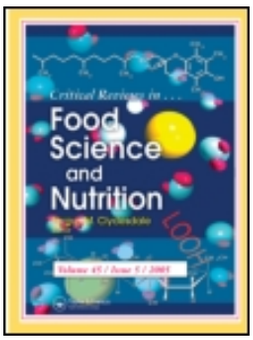

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Physicochemical Characteristics, Nutritional Properties, and Health Benefits of Argan Oil: A Review

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The argan tree (Argania spinosa L. Skeels), an endemic tree in Morocco, is the most remarkable species in North Africa, due to its botanical and bioecologic interest as well as its social value. Argan oil is traditionally well known for its cardioprotective properties and it is also used in the treatment of skin infections. This paper gives an overview of scientific literature available on nutritional and pharmacologic properties of argan oil. Owing to its unique organoleptic properties associated with its cardioprotective properties, argan oil has found, recently, its place in the highly competitive international edible oil market. This success is a very positive sign for the preservation of the argan tree, the argan forests and, therefore, in general, the biodiversity.

Keywords *Argania spinosa*, argan oil, fatty acids, nutrition, pharmacologic properties

BACKGROUND

Human diet contains three macronutrients and several micronutrients like vitamins, minerals, antioxidants, and other beneficial phytochemicals. The macronutrients are sources of different kinds of proteins, carbohydrates, and fats (lipids). Food industry is concerned to supply these as primary products or as constituents of a wide range of foods. Healthy supplies of macronutrients generally contain the necessary micronutrients. Regardless of the impression given by many uniformed sources that fat is an undesirable part of the diet, it remains an essential requirement. Awareness that both quantity and the quality of the fat consumed are important elements of healthy diet is the main challenge of this highly developed world.

Lipids have important physical, chemical, and nutritional properties, and these have to be brought into appropriate balance. This is not always an easy task. Nutritionists may indicate a recommended quantity and quality of fat and, seed producers, farmers, and those in the agricultural and food businesses strive to produce material to meet these targets. With growing problems of obesity and hypercholesterolemia, there is need to reduce consumption of *trans* acids in diet or replace these with *omega-3* acids.

Almost all vegetable oils are obtained from beans or seeds. Oil extraction is normally achieved by pressing or with solvent extraction techniques. Seeds give oil in different proportions. Using the USDA figures for 2008–2009, world average oil yields are: soybean (18%), rapeseed (39%), sunflower (41%), groundnut (32%), coconut oil (62%), and 44% palm kernel (Gunstone, 2011).

The argan tree (*Argania spinosa*) is an endemic plant of southwestern Morocco, where it covers an area of 3200 square miles that constitutes a unique biotope, named "the argan forest." *Argania spinosa* is a tree that has played an essential function in the southwestern Moroccan micro-economy (El Monfalouti et al., 2010). By providing food for human beings and animals as well as fuel, it has played a key role for the

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native population of these regions for centuries. The present review describes detailed physicochemical, nutritional, and health benefits of argan oil.

Botanical Features of the Argan Tree

The argan tree (*Argania spinosa*) is native to Morocco and the second most common tree in the country. It grows wild and profusely in the area extending from Safi to the fringes of the Sahara and bounded by the Atlantic Ocean to the West and the Atlas Mountains to the East. Its geographic distribution is limited: located 29°15′ to 31°20′ N and 8°10′ to 10°25′ W. Within the area where the argan grows, there are approximately 21 million trees which play a vital role in the food chain and the environment, although their numbers are declining now (Batanouny, 2011).

Its deep roots are the most important stabilizing element in the arid ecosystem, providing the final barrier against the encroaching deserts (Lybbert, 2007). The argan tree belongs to a tropical family, *Sapotaceae*, which includes approximately 10 genera and 600 species (M'Hirit et al., 1998). The tree resists domestication and remains extremely difficult to transplant or establish on any meaningful scale outside Morocco (Fig. 1). Argan trees grow between eight and 10 meters in height, and live to be 150–200 years old. They are thorny, with gnarled trunks. The leaves are small, two to four centimeter long, and oval with a rounded apex. The flowers are small, with five pale yellow-green petals; flowering is in April. The fruit is two to four centimeter long and 1.5 to three centimeter broad, with a thick, bitter peel surrounding a sweet-smelling but unpleasantly flavored layer of pulpy pericarp. This surrounds the very hard nut, which contains one (occasionally two or three) small, oil-rich seeds. The fruit takes more than a year to mature, ripening in June to July of the following year. Its average weight ranges from five to 20 g or more. The flesh or pulp is 55 to 75% of the fruit fresh weight (M'Hirit et al., 1998).

Nearly 90% of the rural economy in the region depends on argan-based agroforestry (Benchekroun, 1990). This heavy local dependence on the argan tree has shaped clear and well-established, albeit complex, tenure arrangements that grant usufruct (legal) rights to the fruit of sections of the forest to specific villages and households (Lybbert, 2007). In recognition of its ecologic value and local economic importance, the argan forest region was declared a UNESCO Biosphere Reserve in 1998 (Lybbert, 2007).

