeutic effects of *Pistacia atlantica* volatile oil and gum in reducing colitis indices and myeloperoxidase activity, particularly in the context of ulcerative colitis. The main constituent, alpha-pinene, found in baneh volatile oil, contributes significantly to its anti-inflammatory effects. Research has shown that oral gum and volatile oil of *Pistacia atlantica* subsp. *kurdica* possess anti-inflammatory potential and can reduce colitis indices in experimentally induced colitis in rats. Both oral and rectal administration of *Pistacia atlantica* fruit oil extract has been shown to alleviate bowel inflammation in acetic acid-induced colitis in rats, indicating its potential therapeutic efficacy. The anti-colitis potential of *Pistacia atlantica* is attributed to its ability to inhibit pro-inflammatory cytokines and reduce oxidative stress markers, thereby alleviating colonic injury and inflammation. The essential oil of *Pistacia atlantica* gum exerts its protective effects by modulating inflammatory responses and suppressing the activity of COX-2, a key enzyme involved in inflammation.

2.3.4 Additional medicinal properties

Pistacia atlantica exhibits significant anti-inflammatory effects, as supported by various studies [23]. Anti-inflammatory Effect on Acetic Acid-Induced Colitis: Research has demonstrated the anti-inflammatory potential of *Pistacia atlantica* subsp. *kurdica* volatile oil and gum in treating acetic acid-induced acute colitis in rats. The oral administration of essential oil of *Pistacia atlantica* gum has been shown to protect against ulcerative colitis in rats by inhibiting pro-inflammatory processes. The methanolic extract from *Pistacia atlantica* leaves has also been reported to exhibit strong anti-inflammatory activity, making it a promising candidate for the development of new anti-inflammatory treatments. The anti-inflammatory effects of *Pistacia* *atlantica* may be attributed to its ability to modulate inflammatory responses, inhibit pro-inflammatory cytokines, and reduce oxidative stress markers, thereby mitigating inflammation and tissue damage.

These findings confirm that traditional knowledge concerning the use of *Pistacia atlantica* for managing inflammation is validated by contemporary scientific research. As a result, there is great potential for developing novel therapies using *Pistacia atlantica* derivatives for the treatment of inflammatory diseases. The bioactive compounds detected in *Pistacia atlantica* have been linked to its anti-inflammatory activities. Research has shown that extracts from various parts of *Pistacia atlantica*, including leaves, fruits, and oil, exhibit significant anti-inflammatory properties. These bioactive compounds play a crucial role in modulating inflammatory responses, thereby contributing to the plant's therapeutic effects. Studies have highlighted the presence of secondary metabolites in *Pistacia atlantica*, such as phenylethanoid glycosides, which are believed to be responsible for their anti-inflammatory, antimicrobial, analgesic, and other pharmacological properties. Furthermore, the essential oil derived from *Pistacia atlantica* has been found to possess potent sedative and anti-inflammatory properties in animal models, further supporting its traditional use for inflammatory conditions. The correlation between the bioactive compounds in *Pistacia atlantica* and its anti-inflammatory activities underscores the plant's potential as a natural remedy for managing inflammatory diseases.

3. Conclusion

Based on the research findings on *Pistacia atlantica* Desf. as an anti-inflammatory agent, the conclusion can be drawn that *Pistacia atlantica* exhibits significant anti-inflammatory properties supported by traditional medicinal uses and modern scientific research. Studies have shown that extracts from various parts of *Pistacia atlantica*, including leaves, fruits, and oil, possess potent anti-inflammatory effects. The bioactive compounds present in *Pistacia atlantica* play a crucial role in modulating inflammatory responses, making it a promising candidate for the development of new anti-inflammatory treatments. The correlation between traditional knowledge and pharmacological evidence confirms the plant's potential as a natural remedy for managing inflammatory conditions. Overall, *Pistacia atlantica* shows great promise as an effective anti-inflammatory agent with diverse medicinal applications.

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Section 4

Nut Contaminants

Chapter 6

Major Contaminants of Peanut and Its Products and Their Methods of Management

Esameldin B.M. Kabbashi

Abstract

Peanut (*Arachis hypogeae* L.), Fabaceae, is highly rich in protein (26%). It has popular products such as roasted peanut, peanut butter, and oil. They are vulnerable to many contaminants specified by the Codex Alimentarius, Codex Committee on Contaminants of Food (CCCF), such as biological contaminants, insects, fungi, bacteria, and toxins, which can be byproducts or native contaminants; mycotoxins, which are yard sticks in local and global trade; physical and solid objects (e.g., trash); residues of pesticides and aerial pollutants, such as heavy metals, including lead, copper, nickel, and halogens, etc., from industrial gases and wastes; and industrial byproducts, such as furans and radiation, in addition to the free radicles that arise from rancidity and other metabolic processes. The reactions from and actions taken by the organizations of pertinence are reflected in the setting of maximum acceptable limits (MALs). These include the FAO, WHO, Codex Alimentarius, the European Food Safety Association (EFSA), USA and KSA Food and Drug Administrations, the SSMO (Sudanese Standards & Metrology Organization), etc. However, researchers and governments worldwide are all involved in enormous tedious and fruitful efforts to integrate the management of these contaminants.

Keywords: contaminants, residues, biological, radiant and chemical, management

1. Introduction

Peanut [*Arachis hypogaea* L. (*A. nambyquarae* Hoehne), (*Lathyrus esquirolii* H. Lév.) [1]] is a flowering leguminous crop belonging to the family Fabaceae (Leguminosae).

It has other common names [groundnut, goober (US), pindar (US), and monkey nut (UK)] [2, 3]. This crop is grown in tropical and subtropical regions [4]. Its importance stems from being a good source of protein (an average of 25%) in the panglobal kitchen and a rich source of edible oil as well, in addition to being an essential input for salads, appetizers, etc. The nutritional value of peanut paste and grain includes 21% carbohydrates, and the percentage of vitamins is [6^{-4} B_1 (thiamine); 3^{-4} B_2 (riboflavin); 129^{-4} B_3 (niacin); 18^{-4} B5 (pantothenic acid); 3^{-4} B_6 (5MTHF glucosamine); 246^{-6} B_9 (folate); 66^{-4} E (alpha-tocopherol)]; the dietary fiber has a sizeable share of 9%, and the fat has a lion's share of 48% (7% of it is for saturated fat, and the remainder is for the mono- and polyunsaturated fat) [5]. The mineral content of peanuts contributes well to the recommended daily intake [5]. That is, the reported percentages are as follows: calcium, 62^{-3}; iron, 2^{-3}; magnesium, 184^{-3}; manganese, 2^{-3}; phosphorus, 336^{-3}; potassium, 332^{-3}; and zinc, 33^{-4}, whereas the moisture content percentage is approximately 426^{-5} [5]. The term peanut is not a true nut but is used metaphorically and is a figurative description, as it is treated in Western culinary works such as other used ones such as almonds and walnuts [6].

