Chapter

Minor Compounds of Palm Oil: Properties and Potential Applications

Alexis Gonzalez-Diaz and Jesús Alberto García-Núñez

Abstract

The oil contained in ripe fruits produced by cultivars of African oil palm *Elaeis guineensis Jacq*., as well as that obtained from fresh fruit bunches of certain interspecific hybrid cultivars derived from crossbreeding between *Elaeis oleifera* (*Kunth*) *Cortés* and *E. guineensis* Jacq., have shown to be lipid substrates rich in valuable phytochemicals with exceptional biological properties and functional applications for multiple human health tasks. Eight isoforms of vitamin E (four tocopherols and four tocotrienols), α- and β-carotene, squalene, and various phenolic structures, make up the largest group of minor compounds in palm oil and are essential nutrients with physiological functions that include, but are not limited to their antioxidant properties. Vitamin E regulates the redox (oxidation-reduction) balance in the body, and compounds such as squalene and carotenoids are ubiquitously distributed throughout the body, including cell membranes and lipoproteins. Several studies suggest that regular intake of foods rich in this group of phytonutrients minimizes the reactivity of oxidative chemical species at the cellular level and serves as an effective adjunct in the treatment of oxidative stress.

Keywords: vitamin E, provitamin A, carotenes, phenolic compounds, phytochemicals, nutraceuticals

1. Introduction

In palm oil mills, crude palm oil (CPO) is obtained by mechanical pressing ripe fruits produced by commercial cultivars of African palm *Elaeis guineensis* Jacq. D × P type (i.e., Dura × Pisifera breed) (D × P CPO) or by *Elaeis oleifera (Kunth) Cortés* × *E. guineensis Jacq.* Breeds are commonly known as O × G interspecific hybrids (O × G CPO) under specific pressure and temperature conditions. In its natural unprocessed state, CPO is dark red, a distinctive feature that is attributed to the carotenoid fraction contained in its lipid structure, which includes α- and β-carotene (the precursor to vitamin A that gives carrots their characteristic color), and lycopene (which gives fruits and vegetables their red color) to a lesser extent [1, 2].

CPO is a fatty compound comprising an important fraction of biologically active molecules with varied physiological properties that, in appropriate amounts, stimulate the proper functioning of the immune, digestive, and reproductive systems [3–5]; facilitate the recovery of connective tissue [6]; promote the correct development of vision [5, 7]; have positive effects on the cardiovascular health of adults and the elderly [3]; limit the action of free radicals, provide protection against other reactive oxygen species, and fight oxidative stress [8–14]. A high concentration of tocopherols and tocotrienols, carotenoids, squalene, and phenolic compounds gives CPO its antioxidant power.

Antioxidants are compounds that have the ability to prevent or delay the oxidation of other molecules by inhibiting the initiation or spread of chemical reactions [15]. This allows them to protect the body against the possible effects attributed to the action of free radicals and other reactive oxygen species—ROS—(organic and inorganic oxygen ions and peroxides) [4, 16]. Depending on their source, antioxidants can be classified into two groups, one made up of those synthesized by the body (endogenous) and the other made up of those derived from food intake (exogenous) [17]. Over the last decade, the role of antioxidants in the diet and their impact on human health and the treatment of different diseases have gained significant scientific interest [18–20]. Different studies suggest that antioxidants supplied to the body *via* food intake play a key role in slowing the development of chronic diseases with the greatest impact worldwide, such as neoplastic [21, 22], neurodegenerative [23, 24], and cardiovascular [25, 26] diseases.

Furthermore, CPO is refined and fractioned by physical or chemical processes to obtain refined, bleached, and deodorized (RBD) palm olein (liquid fraction: 65–70% of unsaturated fatty acids) and RBD palm stearin (solid fraction: 30–35% of saturated fatty acids). Refining is the most effective mechanism to remove the natural color, odor, taste, and impurities of CPO [27]. However, about 99% of carotenoids are removed during the bleaching stage of palm oil refining [28], while approximately 36% of vitamin E is degraded during its refining and fractioning [29]. For a few decades now, has minimally processed and refined red palm oil been introduced into Western markets, with varying results in the consumers' perception of the product. In some cases, the natural color of red palm oil proved to be unattractive to some buyers, while for others, this property represented a high nutritional value and the richness in carotenoids of this vegetable oil [30].

In recent decades, several studies have revealed much of the biological functions of the micronutrients found to some extent in palm oil, such as phenols and tocotrienols, β-carotene, squalene, and phytosterols, which make this fatty constituent a unique and ideal raw material for various food applications given its versatility. This chapter highlights the most relevant properties of the most abundant group of minor compounds in palm oil of different sources while proposing it as a suitable material to formulate and develop functional foods enriched with palm phytochemicals.

2. Palm phytochemicals

In addition to triglycerides (>95%) [31], diacylglycerols, and free fatty acids, CPO contains a significant amount of minor compounds representing at least 1% of their lipid composition by weight (**Table 1**). These compounds can be of two types—glycerolipids such as monoglycerides, diglycerides, and phospholipid; and non-glycerolipids, which include tocopherols, tocotrienols, phytosterols, carotenoids, and other vitamins, proteins and amino acids, phenolic and polyphenolic compounds, and free fatty acids [42, 43]. Hence, the content of biologically active phytochemicals in CPO cannot be overlooked, given the attractive biological properties and the nutritional value attributed to this type of substances, as well as the marked preference of the pharmaceutical and nutraceutical industries for natural raw materials to exploit these phytonutrients [44–47].

Minor compounds	D × P CPO ($mg \cdot kg^{-1}$)	Coari La × Mé O × G CPO ($mg \cdot kg^{-1}$)	References
Tocopherols and tocotrienols (vitamin E)	500–800	876–1843	[32, 33]
Total carotenoids	988	514–1042 1172.1–1449.6	[33–35]
Total phytosterols	~300	735–1135	[32, 33]
Squalene	200–500	253.86 247.4 ± 3.3	[36–38]
Total phenolic compounds	~61–91	215–224*, †	[28]
Aliphatic alcohols	100–200	N. D	[36]
Phospholipids	20–80 5–130	N. D	[36, 39]
Isoprenoid alcohols	40–80	160.7–251.3 269.3 ± 60.0	[36, 38, 40]
Methyl sterols	40–80	6.9–14.9 12.7 ± 1.5	[36, 38, 40]
Ubiquinones	18–25 10–80	N. D	[36, 41]
Aliphatic hydrocarbons	50	N. D	[36]

N.D: no data.
**Data from Colombian Oil Palm Research Center—Cenipalma.*
†Expressed in gallic acid equivalent milligrams.

Table 1.
Minor compounds in crude palm oil from different sources.

However, palm oil refining is the most widely implemented conventional process to remove unwanted compounds such as free fatty acids, residual phospholipids, remaining metals, soap traces, volatile oxidation products, and other contaminants [48–50]. To date, there is no known refining technology on an industrial scale that is effective and selective to remove components considered as harmful or that cause adverse effects on the organoleptic qualities of the final product and that to preserve most of the original phytochemicals of CPO. This brings new opportunities for the palm sector worldwide, considering the current trends in the food market with "functional" characteristics and their influence on consumer behavior. Furthermore, this situation translates into new challenges for the oils and fats industry.

Some of the most relevant properties of the minor compounds group in the CPO of different sources are described below.

2.1 Tocopherols and tocotrienols

Tocopherols and tocotrienols are well-known isoforms of vitamin E (**Figure 1**), which greatly improve the oxidative stability of vegetable oils, thanks to their antioxidant properties [52]. In nature, tocopherols are freely found as alcohols, while tocotrienols are found in esterified forms [53]. The term vitamin E refers to eight isoforms of fat-soluble vitamins that can be classified in four tocopherol isoforms (α-, β-, γ-, and δ-Tocopherol) and in four tocotrienol isoforms (α-, β-, γ-, and δ-Tocotrienol) [54, 55], in which the position and number of methyl groups ($-CH_3$) in the chromanol ring of their structures are unequal (**Figure 1**).