South America (Argentina, Brazil, Bolivia, Peru, etc.....) is the center of the origin of peanuts [7]. This is the geographic location where the most abundant diversity of peanuts has been reported [7]. However, the top ten producer countries of peanut are China (which produces almost half of the global annual production, with 47 million tons); India, which has 21% of the total global production; Nigeria (which produces 30% of the total African peanut production); Senegal (which is one of the largest peanut exporters and exports most of its production to China); Burma (which has 2 million tons of peanut annual production and ranks fifth); Chad (which is the backbone of its agricultural production, which is mostly exported); the USA (which produced 3.7 million tons in 2021); Indonesia (which contributes 4% of the total international peanut production); Argentina (which produces the top quality peanut in the world known as the golden peanut); and Ghana (which is the first cash crop in the country) [8].

The production of peanuts is better in light-textured soil with good supplementary fertilization [9]. However, the management of pests and diseases is a cornerstone for feasible production. Many pests (including insects, nematodes, weeds, rodents, and birds) attack peanuts during field and postharvest periods. In addition, a number of diseases (fungal, bacterial, virus, etc.). However, infection with *Aspergillus* species is an important concern in peanut production and marketing [10]. Therefore, it is the most important contaminant of this grain crop and has many medical implications as a cause of acute and chronic diseases, including aflatoxicosis and hepatoma, respectively [11]. In addition to being a yard stick for export quality for international markets [11].

Oil is a major product of peanuts. In addition, a number of other products are used internationally and extensively, including peanut butter (paste); roasted nuts; and product formulations in meat, soups, desserts and confections [12]. In addition, there is peanut flour, defatted peanut protein meal, peanut protein concentrate [13], peanut milk and chocolate [14]. However, there are some complications and concerns related to the consumption of peanuts and their products. Others include weaning foods (Khalil, personal communication). These include the following:

1. The sensitivity to peanuts ranges from difficulty in digestion to severe allergies. The term "allergy to peanut" refers to a specific protein, *viz.* immunoglobulin E (IGE) and anaphylatoxins [APTs, release histamine and secretions of mast cells (enhance degranulation)]. Histamine causes dilation of vessels and pulmonary bronchioles (bronchispasm). The symptoms of this allergy include many signs that vary from vomiting to anaphylactic shock [15]. In Canada, it is not allowed to use any nut or nut products in food industry plants, which are labeled "NUT FREE ZONE."

2. Contaminants: These include physical (stones, trash, pieces of glass, debris, etc.).), biological [microbial (fungal and bacterial) and insect (live and parts

of them and their excreta) [11]], chemical [residues (pesticides, radiants, and heavy metals such as lead), byproducts of cooking (furans [16], nitrosamines, nitrates and nitrites [17], and microbial byproducts (mycotoxins) [11]].

The incessant consumption of peanuts is linked to protection from a variety of diseases, including diabetes II [18]; heart and vessel diseases [19]; cancers of the colon, prostate, and breast [20]; osteoporosis and protein hunger [21]; and combating the complications associated with obesity and metabolic syndrome [22].

2. Contaminants of peanut and its products

Peanut (*A. hypogea*) and its products, such as peanut butter, are considered the main input and spinach, respectively, in the panglobal kitchen. The oil, as a major product, is also subjected to contamination by a number of exotic and ordinary, native, and unwanted problematic constituents. That is, the ordinary products include allergens such as immunoglobulin-E (IGE) and the free radicals of catabolized fatty acids such as hydroperoxide and its other products due to decomposition, mainly by heating [23].

2.1 Native and unwanted seed constituents

These are ordinary materials that naturally constitute the raw peanut or the products that arise from the processing of the peanut itself and have conflicting interests with human digestion and health.

2.1.1 Native constituents

These include immunoglobulin-E, Arachis hypogea 2 (Ara h 2), and Ara h 6, [reduced and alkylated in the presence or absence of glutaraldehyde (RAGA)] [24]. These two proteins are specific markers for peanut allergies. Ara h 2 (the most potent of these allergens) is the dominant allergen, and Ara h 6 shares 60% similarity with the former [25]. Other allergens include Ara h 1, Ara h 3, Ara h 8, 2S, 7S, and 11S [26]. Studies on peanut allergies revealed that it affects more than 1% of the developed world population [24]. Peanut 2S albumins (Ara h 2/6) do not respond to or tolerate proteolysis in the gastrointestinal tract (GIT) of patients or at high temperatures. That is, by doing so, they are found to be the most effective in inducing the more unadorn types of peanut allergies [27].

2.1.2 Native constituent byproducts

2.1.2.1 Polyunsaturated fatty acids (PUFAs)

These compounds are more responsive to changes than the mono- and saturated analogs because of the following:

- *Autooxidation*: These enzymes are highly degradative due to their strong response to autooxidation. This sharply reduces their shelf life at ambient temperature [28]. PUFAs degraded at high oil temperatures (150°C/302°F). The byproducts are free radical chains that result in the production of hydroperoxide, which is a complex of secondary products [23].

- *Hydrogenation*: This process results in a small amount of saturated fatty acids from PUFAs. These products include intermediate monounsaturated carbon 20 derivatives [28].

2.1.2.2 Other products

- The roasting of peanuts in dry air at 140–180°C for 5–10 minutes affects the oil quality. That is, it reduces the peroxide value, radical scavenging activity (RSA), and conjugated dienes. Most of the quality indices of oil from roasted peanuts are greater than those of oil from raw seeds [29].

- Byproducts of cooking produce furans [16], nitrosamines, nitrates and nitrites [17], and microbial byproducts mycotoxins [11]. The nitrogen-containing byproducts result from peanut browning [16].

2.2 Management of peanut allergy

Peanut induces unembellished allergies in humans [30, 31]. To date, no cure has been reported for peanut sensitivity [32]. However, mitigation can be achieved through a number of invented methods. These methods include the following

1. Altering the chemical structure of Ara h2 and Ara h6 causes a reduction in the negative impact of peanut allergy therapy (by approximately 100-fold) [33].

2. The subcutaneous injection of CPE (crude peanut extract) showed good results with a low probability of unwanted effects [34].

3. Modification of the allergenic peanut proteins results in low IgE binding and consequently low allergy [34].

4. The use of peroxidase (POD) as a catalyst in tyrosine oxidation leads to reduced allergenic activity of peanut proteins [35].

5. The allergenicity of peanut proteins is reduced by polyphenol oxidase (PPO) [35].

6. Epinephrine treatment by inhalation and injections for moderate and severe peanut allergies, respectively, is recommended [36].

3. Exotic peanut contaminants

3.1 Physical contaminants

3.1.1 Heavy metals

Metals with an atomic number greater than 20 or an atomic density higher than 5 g cm^{-3} were included [37]. They are divided according to their importance to living organisms into two groups: essential, which includes copper (Cu), iron (Fe), manganese (Mn), cobalt (Co), and zinc (Zn), and nonessential, such as cadmium (Cd) and lead (Pb) [37]. An example of this contamination is the following: A known food company called for approximately 1,500,000 (one and a half million) kilograms of peanut butter after a suspicion of contamination with an iron shed from a defective machine [38]. Another example is the confirmation of the contamination of roasted peanut spinach with lead (Pb) in samples collected from main bus stations in Pan Khartoum (the triangular capital of Sudan). The source of contamination is the engine exhaust of the busses at these stations. That is, most of these automobiles used leaded fuel. This appeared in a Ph. D. thesis at Alahfad University for Women, Omdurman, Sudan (Eldirdiri, a radio interview, Omdurman Radio, Sudan Broadcasting Corporation, 2016). Heavy metals have deleterious effects (in overdoses) on humans and their environment. That is, they ignite cancer and negatively affect DNA, proteins, and lipids by giving rise to free radicals [39]. Metallic pollutants can be managed by a variety of methods, including waste biomass (such as peanut hulls and chitosan cross-linked beads) adsorption methods. Peanut hulls can be used as adsorbing materials for the removal of heavy metals from extracts. Peanut hulls exhibited 88.6 ± 1.9% cadmium removal without a reduction in phenols. However, the weak removal of arsenic by this method necessitates its use as an effective removal method for heavy metals only. That is, the percentage removal of arsenic was 21.7 ± 9.5% [40]. However, in the food industry in Canada, a metallic detection system involving sensitive sensors is used. An alarm sounds when a contaminated item passes through the conveying belt in front of the sensor and is consequently removed from the packaging. However, multiscanning inspection for metals can include X-ray detection devices [38].

3.1.2 Other physical contaminants

These include any hard food, such as jewelry, pieces of glass, plasters and bandages, staples, wraps of plastic and packaging materials, mummies of insects, parts of rodents, and crop residue (debris). That is, all the unwanted objects [41]. The management of physical contaminants in food can include PPE (protective personal equipment), such as hair nets and beard nets; the use of colored bandages to be easily seen and located if dropped into food items; the removal of food plants from jewelry, glass and other similar potential pollutants; the keen cleaning of fruits and vegetables; and the sound management of pests [41].

3.2 Chemical contaminants

These include unwanted chemical constituents from different sources that pollute food. They generally include two major groups according to their origin.

3.2.1 Industrial contaminants

Nitrate, chlorinated environmental contaminants of PCBs (polychlorinated biphenyls), dioxins, and chlorinated pesticides. Other environmental contaminants, such as brominated flame retardants and perfluorinated compounds, and contaminants formed during food preparations, *viz*. acrylamide, furan, 3-MPCD, and polycyclic aromatic hydrocarbons (PCHs) [42]. A plethora of chemicals used in industry in general and in the agri-food industry pollute the environment and eventually affect food safety in one way or another [43]. Some chemical contaminants can arise from chemical reactions in postharvest and cooking conditions. These include free radicals from rancidity in peanut. However, these chemical contaminants include synthetics such as cleaning products (e.g., detergents and sanitizers), pesticides, toxic chemicals in metallic and plastic containers, preservatives, etc., and disposal products from industrial plants such as chlorine, oil leaks and wastes, and radioactive residues.

3.2.1.1 Disposal and waste products

The byproducts of the industrial sector need proper disposal. However, there is usually no proper handling of these materials, which are mostly harmful to the environment. These include liquid chlorine water, ammonia, and other chemicals that endanger human life and the life of his domestics and pollute the environment and consequently any produce from it, directly or indirectly.

3.2.1.2 Environmental pollution

This concerns gas emissions and other radiants and pollutants as well. These include the industrial sector, automobiles, and other machines that emit radiation and pollutants. Advanced countries have a large share of environmental pollution, whereas the reverse is true for developing countries in terms of mismanagement of industrial disposal and pollutants. Both of these factors contribute to global warming panic. These contaminants can affect cultivated crops and peanuts. However, it may be worth mentioning that the International Atomic Energy Agency (IAEA) has performed interstate inspections of the irradiation. In Sudan, a colleague spoke about irradiation over the allowed limits in the Khartoum and Kordofan States. These include irradiation from a therapy unit and natural irradiation from indigenous sources (Hassan, joint occupational safety discussion).

3.2.2 Naturally occurring contaminants

These are the constituents of native origin. These compounds include the alkaloids that occur in tubers (e.g., potato) and fruits (e.g., tomato), *viz*., solanine, which can be observed as green islands. The toxicity of these chemicals depends on the dose taken; generally, the symptoms associated with them extend in severity from headache and digestive upset to convulsion and death [41]. Other native alkaloids of high toxicity are ricin and ricinine in castor bean oil [44]. In peanuts, such native contaminants, including IssgE proteins, which are known allergens, cause symptoms ranging from GIT upset to anaphylactic shock [15]. These harmful proteins include Arachis hypogea 2 (Ara h 2 constitutes approximately 60% of allergens), Ara h 6, Ara h 3, and Ara h 8 [25, 26]. Other allergens include 2S, 7S, and 11S [26].

3.2.3 Residues

Residues are the remains, remainders, or remnants of the chemical used in a treated material or untargeted material (passively). These include inputs in animal production, such as vitamins and antibiotics, as well as volume materials, such as the prion protein that causes bovine spongiform encephalopathy (BSE), and the justification of the transformation of this protein into a pathogenic form that damages the CNS is not yet well understood [45]. However, the interception of beef and chick meat from countries that consume animal protein has long occurred in some countries, such as Saudi Arabia (Addas and Alagab, separate personal discussions). That is, they believe that prion protein residues are the cause of this madness [45]. However, there is an interference between physical and chemical contamination because the residues of metals can also be considered to be similar to other chemical agricultural inputs.

Pesticide residues are among the most important residues in the food production, agri-food, and food industries. Due to the importance and the expected impacts of residues on human health and living possessions, international organizations of concern have set voluminous packages and regulations to manage such conflicting interests in the use of pesticides and chemical agricultural inputs in general. These organizations include the WHO, FAO, UNEP, IFAD, ILO, UNIDO, UNDP, etc. (Palestina, personal discussion). The WHO has annexes of the parameters needed to pass a pesticide for use at the international level [46]. However, every country has its own regulations for the use of pesticides, away from international organizations, but runs the same route of concern about health and safety. In Sudan, the National Council for Drugs and Toxins (NCDT) is responsible for the licensing of pesticides and drugs. However, any pesticide must be tested by the Agricultural Research Corporation (ARC) for two consecutive seasons with thorough residue analysis, regardless of international regulations. The results of the testing and screening will be presented at an annual meeting of the pests and diseases committee at the ARC HQ. A thorough discussion will determine whether a chemical can be passed for use at the commercial level [47]. With respect to peanuts, the pesticides used include those used against terrestrial pests and those that attack foliage. A characteristic and unique phenomenon of peanuts is their flowering and fruiting pattern. That's, the flowers send pegs to the ground and then set fruits underground. Therefore, residue from pesticides applied to the soil is more likely.