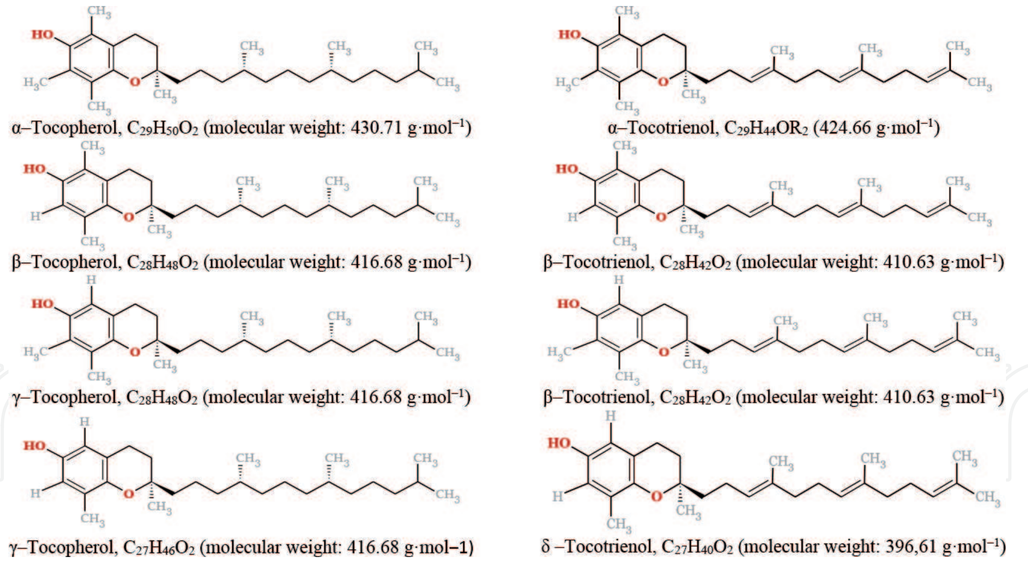

Figure 1.
Tocopherols and tocotrienols in palm oil. Chemical structured developed in ACD/CHEMSktech software [51].

In virgin vegetable oils, the concentration of the different isomeric forms of tocopherols and tocotrienols may depend on the type and quality of the raw material. In some vegetable oils, part of the original vitamin E content is removed involuntarily during refining, especially during the deodorization stage [56]. The main food sources of tocopherols and tocopherols are O × G CPO extracted from the Coari × La Mé cultivar (1316 mg·kg^{-1}) [33]; D × P CPO (914 mg·kg^{-1}) [57]; olive oil (10.4 mg·kg^{-1}) [57]; and barley germ, canola, corn germ, cottonseed, oat bran, peanut, rapeseed, rice bran, rice bran, sesame, soy, sunflower, and wheat germ oils [58, 59].

2.2 Provitamin A: carotenoids

Carotenes are pigments with an organic structure found in plants and other photosynthetic organisms [60]. The α- and β-carotenes (**Figure 2**) are tetraterpenes biochemically synthesized from eight isoprene units (methyl-1,3-butadiene) [61] and are part of more than 600 liposoluble carotenoids identified in natural sources around the world [62].

β-Carotene is a biological precursor (inactive form) of vitamin A or retinol (**Figure 2**), also responsible for the biosynthesis of other retinoids (retinol ester, retinaldehyde or retinal, retinoic acids and its analogs) [63]. β-Carotene is

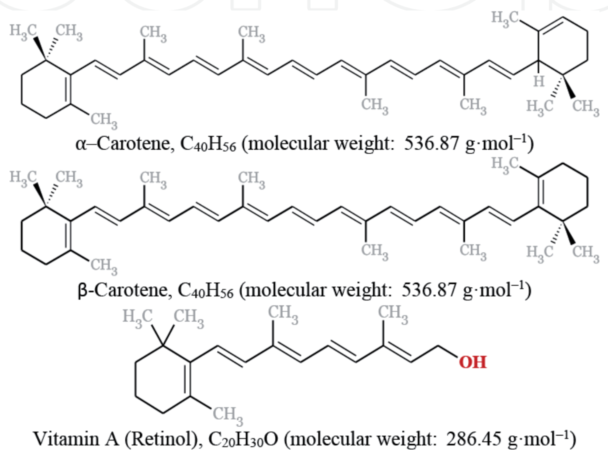

Figure 2.
Molecular structure of the most predominant carotenoids in crude palm oil (α- and β-) and vitamin A (retinol). Chemical structured developed in ACD/CHEMSktech software [51].

considered an indispensable compound for life, which must be obtained from the diet. This substance is capable of producing two retinol molecules thanks to the enzymatic action of β,β-Carotene-15,15'monooxygenase [13, 64].

Structurally, α- and β-carotene consist of 40 carbon atoms and two rings of β-ionone located at each end of the chain (**Figure 2**) [60, 65]. D × P CPO contains between 500 and 700 $mg \cdot kg^{-1}$ of carotenoids, with α-carotene (~ 35%) and β-carotene (~ 56%) being the most prevalent in the matrix [66]. In addition, concentrations between 514 and 1042 $mg \cdot kg^{-1}$ of these compounds have been found in O × G CPO extracted from the Coari × La Mé hybrid cultivar, with β–carotene accounting for approximately 73% of the total carotenoids [33]. The group of foods with high carotenoid content includes vegetables, milk and dairy products, meat and meat products, fish and seafood, eggs and derivatives, fruits, D × P CPO and O × G CPO (**Table 1**), and other vegetable fats, sauces, herbs, and spices [67].

2.3 Squalene

Squalene is a polyunsaturated triterpene made up of six isoprene units, resulting in a compound with six double bonds between carbon atoms in its structure. As a result, squalene is classified as the molecule with the highest degree of unsaturation among lipids, which makes it highly sensitive to oxidation [68]. Squalene belongs to the group of natural antioxidants known as isoprenoids, classified as a bioactive compound with the ability to prevent or minimize the negative effects of free radicals on cells in the human body [69, 70]. Some studies suggest that the squalene secreted in the fatty mantle of human skin provides protection against ultraviolet radiation [71]. D × P CPO has been found to contain between 200 and 500 $mg \cdot kg^{-1}$ of squalene [36], whereas O × G CPO of the Coari × La Mei hybrid cultivar has been found to contain 253.86 $mg \cdot kg^{-1}$ of squalene on average [37]. Currently, squalene is classified as a component with nutritional and medicinal properties with vast expectations for application in the pharmaceutical industry. Some of these properties include cardioprotective, antioxidant, antibacterial, antifungal, anticancer, and detoxifying effects [72].

2.4 Phenolic compounds: phenols and polyphenols

CPO contains significant amounts of phenolic phytohormones (e.g., p-salicylic acid), phenolic aldehydes (e.g., protocatechuic aldehyde), and phenolic acids (e.g., vanillic acid, protocatechuic acid, gallic acid, and ferulic acid) (**Figure 3**) which together make up the largest proportion of phenolic compounds in this type of oil [73]. In plants, phenolic compounds are secondary natural metabolites that are biologically synthesized by the shikimic acid (shikimate-phenylpropanoid) pathway, resulting in phenylpropanoids [74], or by the acetate-malonate pathway (polyketide route), in which monomeric and polymeric phenols and polyphenols are produced [75].

These compounds have important physiological functions in plants and play a key role as defense compounds when environmental stress, pathogen attack, herbivory, and nutrient deficiency lead to a systematic increase in the production of free radicals and other oxidative chemical species [75]. Furthermore, phenolic compounds are regularly described as bioactive substances with antioxidant properties at the cellular level, partly attributed to their ability to act as chelators of metal ions [76–78].

In foods, phenolic compounds influence their appearance, quality, acceptability, and stability because they act as dyes [79], antioxidants [80], and flavorings [81]. Cereals and legumes (e.g., wheat flour, soy, and oats), as well as fruits (e.g., sweet orange, yellow raspberry, and apples) and vegetables (e.g., red cabbage, broccoli,

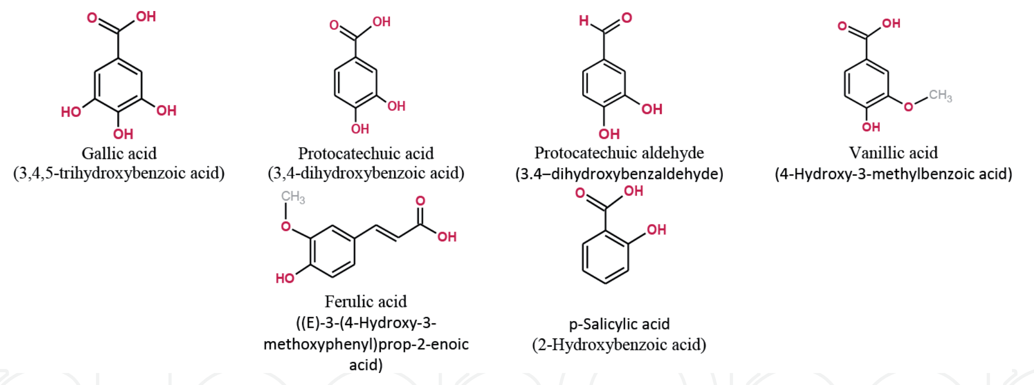

Figure 3.
Phenolic compounds of major relevance in palm oil. Chemical structured developed in ACD/CHEMSktech software [51].

carrots, tomatoes, and spinach) [82], and some vegetable oils (e.g., palm [28, 83], olive [84], soy and cotton [85], coconut [86], sesame and sunflower [87] oils), are part of the food sources of phenolic compounds.

2.5 Phytosterols and phytostanols

Phytosterols and phytostanols are biologically active compounds regularly found in plants and various foods of plant origin. Phytosterols differ from cholesterol in that they have a different elemental distribution in the side chain that forms their chemical structure (**Figure 4**), whereas phytostanols are 5α-saturated derivatives of phytosterols [88]. These structural changes, although minimal, make phytosterols, phytostanols, and cholesterol have particular physicochemical characteristics and differentiate them from each other metabolically and functionally.