The residues were evaluated by sophisticated laboratory techniques, including thin layer chromatography (TLC), gas liquid chromatography (GLC), high-performance liquid chromatography (HPLC), gas chromatography–mass spectrometry (GC–MS), atomic absorption spectrometry (AAS), spectrophotometry, and other sophisticated rapid techniques, such as the use of check papers (paper strip-based sensors) [48]. The FAO/WHO Joint Meeting on Pesticide Residues (JMPR) determined the allowable residue limit for each pesticide for every crop. The allowed daily intakes (ADIs) and the acute reference doses (ARfDs) were also set [49]. Residue analyses of pesticides in peanut butter by the USDA/PDP (United States Department of Agriculture/Pesticide Data Program) reported a number of insecticides in peanut butter. These include piperonyl butoxide at 26.9%, DDE at p,ṕ (3.7%), pentachloroaniline (PCA, 1%), quintozene (PCNB, 0.5%), fluazinam (0.3%), pentachlorobenzene (PCN, 0.1%), and malathion (0.1%) [50]. The safety margin is an important index in crop production and food quality. That is, the period postspraying and before harvest. This will allow the pesticide to be at the recommended allowed level that is not harmful to the consumer and is acceptable in local and international markets [51].

The preventive measures against chemical contaminants include the following:

1. Clean containers and the right label for the chemical containers were used.

2. The chemicals were used cautiously and carefully.

3. The cleaning procedure must be appropriate, and the cleaning materials must be washed carefully.

4. Cross-contamination was avoided by following the appropriate protective measures.

5. Pesticides must be used under experienced supervision in pre- and postharvest practices.

6. Use of sophisticated techniques in monitoring pollutants in food. These include nanomaterial-based electrochemical detection of chemical contaminants [52].

7. The residues in the import and export crops and in the local market were monitored by periodical checks.

8. Since the residue has a large reliance on preharvest practices, a good crop husbandry approach (a good agricultural practice, GAP) is mandatory and requires considerable critical knowledge. This necessitates the supervision of companies and/or official bodies to address these issues, including pesticide application [53].

3.2.4 Mycotoxins

The etymology of the prefix myco refers to the Greek word *mykēt, which means mushroom or fungus. Accordingly, the complex word mycotoxins refers to fungal poisons* [54]. Aflatoxins are fungal metabolites and byproducts that, when ingested, inhaled, or absorbed through the skin, cause lowered performance, ailment, or ultimately death in humans and domestic plants, including birds [55]. Aflatoxins were first discovered in Great Britain in the 1960s after an outbreak of a term "X disease" in turkey folk food, which was fed a contaminated imported peanut from Brazil. The contamination was determined to be due to a toxicant named aflatoxin, which is a fungus producer known as *Aspergillus flavus*. *A. flavus* is a fungus of great global concern because it is the causal organism of acute aflatoxicosis that caused an outbreak in the turkey folk in GB and mass death [56, 57]. However, the more important concern of this fungus is its ability to cause hepatic cancer "hepatoma." Accordingly, keen vigilance is given to imported and locally produced food and feed regarding this toxin [58]. The panorama of this *subtitle* may include the following: the types of mycotoxins and their sources; the set safety limits allowed for these toxins and the figures of different organizations, countries, and unions; the different methods of detection and appraisal of contamination by these toxins; the available protective measures and their applicability; and the treatment methodologies available to date.

3.2.4.1 Types and producers of mycotoxins

A number of toxins from fungal sources were identified decades ago. These mycotoxins include deoxyvalenol (DON), fumonisins, fusarium toxins, and other mycotoxins [acetoxyscirpenediol, acetyldeoxynivalenol, acetylneosolaniol, acetyl T – 2, aflatoxins, aflatrem, altenuic acid, alternariol, austdiol, austamide, austocystin, avenacein +1, beauvericin +2, bentenolide, brevianamide, butenolide, calonectrin, chaetoglobosin, citrinin, citreoviridin, cochliodinol, crotocin, cytochalasin E, cyclopiazonic acid, nevalenol (NIV), ochratoxins, and zearalenone] [59, 60].

3.2.4.1.1 Fusarial toxins

These secondary metabolites are produced by *Fusarium* spp.; they occur naturally in different cereals, and their presence is unavoidable at different concentrations depending on the surrounding factors. These include: 1. Trichothecenes (DON, T–2/HT–2 toxin, and nivalenol); 2. Fumonisins (FB1, FB2, FB3, and FB4); 3. Zearalenone (ZEA, ZON, and F–2 toxin), and 4. Moniliformin [61].

3.2.4.1.1.1 Trichothecenes

These species are not reported in hot and dry climates despite the presence of their known producers (*Fusasrium* spp.) [11].

Deoxynivalenol (DON): DON is produced by some Fusarium spp. in grains in the field or postharvest [62]. However, many mycotoxins have been reported from peanut and maize in East Africa. These mostly include aflatoxins, fumonisins, zearalenone, and deoxynivalenol [63]. The chemical formula of DON is $C_{15}H_{20}O_6$, whereas its IUPAC name is 3α,7α,15-trihydroxy-12-13-epoxytrichothec-9-en-8one [64]. It contaminates food and feed, and the risk to humans is through contaminated food or from animals fed contaminated feed. The health complications of DON include symptoms such as headache, severe nausea, abdominal upset, tiredness, and high body temperature. In addition, there are negative complications such as antagonism and reproductive interference [62]. DON is famous for the name vomitoxin (a potent vomiting-inducing toxin). It is also considered an immunosuppressant toxin; it has a negative effect on immune system activities and leucocytes and can cause death [65]. There has been a reported success in reducing DON contamination in animal feed (contaminated corn). That is, Don was adsorbed by an alginate/carboxymethyl cellulose sodium composite loaded with calcium (SA/CMC-Ca) made by emulsification in a microsphere adsorbent [66]. Three fungi were found to be effective at conjugating DON. These were *Alternaria alternata*, Rhizopus microsporus var. rhizodiformis, and Aspergillus oryzae. They are capable of transforming DON into conjugated hydrolyzable DON with a percentage range of 13–23% in PDA media and 11–36% in corn-based media. However, *Fusarium oryzae (F. oryzae)* was found to achieve 92% degradation of DON in corn-based media over 3 weeks [67].

T – 2: T – 2 toxin (fusariotoxin T2, insariotoxin, and mycotoxin T2) is a trichothecene fungal byproduct toxin. Its molecular formula is $C_{24}H_{34}O_9$. The T2 IUPAC name is (2α,3 α,4β,8α)–4,15–bis(acetyloxy)–3–hydroxy–12,13–epoxytrichothec–9–en–8–yl 3–methylbutanoate [68, 69].

T–2 is poisonous to humans and his domestics. It causes alimental aleukia symptoms such as nausea, vomiting, diarrhea, leukopenia, hemorrhaging, skin inflammation, etc., and cutaneous toxicity is not observed, despite some dermal effects [69]. Its LD_{50} is as high as 1 mg/kg bw. The EFSA (European Food Safety Association) set the average exposure amount of T–2 to be 12–43 ng/kg bw/day. This value is less than the TDI of 100 ng/kg bw for both HT–2 toxin [70]. The treatment of T–2 toxicity is mainly symptomatic, and no cure or medication is prescribed. However, it is advisable for charcoal to bind with this toxin upon ingestion, *i.e.*, it has excellent binding ability with T–2. However, prophylactics have also been reported to be useful in mitigating toxicity [71].

HT-2: HT-2 IUPAC name: [(1S,2R,4S,7R,9R,10R,11R,12S)–2–(acetyloxymethyl)–10,11–dihydroxy–1,5–dimethylspiro [8–oxatricyclo [7.2.1.$0^{2,7}$]dodec–5–ene–12,2′–oxirane]–4–yl]3–methylbutaoate. Its molecular formula is $C_{22}H_{32}O_8$. It is a product of Fusarium fungus and is also a byproduct of the metabolism of T–2 toxin. It is usually a grain contaminant, and accordingly, it is a risk to humans and their animals [72]. It has an advantage over T–2 in that it passes more easily through the blood brain barrier, causing neurotoxic apoptosis [73]. It has also been reported to affect anorexia [74] and weight loss [75]. No observed adverse effect levels (NOAELs) or lowest observed adverse effect levels (LOAELs) were derived for different animal species. In ruminants, an LOAEL was established for the sum of T2 and HT2 of 0.3 mg/kg body weight (bw) per day, based on studies with calves and lambs [76].

Nivalenol: Nivalenol (NIV) is a fusarial toxin that belongs to the trichothecene group. It is a major contaminant of cereal and cereal products in temperate, moist, and cool climates [77]. The chemical formula of this toxin is $C_{15}H_{20}O_7$, and its chemical name is (3α,4β,7α)–12,13–poxy–3,4,15–tetrahydroxy–trichothec–en–8. NIV has been reported to alter many biological routes. The most famous pathway is the NF–kB pathway, which is a transcription factor and a constituent of rather all human cells. It alters cytokine expression. That's, it's a genotoxic agent. It also promotes the production of IL–8, an inflammatory mediator. It also affects MCP–1/CCL2, which govern mononuclear leukocytes [78, 79]. Chemokine secretion is inhibited by NIV, which negatively affects the immune system; all these studies were in small test animals [80, 81]. NIV has not been reported to have adverse effects on humans or domestics other than immunosuppression [82]. NIV is metabolized in the liver but also partly by GIT microbes. However, the main degradation component is the epoxy group, which is the most toxic, and the main deactivation product is de-epoxynivalenol [83]. The metabolites of NIV include acetyldeoxynivelenol, DON, and iso-deepoxy-DONglucuronides [84].

Diacetoxyscirpenol: Its other names are DIA and anguidine. The IUPAC name for DIA is 3α-hydroxy-12α,13-epoxy-trichothec-9-ene-4β,15-diyl diacetate. The chemical formula of DIA is $C_{19}H_{26}O_7$ [85].

Trichothecenes are classified into two categories according to their toxicity. This group has one of the greatest adverse effects on humans and their animals and includes T–2, HT–2, and diacetoxyscirpenol. The second group of less toxic compounds included DON, NIV, and 3- and 15-acetyldeoxynivalenol. However, it is worth mentioning that DON is of concern in Europe because it is the most prevalent trichothecene [86]. Like other trichothecenes, DIA does not require activation to react with host cell constituents. It also induces cytotoxicity, apoptosis, inhibition of nucleic acid synthesis, and mitosis [87]. No antidote for trichothecenes is known; therefore, treating affected patients symptomatically and administering charcoal powder orally when the toxin is ingested is vital [88].

3.2.4.1.1.2 Fumonisins

They are produced by Fusarium spp. and their Liseola section (including *F. verticillioides, F. proliferatum, F. subglutinans, and F. temperatum*) [89, 90]. There are four main types of FBs: FB_1, FB_2, FB_3, and FB_4. However, a number of variable fumonisins have been reported in addition to other secondary metabolites, some of which do not occur naturally [91]. In addition, a peculiar fumonisin is produced in grapes infected with *Aspergillus welwitschiae* [92]. *Fusarium* spp. infect peanuts and contaminate them with FBs. That is, the highest FB contamination, which was 18,184 μg/kg, was reported in maize in Tanzania [63]. Nevertheless, the East African Bureau of Standards has set limits of 5 ppb for AFB1, 10 ppb for total AFs, and 2000 ppb for FBs in maize and peanuts [63]. The IUPAC name of fumonisin B2 is 2–[2–[19–amino–6– (3,4–dicarboxybutaneoyl)–16,18–dihydroxy–5,9–dimethylicosan–7Cyl]–oxy– 2oxoethyl] butanedioc acid. The chemical formula of fumonisin B_2 is $C_{34}H_{59}NO_{14}$. It is structurally analogous to fumonisin B_1, which is less toxic than fumonisin B1, and both are cytotoxic. Fumonisin B_2 impedes sphingosine acyltransferase. It is a member of the monoterpene family that contains two isoprenes [93]. The PMTDI (permitted margin … daily intake) of FB1, FB2, and FB3, separately or together, is 2 μg/kg bw (2 PPb/kg bw), as set by the FAO/WHO/JECFA [93]. FB2 is hepatotoxic and nephrotoxic. It increases apoptosis and consequently cell regeneration. Other complications include bone marrow suppression, sepsis, hemosiderosis, leukopenia, and repeated hemorrhages. Other negative impacts include hypertension, angina, tachycardia, cardiovascular system dysfunction, and disruption of sphingolipid metabolism [93]. The PMTDI (permitted margin … daily intake) of FB1, FB2, and FB3, separately or together, is 2 μg/kg bw, as set by the FAO/WHO/JECFA [93]. Moreover, the East African Bureau of Standards (EABS) set regulatory limits for total fumonisin(s) in peanut and maize at 2000 ppb [63]. The gap between the limits set by international organizations and those set by regional organizations is very large (2 and 2000 ppb, respectively). This needs a quick revision, discussion, and action from the African and the international experts. That's, African health and safety truly matter.

3.2.4.1.1.3 Zearalenones

Zearalenone is a fusarial toxin also known as Zea, Zon, and F-2 [94]. It is also produced by *Gibberella* and mostly *G. zeae* [95]. It is mostly produced in the field and contaminates products [61]. However, many mycotoxins have been reported from peanut and maize in East Africa. These mostly include zearalenone, aflatoxins, fumonisins, and deoxynivalenol [63]. The IUPAC name of Zea is (3S, 11E)–14, 16–dihydroxy–3– methyl –3, 4, 5, 6, 9, 10–hexahydro–1 *H*–2–benzoxacyclotetradecine–1, 7(8*H*)–dione. However, its chemical formula is $C_{18}H_{22}O_5$ [96]. Zea is an analog of estrogen, and its metabolite α-zearalenol has a strong affinity for binding to estrogen receptors (xenoestrogens) [97, 98]. By doing so, it interferes with the reproductive activities of man and his domestics. The abovementioned effects include many sexual disorders, such as deformities in genital organs [99, 100], early puberty in females [101], a reduction in sperm and ova, and a decrease in the viability of the bearings [102]. The topical exposure of humans to zea has not been associated with any expected hormonal complications [69]. The tolerable daily intake of zea is reported to be 0.25 g/kg bw [103]. However, no acute toxicity of zea has been reported. Treatment of zea by nontoxic microbes results in its detoxification, in addition to the success of detoxifying zea by adsorption and biotransformation [104].