Phytosterols and phytostanols are not synthesized by the human body [89, 90]; therefore, they must be supplied to the body through the intake of foods rich in these compounds. The main food sources of phytosterols are vegetable oils, fats, and edible fatty derivatives [91, 92], as well as nuts [93], cereals and derivatives [92], and vegetables [94]. The most abundant phytosterols and phytostanols in the human diet are β-sitosterol, campesterol, sitostanol, and campestanol [95].

D × P CPO contains a substantial amount of natural sterols (325–527 $mg{\cdot}kg^{-1}$) [36], mainly constituted by β-sitosterol (46.55 ± 0.93%), campesterol (31.91 ± 0.5%), and stigmasterol (21.54 ± 0.86%) [59]. Similarly, concentrations between 735 and 1135 $mg{\cdot}kg^{-1}$ of these compounds have been found in O × G CPO extracted from the Coari × La Mé hybrid cultivar, with β-carotene accounting for approximately 63% of the total sterols [33].

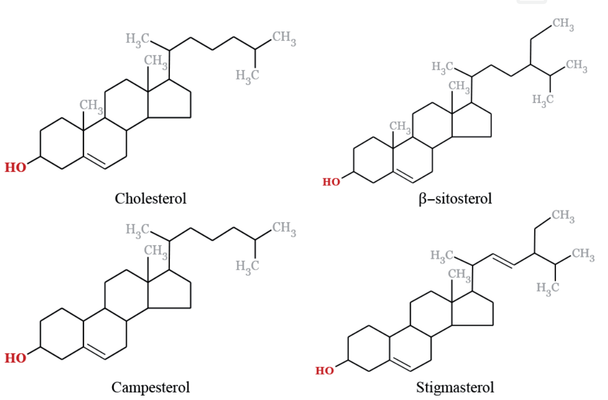

Figure 4.
Phytosterols most abundant in palm oil and cholesterol. Chemical structured developed in ACD/CHEMSktech software [51].

3. Oil palm as natural ingredient rich in biologically active constituents

Both D × P CPO and O × G CPO of the Coari × La Mé cultivar are naturally occurring lipid materials with important tocopherols and tocotrienols contents (**Table 1**), with a wide range of uses in various productive sectors. For the pharmaceutical sector, as for the food and nutraceutical industries, palm oil of different sources may be an active component to enrich various edible matrices or to formulate and develop new products. Given the high content of vitamin E in its lipid composition, palm oil can be incorporated into the formulation of products that may be useful to prevent or treat vitamin E deficiency, associated with health disorders such as peripheral neuropathy, retinopathy pigmentosa ataxia, and myopathy [96–98].

Carotenoids in palm oil can be biologically active primary components in the formulation of new products; furthermore, the amount of tocopherols, tocotrienols, and squalene naturally found in this oil could add even more value to products that may contain them [99–102]. Also, the β-carotene in palm oil can serve as an active component in food aggregates for human and animal diets [103–105] due to the properties that have been identified in this compound at the biological level and due to the reported benefits of its consumption for human [106, 107] and animal [108] health.

On the other hand, the phytosterols that make up the complex of minor compounds in palm oil (**Figure 4**) have industrial uses as essential elements required to manufacture various products [109–111]. β-Sitosterol, one of the natural sterols found in greater amounts in palm oil, could be included in food preparations aimed at reducing low-density lipoproteins (LDL), which are closely related to the development of cardiovascular diseases [112, 113].

To another extent, squalene is a constituent of high biological value used as an aggregate in different products. This compound is part of the raw materials used in cosmetics [114] and the formulation of pharmaceutical and food products [115, 116]. In the food and cosmetic industries, squalene is used as an additive due to the several benefits for human health that have been reported in various works [72, 117]. Squalene in palm oil could contribute to the enrichment of diverse food matrices and, together with tocopherols, tocotrienols and carotenoids, could collectively supplement much of the deficiency of these substances in some organisms. In addition to the aforesaid, some research has found that squalene is an effective chemotherapeutic agent for the treatment of colon carcinomas [118], breast cancer [119], and pancreatic tumors [120].

4. Available technologies to extract, concentrate, and/or purify palm phytochemicals

Several mechanisms have been developed to extract, fraction, and refine the phytochemicals, which are found in CPO. Such processes include, but are not limited to, extraction with supercritical fluids [121], molecular distillation and crystallization [122], and molecular distillation with prior esterification/transesterification of oil [123]. In general, these technologies are repeatedly used to produce oily extracts rich in squalene, carotenoids, tocopherols, and tocotrienols.

By means of solid-phase extraction and fractionation in polar phase mobile bed, a product right in α-tocotrienol free of other isomers of tocotrienols, tocopherols, and carotenoids was obtained from CPO [124]. Squalene, vitamin E, and phytosterols were fractioned from CPO through a process that included esterification, transesterification, vacuum distillation, saponification, crystallization, and exclusion of organic solvents stages [125]. On the other hand, the implementation of supercritical fluids was useful in the production of extracts rich in tocochromanols and carotenoids from CPO.

According to several authors, the vitamin complex composed of tocopherols and tocotrienols can be extracted, fractioned, and purified from various biomaterials by using technologies such as solvent extraction (direct extraction [126], Soxhlet extraction [127], and pressurized fluid extraction (PLE) [128]), supercritical fluid extraction (SFE) [129], enzyme extraction [130], extraction with prior chemical modification of the oil's lipidic matrix (saponification [127] and esterification [131]), absorption [132], sequential adsorption-desorption [133], molecular distillation [134], microwave-assisted extraction (MAE) [135], and membrane filtration [136].

On the other hand, some of the most widely implemented methodologies to extract carotenoids from different vegetable materials include processes such as liquid extraction at atmospheric pressure with maceration [137], Soxhlet extraction [138], MAE [139], ultrasound-assisted extraction (UAE) [140], accelerated solvent extraction (ASE) [141], pulsed electric field-assisted extraction (PEF) and moderate electric field extraction (MEF) [142], SFE [143], complex enzyme-assisted extraction [144], PLE [145], and extraction with green solvents [146]. After an additional separation stage, the analysis of carotenoids has been carried out using instrumental techniques such as high-efficiency liquid chromatography with diode array (HPLC-DAD), thin-layer chromatography, and gas chromatography coupled to mass spectrometry [147].

Currently, fractions rich in phenolic compounds from biomaterials are obtained by implementing technologies such as solid-liquid extraction (SLE) [148], PLE [149], ASE [150], SFE [151], UAE [152], MAE [153], ultrafiltration (UF) [154], and complex enzyme-assisted extraction [155]. These processes have guaranteed the extraction of phenolic compounds with good yields. Likewise, the purification of these compounds by implementing liquid and solid phases has guaranteed the acquisition of extracts with abundant phenol and polyphenol contents with high levels of purity [156].

Finally, squalene and phytosterols have been extracted from natural sources using supercritical carbon dioxide (CO2) (SFE) [157]. In addition, high levels of these same substances have been found in deodorization distillates during the refining of some vegetable oils, such as palm and olive [158, 159]. Furthermore, the most widely used techniques to quantify the compounds mentioned above include gas chromatography with flame ionization detector (FID) and gas chromatography coupled to mass spectrometry [72].

5. Conclusions

D × P CPO and O × G CPO Coari × La Mé are natural oils derived from ripe fruits of the African palm *Elaeis guineensis* Jacq., and from one of the interspecific hybrid cultivars between the species *Elaeis oleifera* (Kunth) Cortés and *E. guineensis* Jacq., respectively, with a significant content of tocopherols and tocotrienols, α- and β-carotene, phytosterols, squalene, and phenolic structures that, when incorporated into the human diet in appropriate doses, promote the correct physiological functioning of organisms. According to the various works mentioned in this chapter, the above components are considered biomolecules indispensable for life due to their biological functions and nutritional attributes.

At present, different processes have been developed to extract, recover, and purify the phytochemicals contained in palm oil with good yields and high concentration values in the extracts obtained as final products. Currently, there is a marked trend toward obtaining phytochemicals from various natural sources by means of green technologies. Furthermore, the number of companies engaged in this work is increasing.

This chapter aims to show the attributes and benefits of including D × P CPO and Coarí × Me O × G CPO in the human diet and seeks to propose them as raw materials to produce functional food rich in phytochemicals of nutritional value.

Acknowledgements

The authors thank the Palm Oil Promotion Fund, administered by the National Federation of Oil Palm Growers—Fedepalma, for funding this study. Moreover, the authors also thank the Colombian Oil Palm Research Center—Cenipalma for all the information support received.