3.2.4.1.1.4 Moniliformin

It is a product of a number of *Fusarium* spp. (*avenaceum*, *subglutinans*, *proliferatum*, *fujikuroi*, etc.). Its IUPAC name is sodium 3,4–dioxo–1–cyclobutene–1–olate. The chemical formula of this mycotoxin is NaC_4HO_3. However, it is hazardous to the cardiovascular system because it is cardiotoxic and interferes with respiration by obstructing the functions of the pyruvate dehydrogenase complex. It also causes hypertrophy of the ventricles. These complications are induced by the sodium salt of deoxysquaric acid (semisquaric acid) [105]. The major symptoms of acute Mon toxicity include muscular fatigue, difficulty breathing, myocardial degeneration, sickness, and changes in organs (e.g., kidney, pancreas, and lungs). In severe toxicity, coma and mortality are expected [106].

3.2.4.2 Aflatrem

Aflatrem is strongly tremorgenic and is a product of terrestrial *Aspergillus flavus*. It is a bundle of different byproducts known as indole–diterpenes [107]. Its chemical formula is $C_{32}H_{39}NO_{4,}$ and its IUPAC name is (1S,4R,5S,16S,19S,23R)-19-hydroxy-4,5,24-tetramethyl-12-(2-methylbut-3-en-2-yl)-25,26-dioxa-7-azaheptacyclo[21.2.1].$0^{1,20}.0^{4,19}.0^{5,16}.0^{6,14}.0^{8,13}$]hexacosa-6(14),8,10,12,20-pentaen-22-one. At a dose of 3 mg/kg, aflatrem reduced the transmitter GABA (gamma amino butyric acid) and glutamate capacity in the rats beginning on day 1. This is attributed to the effect of these toxins on nerve terminals [108].

3.2.4.3 AFXs

Aflatoxins are mainly produced by two fungi, *Aspergillus flavus* and Aspergillus *parasiticus*. The first fungus produces B aflatoxins (AFB1 and AFB2), whereas the latter produces both AFB and G types (AFG1 and AF2). Only half of the strains of *A. flavus* are capable of producing aflatoxins (toxigenic fungi), whereas 99% of the strains of *A. prasiticus* can produce aflatoxins [11]. The shedding of ultraviolet light into AFBs, AFGs, and AFM_1 yields the following: 1. The blue color indicates AFB_s and AFB_2; 2. Green indicates AFG_1 and AFG_2, and 3. Blue–violet color for AFM_1 [109, 110].

3.2.4.3.1 AflatoxinB

The AFB_1 IUPAC name is (6aR,9aS)–4–methoxy–2,3,6a,9a–teterahydrocyclopenta [3′,2′.4,5] furo [2,3-h] [1] benzopyran–1,11– dione. Its chemical formula is $C_{17}H_{12}O_6$ [111, 112]. It is mainly produced by *A. flavus* and *A. parasiticus*. It is a super potent hepatocarcinogen [113]. AFB1 is a known contaminant of peanuts and many foods, including cottonseed and grain, in addition to feed [114]. Ingestion of AFB1 causes many health complications, including immunosuppression, teratogenicity, mutagenesis, and hepatoma, and is a chronic ailment. However, aflatoxicosis is an acute sickness caused by AFs [115, 116]. It can also cause infection in humans through the skin or inhalation. Infection can cause many complications due to the growth of the fungus *A. flavus*, which has long hyphae and colonizes the lungs, respiratory tract, or even cavities around the brain. This may also cause death and other fatal complications that require surgical intervention and long-term treatment (Ahmed, the National Medical Laboratory, Khartoum, joint work and consultancy, 2001). However, a master's student at the University of Khartoum died from infection due to the fungus he was working on in his laboratory in the 1980s (Bhagdadi, personal discussion). The tumor dose that causes half of the test population without tumors throughout the test period (TD_{50}) for AFB_1 is 3.2 μg/kg/day in rats [117]. The oral LD_{50} for AFB1, which causes acute toxicity, ranges between 0.3 and 17.9 mg/kg bw for most animal species [118]. The maximum permitted level (mpls) of total AFs set by the US FDA is 20 μg/kg (ppb) in all food items [119], despite milk having a mpl of 0.5 ppb [120]. However, 100–300 ppb TAF is permitted in feed in the USA [120]. However, for the EU, mpls are 2–12 ppb for most foods and only 0.1 ppb for AFB1 in infant foods [121]. The corresponding values for the JECFA/FAO/WHO are 15 ppb for the total AFs in raw peanuts and only 10 ppb in processed peanuts [122]. However, the mpl of AFB1 alone is 5 ppb in dairy cattle feed [123].

3.2.4.3.2 AFX B2

The chemical formula of AFB_2 is $C_{17}H_{14}O_{6,}$ and its chemical name is Cyclopenta [c]furo [3′,2′,4,5] furo [2,3-h] [1] benzopyran-1,11-dione, 2,3,6a,8,9,9a-hexahydro4-methoxy-, (6aR-cis) [124]. It is less toxic than AFB_1. It is mainly produced by *A. flavus* and *A. parasiticus*.

3.2.4.3.3 Aflatoxin G1

Aflatoxin Gs are coumarins. That's, they are benzopyrones and hepatotoxic. They are mainly produced by *A. parasiticus*. The IUPAC name of AFG_1 is 11–methoxy–6,8,16,20–tetraoxapentacyclo[10.8.0.$0^{2,9}$.$0^{3,7}$.$0^{13,18}$]icosa–1,4,9,11,13(18)–pentaaene–17,19–dione, and its chemical formula is $C_{17}H_{12}O_7$. The acute toxicity of this toxin is characterized by the following symptoms: skin and eye irritation, vomiting, abdominal colic, hemorrhage, and pulmonary edema [125]. The treatment is mainly symptomatic, and no antidote is available.

3.2.4.3.4 Aflatoxin G2

The AFG2 IUPAC name is (3S,7R)–11–methoxy–6,8,16,20–tetraoxapentacyclo[10.8.0.$0^{2,9}$.$0^{3,7}$.$0^{13,18}$]icosa–1,4,9,11,13(18)–tetaene–17,19–dione, and its chemical formula is $C_{17}H_{14}O_7$ [126]. It is mainly produced by *A. parasiticus* [125]. B and G are the least toxic aflatoxins.

3.2.4.3.5 Other aflatoxins

Aflatoxins other than those in the B and G groups include AFM_1, which is a metabolite of AFB_1 in humans and animals. It is usually found in milk and possibly in meat. AFM_2 is a common contaminant of milk and animal food products and a product of AFB_2 [127]. AFQ_1 is an *in vitro* product of AFB_1 metabolism in the liver of higher animals, and aflatoxicol is a product of the breakage of the lactone ring [128]. AFM, AFQ, and AFL can be used to detect epoxides. However, they are far less toxic than their original sources [129].

3.2.4.3.6 Protective measures against aflatoxins

3.2.4.3.6.1 Aflatoxin analysis

The general appearance of the seed: A healthy seed lot has the typical appearance of a peanut seed. That's, a sound seed with no spots, intact, no pits, clear of breaks, and any abnormality, generally speaking.

Checking for toxins: This can be performed through a variety of methods that can meet demand and availability requirements. These tests include the aflacheck® test, which is a rapid and easy-to-apply method; the other immunoaffinity test is the enzyme–linked immunosorbent assay (ELISA) [11].

Other tests require high-quality and precise equipment and instrumentation. These include TLC (thin layer chromatography), high-performance liquid chromatography (HPLC), gas chromatography–mass spectrometry (GC–MS) and high-performance thin layer chromatography (HPTLC) [11].

3.2.4.3.6.2 Preharvest aflatoxin preventive measures

These include the following.

1. Avoidance of drought stress 2. GAPs (good agricultural practices), which include good weeding, insect control, and recommended spacing; 3. Avoidance of breakage in the seed lot and use of grading to eliminate unsound seeds. 4. Considering that *A. flavus* is a commensal fungus in the field, adopting the GAP approach will at least minimize its occurrence. 5. Use of resistant varieties by AF producers.

Preventive postharvest measures for aflatoxin treatment.

1. The harvest was kept *dry* and *cool*. 2. Good harvesting methods can end with sound seed lots. 3. Good transportation (no contamination, no seed damage, etc.). 4. Competitive exclusion biocontrol is also helpful. 5. The harvest was inspected to eliminate unsound seeds due to damage, coloring, etc..... 6. Good storage is needed.

3.2.4.3.7 Aflatoxin treatment

The occurrence of aflatoxins is inevitable [61]. Accordingly, methods for treatment are highly needed to detoxify these toxins and contaminants in food commodities. A number of methods and trials have been reported to address this concern. These include the following:

1. Good manufacturing practices, as mentioned earlier, can remove aflatoxins by proper refining of oil.

2. The bacterial strains *Lactobacillus* sp. and yeast can detoxify AFB_1 by 60 and 65%, respectively [130].

3. Lactic acid bacteria (LAB) strains were used to detoxify AFB_1 and ochratoxin A (OTA). *Lactococcus lactis* ssp. *lactis* 1, *Lactococcus lactis* ssp. *lactis* 2, and *Lactobacillus paracasei* ssp. *paracasei*, were specifically identified by molecular biology as *Enterococcus faecium* and *Enterococcus durans*. The removal ability of both AFB1 and OTA was 50%, regardless of the viability of the bacterial cells [131].

4. Extracts of 13 herbs were tested for aflatoxins. The most potent of these extracts against the mentioned toxins were *Hybanthus enneaspermus*, *Eclipta prostrata,* and *Centella asiatica*. Therefore, 70% of AFB1 detoxification was confirmed by GC–MS [131].

5. The juice of lime (*Citrus aurantifolia* L.) was used to detoxify AFB_1 in peanut paste (Dakwa). The results revealed a reduction in AFB_1 of 11 and 31% after treatment with 0.5:1 and 1:1 lime juice (ml): Paste (g) for 1 day, respectively. In addition, the corresponding results after 3 days and 7 days of storage of the abovementioned proportions were 54 and 66% and 74 and 92%, respectively [132].

6. Bioagent detoxification of AFs is an environmentally friendly technique and innovation. These materials are specific, tolerate high temperatures, and do not harm the environment. The probiotics *Bacillus subtilis* and *B. velezensis* are highly effective at degrading AFs [133].

7. Ammoniation is considered the best aflatoxin detoxification technique for grain. This approach is easy, applicable, and economical at the commercial level [134].

8. High-temperature treatment is used by some researchers to degrade AFs. However, this is not a suitable technique because of the following

    a. AFs are resistant to high temperatures up to 300°C [55].

    b. High temperature may reduce aflatoxin contamination but will negatively affect food quality drastically.

3.3 Biological contaminants

There are two main categories of store product insects (SPIs) of grain: primary and secondary pests. The primary pests penetrate and directly damage the grain or seed, whereas the secondary ones are opportunistic and make use of the damage caused by the primary ones or any other ones to further damage and feed on them. The damage caused by secondary pests is sometimes far greater than that caused by primary pests. The SPIs that may contaminate peanuts include the following: lesser grain borer (Rhyzopertha dominica L.), grain weevil [*Sitophilus* spp. (*oryae*, *Zeamais*, and *Granarius*)], red flour beetle (*Tribolium castaneum* Herbest), loose flour beetle (*Tribolium confusum* Jacquelin du Val), Weevils [*Sitophilus* spp. (*zeamais*, *Garanarius*, and *oryzae*)], sawed–toothed grain beetle [*Orazaephilus surinamensis* (L.)], booklice, psocids, (Liposcelis bostrychophila Badonnel.), almond moth [*Ephestia keuhneilla = Cadra cautella* (Walker)], Angoumois grain moth [*Sitotrga cerealella* (Olivier)], dermestids [Khapra beetle (Trogoderma granarium Everst) *and* warehouse beetle (*Trogderma variabile* Ballion)], flat grain beetle [Cryptolestes ferrugineus (Schönherr)], bruchids [bean weevil (*Acanthoscelides obtectus* Latreille)], larger grain borer [Prostephanus truncatus (Horn)], cowpea bruchid [*Callosobruchus* maculatus (Fabricius)] and some moths such as the almond moth [*Ephestia cautella* (Walker)] [11]. The management of these pests begins in the field, followed by storage. These include cultural, biological, chemical, legislative control, and the production of resistant cultivars and IPM [11].

4. Organic production approach

The production of organic matter, which is a naturally produced food, has received vigilance and a focus all over the world. That is, organic (sometimes known as bio) food commodities are more expensive, often folded, than ordinarily produced ones. This reflects the importance of the economies of such production and its health impacts. From the point of view of contaminants, this approach plays a large role and has a large role in solving this problem. The slogan of the environmentalist "Back to Nature" is valid here.

5. Conclusion

The peanut plant (*A. hypogea*) is an important food crop that is rich in protein, oil, and other essential minerals and nutritional elements, such as dietary fibers. It is an important global item in food security plans. That is, it has, rather, an unavoidable appearance at the dining table in a mosaic of recipes such as appetizers, dressings, sauces, salads, stews, and spinach for the rich and the poor.