Author details

Alexis Gonzalez-Diaz* and Jesús Alberto García-Núñez
Colombian Oil Palm Research Center—Cenipalma, Bogotá, Colombia

*Address all correspondence to: agonzalezd@cenipalma.org

References

[1] Ma T et al. Influence of technical processing units on the α-carotene, β-carotene and lutein contents of carrot (*Daucus carrot* L.) juice. Journal of Functional Foods. 2015;**16**:104-113. DOI: 10.1016/j.jff.2015.04.020

[2] Suwanaruang T. Analyzing lycopene content in fruits. Agriculture and Agricultural Science Procedia. 2016;**11**:46-48. DOI: 10.1016/j.aaspro.2016.12.008

[3] Lewis ED, Meydani SN, Wu D. Regulatory role of vitamin E in the immune system and inflammation. IUBMB Life. 2019;**71**(4):487-494. DOI: 10.1002/iub.1976

[4] Patlevič P, Vašková J, Švorc P, Vaško L, Švorc P. Reactive oxygen species and antioxidant defense in human gastrointestinal diseases. Integrative Medicine Research. 2016;**5**(4):250-258. DOI: 10.1016/j.imr.2016.07.004

[5] Amengual J. Bioactive properties of carotenoids in human health. Nutrients. 2019;**11**(10):1-6. DOI: 10.3390/nu111 02388

[6] Zerres S, Stahl W. Carotenoids in human skin. Biochimica et Biophysica Acta (BBA)—Molecular and Cell Biology of Lipids. 2020;**1865**(11):158588. DOI: 10.1016/j.bbalip.2019.158588

[7] Zielińska MA, Wesołowska A, Pawlus B, Hamułka J. Health effects of carotenoids during pregnancy and lactation. Nutrients. 2017;**9**(8):1-25. DOI: 10.3390/nu9080838

[8] Gul K, Singh AK, Jabeen R. Nutraceuticals and functional foods: The foods for the future world. Critical Reviews in Food Science and Nutrition. 2016;**56**(16):2617-2627. DOI: 10.1080/10408398.2014.903384

[9] Kumar PKP, Krishna AGG. Physico-chemical characteristics and nutraceutical distribution of crude palm oil and its fractions. Grasas y Aceites. 2014;**65**(June):1-2

[10] Ting-Fu K, Yih-Ming W, Chiou RY-Y. Squalene content and antioxidant activity of *Terminalia catappa* leaves and seeds. Journal of Agricultural and Food Chemistry. 2002;**50**(19):5343-5348

[11] May CY, Nesaretnam K. Research advancements in palm oil nutrition. European Journal of Lipid Science and Technology. 2014;**116**(10):1301-1315. DOI: 10.1002/ejlt.201400076

[12] Meléndez-Martínez AJ, Stinco CM, Mapelli-Brahm P. Skin carotenoids in public health and nutricosmetics: The emerging roles and applications of the UV radiation-absorbing colourless carotenoids phytoene and phytofluene. Nutrients. 2019;**11**(5). pp. 1-39. DOI: 10.3390/nu11051093

[13] Bohn T et al. β-Carotene in the human body: Metabolic bioactivation pathways - from digestion to tissue distribution and excretion. Proceedings of the Nutrition Society. 2019;**78**(1):68-87. DOI: 10.1017/S0029665118002641

[14] Kim SK, Karadeniz F. Biological Importance and Applications of Squalene and Squalane. 1st ed. Vol. 65. Busan, Republic of Korea: Elsevier Inc.; 2012. DOI: 10.1016/B978-0-12-416003-3.00014-7

[15] Lorenzo JM et al. Bioactive peptides as natural antioxidants in food products—A review. Trends in Food Science & Technology. 2018;**79**:136-147. DOI: 10.1016/j.tifs.2018.07.003

[16] Schumacker PT. Reactive oxygen species in cancer: A dance with the devil. Cancer Cell. 2015;**27**(2):156-157. DOI: 10.1016/j.ccell.2015.01.007

[17] Neha K, Haider MR, Pathak A, Yar MS. Medicinal prospects of

antioxidants: A review. European Journal of Medicinal Chemistry. 2019;**178**(June):687-704. DOI: 10.1016/j.ejmech.2019.06.010

[18] Singh B, Singh JP, Kaur A, Singh N. Phenolic composition, antioxidant potential and health benefits of citrus peel. Food Research International. 2020;**132**(February):109114. DOI: 10.1016/j.foodres.2020.109114

[19] Shahidi F, Ambigaipalan P. Phenolics and polyphenolics in foods, beverages and spices: Antioxidant activity and health effects—A review. Journal of Functional Foods. 2015;**18**:820-897. DOI: 10.1016/j.jff.2015.06.018

[20] Chang SK, Alasalvar C, Shahidi F. Review of dried fruits: Phytochemicals, antioxidant efficacies, and health benefits. Journal of Functional Foods. 2016;**21**(March):113-132. DOI: 10.1016/j.jff.2015.11.034

[21] Xie J et al. Apoptotic activities of brusatol in human non-small cell lung cancer cells: Involvement of ROS-mediated mitochondrial-dependent pathway and inhibition of Nrf2-mediated antioxidant response. Toxicology. 2021;**451**:152680. DOI: 10.1016/j.tox.2021.152680

[22] Chien JT, Chang R-H, Hsieh C-H, Hsu C-Y, Wang C-C. Antioxidant property of *Taraxacum formosanum* Kitam and its antitumor activity in non-small-cell lung cancer cells. Phytomedicine. 2018;**49**:1-10. DOI: 10.1016/j.phymed.2018.06.011

[23] Mazumder MK, Choudhury S, Borah A. An in silico investigation on the inhibitory potential of the constituents of Pomegranate juice on antioxidant defense mechanism: Relevance to neurodegenerative diseases. IBRO Reports. 2019;**6**(May):153-159. DOI: 10.1016/j.ibror.2019.05.003

[24] Losada-Barreiro S, Bravo-Díaz C. Free radicals and polyphenols: The redox chemistry of neurodegenerative diseases. European Journal of Medicinal Chemistry. 2017;**133**:379-402. DOI: 10.1016/j.ejmech.2017.03.061

[25] Kim JH. Pharmacological and medical applications of Panax ginseng and ginsenosides: A review for use in cardiovascular diseases. Journal of Ginseng Research. 2018;**42**(3):264-269. DOI: 10.1016/j.jgr.2017.10.004

[26] Gianazza E, Brioschi M, Fernandez AM, Banfi C. Lipoxidation in cardiovascular diseases. Redox Biology. 2019;**23**(January):101119. DOI: 10.1016/j.redox.2019.101119

[27] Gibon V. 12—Palm oil and palm kernel oil refining and fractionation technology. In: Lai O-M, Tan C-P, Akoh CCBT-PO, editors. Palm Oil—Production, Processing, Characterization, and Uses. Zaventem, Belgium: AOCS Press; 2012. pp. 329-375. DOI: 10.1016/B978-0-9818936-9-3.50015-0

[28] Szydłowska-Czerniak A, Trokowski K, Karlovits G, Szłyk E. Effect of refining processes on antioxidant capacity, total contents of phenolics and carotenoids in palm oils. Food Chemistry. 2011;**129**(3):1187-1192. DOI: 10.1016/j.foodchem.2011.05.101

[29] Nagendran B, Unnithan UR, Choo YM, Sundram K. Characteristics of red palm oil, a carotene- and vitamin E-rich refined oil for food uses. Food and Nutrition Bulletin. 2000;**21**(2):189-194. DOI: 10.1177/156482650002100213

[30] Andrianto M. Preliminary product acceptance and initial price of virgin red palm oil on African expatriate community in Jakarta. International Journal of Oil Palm. 2019;**2**(2):87-93. DOI: 10.35876/ijop.v2i2.27

[31] Pande G, Akoh CC, Lai OM. Food uses of palm oil and its components. In: Tan C-P, Akoh CC, Lai O-M, editors. Palm Oil: Production, Processing,

Characterization, and Uses. Athens, GA, USA and Sedang, Selangor, Malaysia: AOCS Press; 2012. pp. 561-586. DOI: 10.1016/B978-0-9818936-9-3.50022-8

[32] Sambanthamurthi R, Sundram K, Tan Y. Chemistry and biochemistry of palm oil. Progress in Lipid Research. 2000;**39**(6):507-558. DOI: 10.1016/s0163-7827(00)00015-1

[33] Rincón-Miranda SM et al. Use of phenological stages of the fruits and physicochemical characteristics of the oil to determine the optimal harvest time of oil palm interspecific OxG hybrid fruits. Industrial Crops and Products. 2013;**49**:204-210. DOI: 10.1016/j.indcrop.2013.04.035

[34] Ribeiro JAA, Almeida ES, Neto BAD, Abdelnur PV, Monteiro S. Identification of carotenoid isomers in crude and bleached palm oils by mass spectrometry. LWT - Food Science and Technology. 2018;**89**(November):631-637. DOI: 10.1016/j.lwt.2017.11.039

[35] Chaves G, Ligarreto-Moreno GA, Cayon-Salinas DG. Physicochemical characterization of bunches from American oil palm (*Elaeis oleifera* H.B.K. Cortes) and their hybrids with African oil palm (*Elaeis guineensis* Jacq.). Acta Agronomica. 2018;**67**(1):168-176. DOI: 10.15446/acag.v67n1.62028

[36] Zou Y, Jiang Y, Yang T, Hu P, Xu X. Minor constituents of palm oil: Characterization, processing, and application. In: Lai O-M, Tan C-P, Akoh CC, editors. Palm Oil: Palm Oil Production, Processing, Characterization, and Uses. Shanghai 200137, China and Aarhus C 8000, Denmark; 2012. pp. 471-526. DOI: 10.1016/B978-0-9818936-9-3.50019-8

[37] Gonzalez-Diaz A, Pataquiva-Mateus A, García-Núñez JA. Characterization and response surface optimization driven ultrasonic nanoemulsification of oil with high phytonutrient concentration recovered from palm oil biodiesel distillation. Colloids and Surfaces A: Physicochemical and Engineering Aspects, December. 2020;**612**:2021. DOI: 10.1016/j.colsurfa.2020.125961

[38] Mozzon M, Pacetti D, Frega NG, Lucci P. Crude Palm oil from interspecific hybrid *Elaeis oleifera* × *E. guineensis*: Alcoholic constituents of unsaponifiable matter. Journal of the American Oil Chemists' Society. 2015;**92**(5):717-724

[39] Panpipat W, Chaijan M. Palm phosp/holipids. In: Ahmad M, Xu X, editors. Polar Lipids: Biology, Chemistry, and Technology. 1st ed. Thasala, Nakhon Si Thammarat, Thailand: Elsevier Inc.; 2015. pp. 77-90. DOI: 10.1016/B978-1-63067-044-3.50008-X

[40] Lucci P, Pacetti D, Frega NG, Mozzon M. Phytonutrient concentration and unsaturation of glycerides predict optimal harvest time for *Elaeis oleifera* × *E. guineensis* palm oil hybrids. European Journal of Lipid Science and Technology. 2015;**117**(7):1027-1036. DOI: 10.1002/ejlt.201400599

[41] Mba OI, Dumont MJ, Ngadi M. Palm oil: Processing, characterization and utilization in the food industry—A review. Food Bioscience. 2015;**10**(1):26-41. DOI: 10.1016/j.fbio.2015.01.003

[42] Chen B, McClements DJ, Decker EA. Minor components in food oils: A critical review of their roles on lipid oxidation chemistry in bulk oils and emulsions. Critical Reviews in Food Science and Nutrition. 2011;**51**(10):901-916. DOI: 10.1080/10408398.2011.606379

[43] Aluyor EO, Ozigagu CE, Oboh OI, Aluyor P. Chromatographic analysis of vegetable oils: A review. Scientific Research and Essays. 2009;**4**(4):191-197

[44] Singh D, Chaudhuri PK. A review on phytochemical and pharmacological

properties of Holy basil (*Ocimum sanctum* L.). Industrial Crops and Products. 2018;**118**(August):367-382. DOI: 10.1016/j.indcrop.2018.03.048

[45] Bursać Kovačević D et al. Innovative technologies for the recovery of phytochemicals from *Stevia rebaudiana* Bertoni leaves: A review. Food Chemistry. 2018;**268**(June):513-521. DOI: 10.1016/j.foodchem.2018.06.091

[46] Mannino G, Perrone A, Campobenedetto C, Schittone A, Margherita Bertea C, Gentile C. Phytochemical profile and antioxidative properties of *Plinia trunciflora* fruits: A new source of nutraceuticals. Food Chemistry. 2020;**307**:125515. DOI: 10.1016/j.foodchem.2019.125515

[47] Ashraf MA. Phytochemicals as potential anticancer drugs: Time to Ponder Nature's Bounty. BioMed Research International. 2020;**2020**. pp. 1-7. DOI: 10.1155/2020/8602879

[48] Gibon V, De Greyt W, Kellens M. Palm oil refining. European Journal of Lipid Science and Technology. 2007; **109**(4):315-335. DOI: 10.1002/ejlt.200600307

[49] Rossi M, Gianazza M, Alamprese C, Stanga F. The role of bleaching clays and synthetic silica in palm oil physical refining. Food Chemistry. 2003;**82**(2): 291-296. DOI: 10.1016/S0308-8146(02)00551-4

[50] Choong CG, McKay A. Sustainability in the Malaysian palm oil industry. Journal of Cleaner Production. 2014;**85**: 258-264. DOI: 10.1016/j.jclepro.2013.12.009

[51] Advanced Chemistry Development Inc. (ACD/Labs). ACD/ChemSketch. Toronto; 2018

[52] Grosshagauer S, Steinschaden R, Pignitter M. Strategies to increase the oxidative stability of cold pressed oils. LWT. 2019;**106**:72-77. DOI: 10.1016/j.lwt.2019.02.046

[53] Combs GF, McClung JP. Chapter 8—Vitamin E. In: Combs GF, McClung JP, editors. The Vitamins Fundamental Aspects in Nutrition and Health. 5th ed. Westborough, MA: Academic Press; 2017. pp. 207-242. DOI: 10.1016/B978-0-12-802965-7.00008-3

[54] Peh HY, Tan WSD, Liao W, Wong WSF. Vitamin E therapy beyond cancer: Tocopherol versus tocotrienol. Pharmacology and Therapeutics. 2016;**162**:152-169. DOI: 10.1016/j.pharmthera.2015.12.003

[55] Bartella L, di Donna L, Napoli A, Sindona G, Mazzotti F. High-throughput determination of vitamin E in extra virgin olive oil by paper spray tandem mass spectrometry. Analytical and Bioanalytical Chemistry. 2019;**411**(13):2885-2890. DOI: 10.1007/s00216-019-01727-z

[56] W C on O and E O Processing. The proceedings of the world conference on oilseed and edible oils processing. In: Koseoglu SS, Rhee KC, Wilson RF, editors. Emerging Technologies, Current Practices, Quality Control, Technology Transfer, and Environmental Issues. World Conference on Oilseed and Edible Oils Processing. Vol. 1. 1998

[57] Azlan A et al. Comparison of fatty acids, vitamin E and physicochemical properties of Canarium odontophyllum Miq. (dabai), olive and palm oils. Journal of Food Composition and Analysis. 2010;**23**(8):772-776. DOI: 10.1016/j.jfca.2010.03.026

[58] Wanasundara PKJPD, Shahidi F, Shukla VKS. Endogenous antioxidants from oilseeds and edible oils. Food Reviews International. 1997;**13**(2):225-292. DOI: 10.1080/87559129709541106

[59] Li C et al. Comparison and analysis of fatty acids, sterols, and tocopherols in

eight vegetable oils. Journal of Agricultural and Food Chemistry. 2011;**59**(23):12493-12498. DOI: 10.1021/jf203760k

[60] Qian C, Decker EA, Xiao H, McClements DJ. Physical and chemical stability of β-carotene-enriched nanoemulsions: Influence of pH, ionic strength, temperature, and emulsifier type. Food Chemistry. 2012;**132**(3):1221-1229. DOI: 10.1016/j.foodchem.2011.11.091

[61] Khalil S et al. Retinoids: A journey from the molecular structures and mechanisms of action to clinical uses in dermatology and adverse effects. Journal of Dermatological Treatment. Nov. 2017;**28**(8):684-696. DOI: 10.1080/09546634.2017.1309349

[62] Gul K, Tak A, Singh AK, Singh P, Yousuf B, Wani AA. Chemistry, encapsulation, and health benefits of β-carotene—A review. Cogent Food & Agriculture. 2015;**1**(1):1-12. DOI: 10.1080/23311932.2015.1018696

[63] Saurat J-H, Sorg O. Retinoids. In: European Handbook of Dermatological Treatments. 3rd ed. Berlin Heidelberg, Germany: Springer-Verlag; 2015. pp. 1493-1511. DOI: 10.1007/978-3-662-45139-7

[64] Wu L et al. Molecular aspects of β, β-carotene-9′, 10′-oxygenase 2 in carotenoid metabolism and diseases. Experimental Biology and Medicine. 2016;**241**(17):1879-1887. DOI: 10.1177/1535370216657900

[65] Iftikhar HT, Zhao Y. Enrichment of β-carotene from palm oil using supercritical carbon dioxide pretreatment-solvent extraction technique. LWT—Food Science and Technology. 2017;**83**:262-266. DOI: 10.1016/j.lwt.2017.05.026

[66] Okogeri O, Uchenna-Onu U. Changes occurring in quality indices during storage of adulterated red palm oil. International Journal of Food Science and Nutrition. 2016;**1**(3):1-5

[67] Beltrán-de-Miguel B, Estévez-Santiago R, Olmedilla-Alonso B. Assessment of dietary vitamin A intake (retinol, α-carotene, β-carotene, β-cryptoxanthin) and its sources in the National Survey of Dietary Intake in Spain (2009-2010). International Journal of Food Sciences and Nutrition. 2015;**66**(6):706-712. DOI: 10.3109/09637486.2015.1077787