The contaminants of peanuts and their products play a determining role in their marketing and food safety concerns. These contaminants can be natural (peanut constituents), physical, chemical, biological, industrial, or any other foreign material. The most important of these with respect to national and international trade are mycotoxins and their residues. The vigilance is focused mostly on aflatoxins for mycotoxins and pesticides for mycotoxins. Aflatoxins are fungal poisons that were first reported in 1960 in a mass death of turkey in England when the diagnosis concluded to be a disease called turkey-X disease, which was later defined as a toxin secreted by a fungus identified as *Aspergillus flavus,* and the disease is termed after the causal organism as well (aspergillosis), which was reported to kill a postgraduate student at the University of Khartoum in the 1970s who worked on it. Other mycotoxins of importance are ochratoxins and an endless list of fungal toxins and their metabolites. The residues can be physical, such as metals (lead, Pb), from automobile exhaust, iron (Fe) pieces and powder from defective machines, chlorine from unbalanced treated water, etc. However, pesticide residue is a mandatory issue in the checklist of safe food sold in markets. That is, many concerns have been reported and nullified many contracts and reversed shipments to their homelands. Accordingly, international food safety organizations have reacted promptly to these situations and set safe margins for mycotoxins and residues in different food items. That is, EFSA and CONTAM (European Food Safety Association, Contaminants on Food Chain Panel) specified 4–15 and 2–8 ppb (μg/kg) for total aflatoxins (AFTs) and aflatoxin B1 (AFB1), respectively, whereas the corresponding figures from the USFDA (United States Food and Drug Administration) and SSMO (Sudanese Standards and Metrology Organization) were 20 and 20 ppb, respectively; Codex.

10–15 and 10–15; FSSAI (Food Safety and Standards Authority of India) 15 and 10, and FSANZ (Food Standards Australia and New Zealand) 15 and 15 ppb, for AFT and AFB1 in peanuts and nuts, respectively. For pesticide residues, the maximum allowed levels were set by the joint committee of the FAO and WHO for each food item in annexes available for the experts and the public on their websites. For biological contamination, quarantine inspection is a standby service and duty at airports, seaports, and land terminals. Some outbreaks of diseases were made by improper checks, and a citing example of this matter was the USA outbreak of typhoid due to shipments of mango treated with hot water contaminated with *Salmonella typhi* in the last century.

The management of food contamination requires multidisciplinary plans that include preventive and curative actions. For physical contamination, there are many preventive rules, such as good practices and maintenance of tools and machines. The integrative curative measures include checking the products for contamination, sensitive sensors, toolkits, and keen macroscopic and microscopic vigilance of the samples by the quality management authority. Prevention of aflatoxins necessitates preharvest measures that include good agricultural practices (GAPs) for preharvest time and keen quality postharvest handling. In addition to some methods of treatment tested and passed worldwide, such as good manufacturing practices (GMPs, e.g., proper refineries of oil), *Lactobacillus* sp. bacteria (detoxifying AFB1 and OTA), reported a 60–65% reduction in lactic acid bacteria [*Lactococcus lactis* ssp. *lactis (1 and 2), Lactobacillus paracasei* ssp. *paracasei*, which were precisely identified as *Enterococcus faecium* and *Enterococcus durans], reported a 50% reduction; some herbal extracts achieved a 70% reduction (e.g., Hybanthus enneaspermus); lime juice was tested* *against AFB1 and reflected up to a 92% reduction; and ammoniation in grains; however, fermentation was found to be effective in reducing AFT by up to 84%; that is, the use of Lactobacillus rhamnosus* yoba 2012 and *Streptococcus thermophilus* C106 did so in fermented maize in Uganda [135]. However, in Finland, some researchers have reported the ineffectiveness of the fermentation in reducing AFM in yogurt (Korhonen, H. J., personal discussion at University of Nairobi, October 2012). The allergens of the peanut must receive more extensive research attention for the benefit of consumers, especially in developing countries where protein hunger is dominant, and for kids because of this important component in snacks and spinach shelves. However, the adoption of modern techniques for the detection of contaminants, together with efficient rapid detection techniques (RDTs), which are time-saving and highly practical whenever needed, is mandatory. An example of a modern technique is the use of nanotechnology for the detection of chemical contaminants [52], and for RDTs, an Aflacheck® (of Waters Incorporation, USA) is used for the rapid detection of aflatoxins in minutes. It may be worth discussing the intracalibration and intercalibration of the contaminants in the analytical devices. That is, the devices of the same brand and those bearing different brands were calibrated. The results of the analysis of a sample may differ significantly when different brand devices perform the same task. The UN organizations perform international calibrations of the devices of the known attested national and international test organizations and institutes. To my good knowledge, this check is periodical but lacks extensive inclusion of more institutes and shortening of the check period. I guess it may be better to do it every few years and in a rotating plan and to be considered as a mandate to keep the name of the firms as internationally authenticated. The research work, in essence, must include full information about the devices used in the analysis with their brands and the full details of any step that may significantly affect the results since the figures of the contaminants are so minute and in ppb. What is mentioned is necessary for safety and trade in general and for national safety and trade in particular because international trade and safety have precise and efficient check procedures, but doing so requires considerable time and tedious work.

Some controversies, paradoxes, or conflicts may arise from the research interest in the treatment of aflatoxins with thermal methods. However, more cooperation and illumination are needed considering food quality and the adverse effects of overheating on the constituents of commodities. An example of this is the boiling of milk, a common habitual trend in developing countries, which degrades many essential elements of this necessary food item. The heating of milk beyond 60°C results in the denaturation of vitamins, proteins, and other important components. This is why Lewis Pasteur invented pasteurization. Accordingly, the use of other detoxification techniques is the right choice. However, aflatoxins are reported to degrade in very acidic (pH < 3) and very basic (pH > 10) media and melt at 237°C and 299°C for AFG1 and AFM1, respectively. However, autoclaving is capable of removing aflatoxins, but normal cooking cannot [136].

Another important concern in the treatment of aflatoxins and other peanut and food contaminants is the products of these methods. That is, some metabolic processes may result in the production of more toxic metabolites than the toxin itself, as in the case of arsenite and monomethylarsonous acid [137].

Another important concern in the treatment of aflatoxins and other peanut and food contaminants is the products of these methods. Therefore, some metabolic processes may involve the metabolites of AFB1/AFG1 and AFB2/AFG2, which are AFM1 and AFM, respectively. These findings have been reported in nursing mothers and milking animals. They are more hazardous to infants, babies and younger kids than their precursors due to exposure. This was reported in sizeable amounts in the milk of nursing mothers in Sudan Gezira, Africa (Ahmed, I. A. M. Joint Supportive Consultancy, 1994). The fate of the byproducts of AFB1 removal from lime juice is not yet known.

More thorough research on these aspects is mandatory and needed. However, for pesticides, malathion intoxication and malathionic acid in the form of malathion upon its degradation in stores are also interesting.

Preventive measures for aflatoxin and mycotoxin occurrence and other food contaminants must be taken seriously because they necessitate the avoidance of any need for further treatment(s). The most important of these may be the maintenance of coolness and dryness, the avoidance of drought spells, and GAP, in the broadest sense.

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Given the growing interest in the nutritional properties and health recommendations surrounding nut consumption, this book, *Nut Consumption and its Usefulness in the Modern World*, seeks to provide the most comprehensive presentation of current information available in the literature to enhance existing knowledge. The book is structured into four sections, each covering distinct aspects of nut research:

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