[68] Pham DM, Boussouira B, Moyal D, Nguyen QL. Oxidization of squalene, a human skin lipid: A new and reliable marker of environmental pollution studies. International Journal of Cosmetic Science. 2015;**37**(4):357-365. DOI: 10.1111/ics.12208

[69] Fernando IPS, Sanjeewa KKA, Samarakoon KW, Lee WW, Kim HS, Jeon YJ. Squalene isolated from marine macroalgae *Caulerpa racemosa* and its potent antioxidant and anti-inflammatory activities. Journal of Food Biochemistry. 2018;**42**(5). pp. 1-10. DOI: 10.1111/jfbc.12628

[70] Spanova M, Daum G. Squalene: Biochemistry, molecular biology, process biotechnology, and applications. European Journal of Lipid Science and Technology. 2011;**113**(11):1299-1320. DOI: 10.1002/ejlt.201100203

[71] J. J. Gaforio, C. Sánchez-Quesada, A. López-Biedma, M. del C. Ramírez-Tortose, and F. Warleta, "Molecular aspects of squalene and implications for olive oil and the mediterranean diet," in The Mediterranean Diet: An Evidence-Based Approach, V. R. Preedy and R. Ross Watson, Eds. Jaén and Granada, Spain: Elsevier Inc, 2015, pp. 281-290. doi: 10.1016/B978-0-12-407849-9.00026-9.

[72] Lozano-Grande MA, Gorinstein S, Espitia-Rangel E, Dávila-Ortiz G, Martínez-Ayala AL. Plant sources,

extraction methods, and uses of squalene. International Journal of Agronomy. 2018;**2018**:. pp. 1-13. DOI: 10.1155/2018/1829160

[73] Rodríguez JC et al. Effects of the fruit ripening stage on antioxidant capacity, total phenolics, and polyphenolic composition of crude palm oil from interspecific hybrid *Elaeis oleifera* × *Elaeis guineensis*. Journal of Agricultural and Food Chemistry. 2016;**64**(4):852-859. DOI: 10.1021/acs.jafc.5b04990

[74] Vogt T. Phenylpropanoid biosynthesis. Molecular Plant. 2010;**3**(1):2-20. DOI: 10.1093/mp/ssp106

[75] Lattanzio V. Phenolic Compounds: Introduction. In: Ramawat KG, Mérillon J-M, editors. Natural Products: Phytochemistry, Botany and Metabolism of Alkaloids, Phenolics and Terpenes. New Delhi, India: Springer-Verlag Berlin Heidelberg; 2013. pp. 1-4242. DOI: 10.1007/978-3-642-22144-6

[76] Nimse SB, Pal D. Free radicals, natural antioxidants, and their reaction mechanisms. RSC Advances. 2015;**5**(35): 27986-28006. DOI: 10.1039/c4ra13315c

[77] Liochev SI. Reactive oxygen species and the free radical theory of aging. Free Radical Biology and Medicine. 2013;**60**: 1-4. DOI: 10.1016/j.freeradbiomed.2013.02.011

[78] Darvin ME, Fluhr JW, Meinke MC, Zastrow L, Sterry W, Lademann J. Topical beta-carotene protects against infra-red-light-induced free radicals. Experimental Dermatology. 2011;**20**(2):125-129. DOI: 10.1111/j.1600-0625.2010.01191.x

[79] Wojdyło A, Samoticha J, Chmielewska J. Effect of different pre-treatment maceration techniques on the content of phenolic compounds and color of Dornfelder wines elaborated in cold climate. Food Chemistry. 2021;**339**:127888. DOI: 10.1016/j.foodchem.2020.127888

[80] Vuolo MM, Lima VS, Maróstica Junior MR. In: Campos MRSBT-BC, editor. Phenolic Compounds: Structure, Classification, and Antioxidant Power. Campinas, Brazil and Coari, Brazil: Woodhead Publishing; 2019. pp. 33-50. DOI: 10.1016/B978-0-12-814774-0.00002-5

[81] Wang H, Chambers E, Kan J. Sensory characteristics of combinations of phenolic compounds potentially associated with smoked aroma in foods. Molecules. 2018;**23**(8). pp. 1-11. DOI: 10.3390/molecules23081867

[82] Reis Giada MdL, "Food phenolic compounds: Main classes, sources and their antioxidant power maria," Oxidative Stress and Chronic Degenerative Diseases A Role for Antioxidants, J. A. Morales-Gonzalez, Rio de Janeiro, Brazil: IntechOpen, 2013, 87-112.

[83] Ferreira CD et al. Physicochemical characterization and oxidative stability of microencapsulated crude palm oil by spray drying. Food and Bioprocess Technology. 2016;**9**(1):124-136. DOI: 10.1007/s11947-015-1603-z

[84] Gouvinhas I, Machado J, Gomes S, Lopes J, Martins-Lopes P, Barros AIRNA. Phenolic composition and antioxidant activity of monovarietal and commercial Portuguese olive oils. JAOCS, Journal of the American Oil Chemists' Society. 2014;**91**(7):1197-1203. DOI: 10.1007/s11746-014-2462-x

[85] Mohdaly AAE-R, El-Hameed Seliem KA, EL-Hassan AE-MMA, Mahmoud AAT. Effect of refining process on the quality characteristics of soybean and cotton seed oils. International Journal of Current Microbiology and Applied Sciences. 2017;**6**(1):207-222. DOI: 10.20546/ijcmas.2017.601.026

[86] Marina AM, Che Man YB, Nazimah SAH, Amin I. Antioxidant capacity and phenolic acids of virgin coconut oil. International Journal of

Food Sciences and Nutrition. 2009;**60**(SUPPL. 2):114-123. DOI: 10.1080/09637480802549127

[87] Janu C, Kumar DRS, Reshma MV, Jayamurthy P, Sundaresan A, Nisha P. Comparative study on the total phenolic content and radical scavenging activity of common edible vegetable oils. Journal of Food Biochemistry. 2014;**38**(1):38-49. DOI: 10.1111/jfbc.12023

[88] Gylling H, Simonen P. Phytosterols, phytostanols, and lipoprotein metabolism. Nutrients. 2015;**7**(9):7965-7977. DOI: 10.3390/nu7095374

[89] Piironen V, Lampi A-M. Occurrence and levels of phytosterols in foods. In: Dutta PC, editor. Phytosterols as Functional Food Components and Nutraceuticals. 1st ed. Helsinki, Finland: CRC Press; 2004. pp. 1-32. DOI: 10.1201/9780203913413

[90] Lagarda MJ, García-Llatas G, Farré R. Analysis of phytosterols in foods. Journal of Pharmaceutical and Biomedical Analysis. 2006;**41**(5):1486-1496. DOI: 10.1016/j.jpba.2006.02.052

[91] Yang R et al. Phytosterol contents of edible oils and their contributions to estimated phytosterol intake in the Chinese diet. Foods. 2019;**8**(8). pp. 1-12. DOI: 10.3390/foods8080334

[92] Pokkanta P, Sookwong P, Tanang M, Setchaiyan S, Boontakham P, Mahatheeranont S. Simultaneous determination of tocols, γ-oryzanols, phytosterols, squalene, cholecalciferol and phylloquinone in rice bran and vegetable oil samples. Food Chemistry. 2019;**271**:630-638. DOI: 10.1016/j.foodchem.2018.07.225

[93] Islam MA, Jeong B-G, Jung J, Shin E-C, Choi S-G, Chun J. Phytosterol determination and method validation for selected nuts and seeds. Food Analytical Methods. 2017;**10**(10):3225-3234. DOI: 10.1007/s12161-017-0877-3

[94] Naumoska K, Vovk I. Analysis of triterpenoids and phytosterols in vegetables by thin-layer chromatography coupled to tandem mass spectrometry. Journal of Chromatography A. 2015;**1381**:229-238. DOI: 10.1016/j.chroma.2015.01.001

[95] Srigley CT, Haile EA. Quantification of plant sterols/stanols in foods and dietary supplements containing added phytosterols. Journal of Food Composition and Analysis. 2015;**40**:163-176. DOI: 10.1016/j.jfca.2015.01.008

[96] Raederstorff D, Péter S, Weber P. Vitamin E in human health. In: Weber P, Birringer M, Blumberg J, Eggersdorfer M, Frank J, editors. Vitamin E in Human Health. 1st ed. Wellington: Humana Press; 2019. pp. 163-174. DOI: 10.1007/978-3-030-05315-4

[97] Sokol RJ. A new old treatment for vitamin E deficiency in cholestasis. Journal of Pediatric Gastroenterology and Nutrition. 2016;**63**(6):577-578. DOI: 10.1097/MPG.0000000000001330

[98] Rahmoune H, Boutrid N, Amrane M, Chekkour MC, Bioud B. Ataxia in children: Think about Vitamin E deficiency ! (comment on: Ataxia in children: Early recognition and clinical evaluation). Italian Journal of Pediatrics. 2017;**43**(1):1-2. DOI: 10.1186/s13052-017-0378-4

[99] Phoon KY, Ng HS, Zakaria R, Yim HS, Mokhtar MN. Enrichment of minor components from crude palm oil and palm-pressed mesocarp fibre oil via sequential adsorption-desorption strategy. Industrial Crops and Products. 2018;**113**(September 2017):187-195. DOI: 10.1016/j.indcrop.2018.01.039

[100] Nur Sulihatimarsyila AW, Lau HLN, Nabilah KM, Nur Azreena I. Refining process for production of refined palm-pressed fibre oil. Industrial Crops and Products.

2019;**129**(November 2018):488-494. DOI: 10.1016/j.indcrop.2018.12.034

[101] Sangkharak K, Pichid N, Yunu T, Kingman P. Separation of carotenes and vitamin e from palm oil mill effluent using silica from agricultural waste as an adsorbent. Walailak Journal of Science and Technology. 2016;**13**(11):939-947. DOI: 10.14456/vol13iss12pp%p

[102] Kua YL, Gan S, Morris A, Ng HK. Simultaneous recovery of carotenes and tocols from crude palm olein using ethyl lactate and ethanol. Journal of Physics: Conference Series. 2018;**989**(1). DOI: 10.1088/1742-6596/989/1/012005

[103] Álvarez R, Meléndez-Martínez AJ, Vicario IM, Alcalde MJ. Carotenoid and vitamin A contents in biological fluids and tissues of animals as an effect of the diet: A review. Food Reviews International. 2015;**31**(4):319-340. DOI: 10.1080/87559129.2015.1015139

[104] Berman J et al. Nutritionally important carotenoids as consumer products. Phytochemistry Reviews. 2015;**14**(5):727-743. DOI: 10.1007/s11101-014-9373-1

[105] Rubin LP, Ross AC, Stephensen CB, Bohn T, Tanumihardjo SA. Metabolic effects of inflammation on vitamin A and carotenoids in humans and animal models. Advances in Nutrition: An International Review Journal. 2017;**8**(2):197-212. DOI: 10.3945/an.116.014167

[106] Rodriguez-Concepcion M et al. A global perspective on carotenoids: Metabolism, biotechnology, and benefits for nutrition and health. Progress in Lipid Research. 2018;**70**:62-93. DOI: 10.1016/j.plipres.2018.04.004

[107] Woodside JV, McGrath AJ, Lyner N, McKinley MC. Carotenoids and health in older people. Maturitas. 2015;**80**(1):63-68. DOI: 10.1016/j.maturitas.2014.10.012

[108] Green AS, Fascetti AJ. Meeting the vitamin A requirement: The efficacy and importance of β-carotene in animal species. Scientific World Journal. 2016;**2016**. pp. 1-22. DOI: 10.1155/2016/7393620

[109] Ras RT et al. Increases in plasma plant sterols stabilize within four weeks of plant sterol intake and are independent of cholesterol metabolism. Nutrition, Metabolism and Cardiovascular Diseases. 2016;**26**(4):302-309. DOI: 10.1016/j.numecd.2015.11.007

[110] Weingärtner O et al. Plant sterol ester diet supplementation increases serum plant sterols and markers of cholesterol synthesis, but has no effect on total cholesterol levels. Journal of Steroid Biochemistry and Molecular Biology. 2017;**169**(July 2016):219-225. DOI: 10.1016/j.jsbmb.2016.07.016

[111] Baumgartner S et al. Effects of plant stanol ester consumption on fasting plasma oxy(phyto)sterol concentrations as related to fecal microbiota characteristics. Journal of Steroid Biochemistry and Molecular Biology. 2017;**169**:46-53. DOI: 10.1016/j.jsbmb.2016.02.029

[112] Johnston TP, Korolenko TA, Pirro M, Sahebkar A. Preventing cardiovascular heart disease: Promising nutraceutical and non-nutraceutical treatments for cholesterol management. Pharmacological Research. 2017;**120**:219-225. DOI: 10.1016/j.phrs.2017.04.008

[113] Vazquez-Vidal I, Jones PJH. Nutrigenetics and blood cholesterol levels in response to plant sterols. In: Principles of Nutrigenetics and Nutrigenomics. Vol. 2. Innipeg, MB, Canada and Vaudreuil-Dorion, QC, Canada: Elsevier Inc.; 2020. pp. 227-230. DOI: 10.1016/b978-0-12-804572-5.00029-x

[114] Lacatusu I, Arsenie LV, Badea G, Popa O, Oprea O, Badea N. New cosmetic formulations with broad photoprotective

and antioxidative activities designed by amaranth and pumpkin seed oils nanocarriers. Industrial Crops and Products. 2018;**123**:424-433. DOI: 10.1016/j.indcrop.2018.06.083

[115] Narayan Bhilwade H, Tatewaki N, Nishida H, Konishi T. Squalene as novel food factor. Current Pharmaceutical Biotechnology. 2010;**11**(8):875-880. DOI: 10.2174/138920110793262088

[116] Kim S-K, Karadeniz F. Chapter 14—Biological importance and applications of squalene and squalane. In: S-KBT-AF, Kim NR, editors. Marine Medicinal Foods. Vol. 65. Busan, Republic of Korea: Academic Press; 2012. pp. 223-233. DOI: 10.1016/B978-0-12-416003-3.00014-7.

[117] Jin R, Yin H, Wang H, Zhang D, Cao K, Yuan C. Preparation and characterization of squalene micro-capsules by complex coacervation. Journal of Food Process Engineering. 2018;**41**(6):1-6. DOI: 10.1111/jfpe.12847

[118] Kim JH, Kim CN, Kang DW. Squalene epoxidase correlates E-cadherin expression and overall survival in colorectal cancer patients: The impact on prognosis and correlation to clinicopathologic features. Journal of Clinical Medicine. 2019;**8**(5):632. DOI: 10.3390/jcm8050632

[119] Cirmena G et al. Squalene epoxidase as a promising metabolic target in cancer treatment. Cancer Letters. 2018;**425**:13-20. DOI: 10.1016/j.canlet.2018.03.034

[120] Birhanu G, Javar HA, Seyedjafari E, Zandi-Karimi A. Nanotechnology for delivery of gemcitabine to treat pancreatic cancer. Biomedicine and Pharmacotherapy. 2017;**88**:635-643. DOI: 10.1016/j.biopha.2017.01.071

[121] Brunner G, Gast K, Chuang MH, Kumar S, Chan P, Chan WP. Process for the production of highly enriched fractions of natural compounds of palm oil with supercritical and almost critical fluids (Processo para a produção de frações altamente enriquecidas de compostos naturais de oleo de palma com fluidos supercrit). BRPI0706288B1. 2017

[122] Pathak PV, Charhate PS, Kurkarni MG. Process for the Preparation of Tocols & Squalene. PCT/IN2017/050557-WO2018/109780 A1. 2018

[123] May CY, Nang HLL, Wei PC, Ah Ngan M, Basiron Y. Recovery of phytonutrients from palm oil. EP 1398311 B1. 2007

[124] Oroskar AG, Sharma D, Oroskar A, Oroskar G. Recovery of highly pure alpha-tocotrienol from crude palm oil extract. US008937191B2. 2015

[125] Choo Yuen M, Lik Nang Lau H, Ngan MA, Basiron Y. Extraction of palm vitamin E, phytosterols and squalene from palm oil, US 2005/0250953 A1. 2005

[126] Peterson DM, Jensen CM, Hoffman DL, Mannerstedt-Fogelfors B. Oat tocols: Saponification vs. direct extraction and analysis in high-oil genotypes. Cereal Chemistry. 2007;**84**(1):56-60. DOI: 10.1094/CCHEM-84-1-0056

[127] Lee YY et al. Comparing extraction methods for the determination of tocopherols and tocotrienols in seeds and germinating seeds of soybean transformed with OsHGGT. Journal of Food Composition and Analysis. 2012;**27**(1):70-80. DOI: 10.1016/j.jfca.2012.03.010

[128] dos Santos Freitas L, Jacques RA, Richter MF, da Silva AL, Caramão EB. Pressurized liquid extraction of vitamin E from Brazilian grape seed oil. Journal of Chromatography A. 2008;**1200**(1):80-83. DOI: 10.1016/j.chroma.2008.02.067

[129] Lau HLN, Choo YM, Ma AN, Chuah CH. Selective extraction of palm carotene and vitamin E from fresh

palm-pressed mesocarp fiber (*Elaeis guineensis*) using supercritical CO2. Journal of Food Engineering. 2008;**84**(2):289-296. DOI: 10.1016/j.jfoodeng.2007.05.018

[130] Teixeira CB, Macedo GA, Macedo JA, da Silva LHM, Rodrigues AM d C. Simultaneous extraction of oil and antioxidant compounds from oil palm fruit (*Elaeis guineensis*) by an aqueous enzymatic process. Bioresource Technology. 2013;**129**:575-581. DOI: 10.1016/j.biortech.2012.11.057

[131] Jiang ST, Shao P, Pan LJ, Zhao YY. Molecular distillation for recovering tocopherol and fatty acid methyl esters from rapeseed oil deodoriser distillate. Biosystems Engineering. 2006;**93**(4):383-391. DOI: 10.1016/j.biosystemseng.2006.01.008

[132] Chandrasekaram K, Han NM, May CY, Hock CC. Concentration and isolation of individual vitamin e components in palm phytonutrients concentrate using high performance liquid chromatography with flourescence detection. Journal of Oil Palm Research. 2009;**21**(June):621-626

[133] Phoon KY, Ng HS, Zakaria R, Yim HS, Mokhtar MN. Enrichment of minor components from crude palm oil and palm-pressed mesocarp fibre oil via sequential adsorption-desorption strategy. Industrial Crops and Products. 2018;**113**:187-195. DOI: 10.1016/j.indcrop.2018.01.039

[134] Posada LR, Shi J, Kakuda Y, Xue SJ. Extraction of tocotrienols from palm fatty acid distillates using molecular distillation. Separation and Purification Technology. 2007;**57**(2):220-229. DOI: 10.1016/j.seppur.2007.04.016

[135] Zigoneanu IG, Williams L, Xu Z, Sabliov CM. Determination of antioxidant components in rice bran oil extracted by microwave-assisted method. Bioresource Technology. 2008;**99**(11):4910-4918. DOI: 10.1016/j.biortech.2007.09.067

[136] Aryanti N, Wardhani DH, Nafiunisa A. Ultrafiltration membrane for degumming of crude palm oil-isopropanol mixture. Chemical and Biochemical Engineering Quarterly. 2018;**32**(3):325-334. DOI: 10.15255/CABEQ.2017.1244

[137] Mezzomo N, Maestri B, dos Santos RL, Maraschin M, Ferreira SRS. Pink shrimp (*P. brasiliensis* and *P. paulensis*) residue: Influence of extraction method on carotenoid concentration. Talanta. 2011;**85**(3):1383-1391. DOI: 10.1016/j.talanta.2011.06.018

[138] Cardenas-Toro FP, Alcázar-Alay SC, Coutinho JP, Godoy HT, Forster-Carneiro T, Meireles MAA. Pressurized liquid extraction and low-pressure solvent extraction of carotenoids from pressed palm fiber: Experimental and economical evaluation. Food and Bioproducts Processing. 2015;**94**:90-100. DOI: 10.1016/j.fbp.2015.01.006

[139] Hiranvarachat B, Devahastin S. Enhancement of microwave-assisted extraction via intermittent radiation: Extraction of carotenoids from carrot peels. Journal of Food Engineering. 2014;**126**:17-26. DOI: 10.1016/j.jfoodeng.2013.10.024

[140] Tsiaka T, Zoumpoulakis P, Sinanoglou VJ, Makris C, Heropoulos GA, Calokerinos AC. Response surface methodology toward the optimization of high-energy carotenoid extraction from *Aristeus antennatus* shrimp. Analytica Chimica Acta. 2015;**877**:100-110. DOI: 10.1016/j.aca.2015.03.051

[141] Zaghdoudi K et al. Accelerated solvent extraction of carotenoids from: Tunisian Kaki (*Diospyros kaki* L.), peach (*Prunus persica* L.) and apricot (*Prunus armeniaca* L.). Food Chemistry. 2015;**184**:131-139. DOI: 10.1016/j.foodchem.2015.03.072

[142] Jaeschke DP, Menegol T, Rech R, Mercali GD, Marczak LDF. Carotenoid and lipid extraction from *Heterochlorella luteoviridis* using moderate electric field and ethanol. Process Biochemistry. 2016;**51**(10):1636-1643. DOI: 10.1016/j.procbio.2016.07.016

[143] Zaghdoudi K et al. Response surface methodology applied to Supercritical Fluid Extraction (SFE) of carotenoids from Persimmon (*Diospyros kaki* L.). Food Chemistry. 2016;**208**:209-219. DOI: 10.1016/j.foodchem.2016.03.104

[144] Sowbhagya HB, Chitra VN. Enzyme-assisted extraction of flavorings and colorants from plant materials. Critical Reviews in Food Science and Nutrition. 2010;**50**(2):146-161. DOI: 10.1080/10408390802248775

[145] Kwang HC, Lee HJ, Koo SY, Song DG, Lee DU, Pan CH. Optimization of pressurized liquid extraction of carotenoids and chlorophylls from chlorella vulgaris. Journal of Agricultural and Food Chemistry. 2010;**58**(2):793-797. DOI: 10.1021/jf902628j

[146] Yara-Varón E, Fabiano-Tixier AS, Balcells M, Canela-Garayoa R, Bily A, Chemat F. Is it possible to substitute hexane with green solvents for extraction of carotenoids? A theoretical versus experimental solubility study. RSC Advances. 2016;**6**(33):27750-27759. DOI: 10.1039/c6ra03016e

[147] Saini RK, Keum YS. Carotenoid extraction methods: A review of recent developments. Food Chemistry. 2018;**240**(April 2017):90-103. DOI: 10.1016/j.foodchem.2017.07.099

[148] Moreira BO et al. Application of response surface methodology for optimization of ultrasound-assisted solid-liquid extraction of phenolic compounds from *Cenostigma macrophyllum*. Journal of Chemometrics. 2020;**34**(10):1-12. DOI: 10.1002/cem.3290

[149] Tripodo G, Ibáñez E, Cifuentes A, Gilbert-López B, Fanali C. Optimization of pressurized liquid extraction by response surface methodology of Goji berry (*Lycium barbarum* L.) phenolic bioactive compounds. Electrophoresis. 2018;**39**(13):1673-1682. DOI: 10.1002/elps.201700448

[150] Gomes SVF et al. Accelerated solvent extraction of phenolic compounds exploiting a Box-Behnken design and quantification of five flavonoids by HPLC-DAD in Passiflora species. Microchemical Journal. 2017;**132**:28-35. DOI: 10.1016/j.microc.2016.12.021

[151] Rodríguez-Solana R, Salgado JM, Domínguez JM, Cortés-Diéguez S. Comparison of soxhlet, accelerated solvent and supercritical fluid extraction techniques for volatile (GC-MS and GC/FID) and phenolic compounds (HPLC-ESI/MS/MS) from lamiaceae species. Phytochemical Analysis. 2015;**26**(1):61-71. DOI: 10.1002/pca.2537

[152] Altemimi A, Watson DG, Choudhary R, Dasari MR, Lightfoot DA. Ultrasound assisted extraction of phenolic compounds from peaches and pumpkins. PLoS ONE. 2016;**11**(2):1-20. DOI: 10.1371/journal.pone.0148758

[153] Setyaningsih W, Saputro IE, Palma M, Barroso CG. Optimisation and validation of the microwave-assisted extraction of phenolic compounds from rice grains. Food Chemistry. 2015;**169**: 141-149. DOI: 10.1016/j.foodchem.2014.07.128

[154] Conidi C, Cassano A, Caiazzo F, Drioli E. Separation and purification of phenolic compounds from pomegranate juice by ultrafiltration and nanofiltration membranes. Journal of Food Engineering. 2017;**195**:1-13. DOI: 10.1016/j.jfoodeng.2016.09.017

[155] Schroyen M, Vervaeren H, Vandepitte H, Van Hulle SWH, Raes K.

Effect of enzymatic pretreatment of various lignocellulosic substrates on production of phenolic compounds and biomethane potential. Bioresource Technology. 2015;**192**:696-702. DOI: 10.1016/j.biortech.2015.06.051

[156] Ajila CM, Brar SK, Verma M, Tyagi RD, Godbout S, Valéro JR. Extraction and analysis of polyphenols: Recent trends. Critical Reviews in Biotechnology. 2011;**31**(3):227-249. DOI: 10.3109/07388551.2010.513677

[157] Dąbrowski G, Czaplicki S, Konopka I. Fractionation of sterols, tocols and squalene in flaxseed oils under the impact of variable conditions of supercritical CO2 extraction. Journal of Food Composition and Analysis. 2019;**83**:103261. DOI: 10.1016/j.jfca.2019.103261

[158] Tarhan İ, Kara H. A new HPLC method for simultaneous analysis of sterols, tocopherols, tocotrienols, and squalene in olive oil deodorizer distillates using a monolithic column with chemometric techniques. Analytical Methods. 2019;**11**(36):4681-4692. DOI: 10.1039/c9ay01525f

[159] Bouriakova A, Mendes PSF, Elst K, De Clercq J, Thybaut JW. Techno-economic evaluation of squalene recovery from oil deodorizer distillates. Chemical Engineering Research and Design. 2020;**154**:122-134. DOI: 10.1016/j.cherd.2019.12.003