Kingdom	**Plantae**
Phylum	Magnoliophyta
Class	Magnoliopsida
Order	Ebenales
Family	Sapotaceae
Genus	Argania
Species	*Argania spinosa*

Figure 1 Taxonomy of Argan plant (Guillaume and Charrouf, 2011a, 2011b). (Color figure available online.)

Table 1 Composition of different argan oil (El-Monfalouti et al., 2010)

	Traditional oil	Edible oil	Cosmetic oil
Materials	Roasted kernels	Roasted kernels	Unroasted kernels
Process	Hand malaxing	Press	Solvent or press
Preservation	Seven to 14 days	Several months	Several months
Taste	Not reproducible	Hazelnut like	Bitter
Color	Yellowish brown	Copper like	Gold like
Quality	Low	Very high	Very high
Moisture	Variable	Low	very low
Antioxidants	Variable	High	High

ARGAN OIL

The Argan oil consumption has recently increased in the European, North American, and Japanese oil market (Charrouf and Guillaume, 2010). Edible Argan oil is a cold-pressed oil (Charrouf et al., 2002a, 2002b). The term "cold-pressed oil" can be used when a careful, gentle mechanical extraction of the raw material without application of heat is used. However, heat-treatment is allowed during preparation of the raw material and/or of the oil after the pressing process. Argan oil is produced from the fruits of the argan tree and it is a "living product" whose composition inevitably undergoes slight variations (Hilali et al., 2005). According to usage pattern (cosmetics, pharmaceutical, cooking, etc.) oil argan are extracted by different methods (Charrouf and Guillaume, 2010; El Monfalouti et al., 2010) such as hand extraction, cold press technique, and solvent extraction—all of these extraction methods result in different composition of oil. The comparison of preparation and quality of different argan oils are presented in Table 1.

ARGAN OIL EXTRACTION METHODS

Traditional Method

Traditionally, argan oil is extracted by women. The ripe-fruit pulp and peel are carefully discarded, then argan nuts are broken with stones, and the kernels are air dried in clay containers and roasted by mild heating. Roasted kernels are cooled then ground producing a brownish dough. This latter is finally hand-mixed with mild water for several minutes. To extract the oil, the dough is hand-pressed until it solidifies and the brownish emulsion thus obtained is decanted, furnishing—after several minutes—limpid oil with a taste of hazelnuts. The extraction residue or "press-cake" is dark-brown to black and generally still contains up to 10% of oil. It is very palatable to cattle (Charrouf and

Guillaume, 1999). This hand-made extraction technique is very slow and approximately 10 hours are necessary to produce one liter of oil. This technique barely affords more than 30% of oil that then is poorly preserved due to the water added during the extraction process. Traditionally, the oil is extracted when necessary, and salt is added for its preservation (Charrouf and Guillaume, 1999).

Press Extraction

Recently, a mechanical press has been introduced to extract argan oil. Using this technique, mixing of the dough and water is unnecessary and the dough can be directly pressed. All other steps remaining unchanged, the oil is obtained in approximately 43% yield (calculated from the kernels) and only two hours are needed to get one liter of oil that preserves correctly.

Solvent Extraction

For industrial or laboratory purposes, argan oil can be extracted from ground kernels using any volatile lipophilic solvent. After evaporation of this latter, and one or two cycles of extraction, the oil is obtained in 50 to 55% yield. However, this type of extraction furnishes oil with unsatisfactory organoleptic properties compared with the traditional or press extraction (Charrouf and Guillaume, 1999). This technique is exclusively reserved to prepare argan oil for cosmetic purposes. Preservatives are frequently added to compensate for the naturally protective agents lost during extraction and/or distillation (tocopherols, polyphenols, etc.).

TYPES OF ARGAN OIL

Argan oil has been given different names, based upon its usage, like virgin argan oil, cosmetic argan oil, cold-press argan oil, and so on (Charrouf and Guillaume, 2010). The compositions of oil obtained by different methods are presented in Table 2.

Virgin and Extra-Virgin Argan Oil

Extra-virgin argan oil refers to argan oil whose acidity value is lower than 0.8 (Norme Marocaine, 2003). Virgin argan oil has an acidity value lower than 1.5 (Norme Marocaine, 2003).

Edible Argan Oil

Edible argan oil is prepared from roasted kernels, whereas unroasted kernels are used in the production of cosmetic argan oil (El Monfalouti et al., 2010). The edible argan oil has a taste similar to hazelnuts. It is of very high quality with low moisture and high antioxidant content. Edible argan oil is also the major constituent of "Amlou," a highly nutritive preparation whose composition also includes large quantities of crushed almonds and honey (El Monfalouti et al., 2010).

Table 2 Physicochemical parameters of different argan oils (Marfil et al., 2011; Guillaume and Charrouf, 2011a, 2011b)

Physicochemical parameters	Beauty	Cosmetic	Enriched
Acid value (mg KOH/g oil)	<1	1	<4
Iodine value (g I2/100 g oil)	102	98.1	100
Peroxide value (Meq O_2/Kg oil)	1.2	0.8	>10
Saponification value (mg KOH/g oil)	196	195	195
Unsaponifiable matter (%)	0.8	1	3.8
TOCOPHEROLS			
Total tocopherols (mg/kg)	771	250	1834
FATTY ACID COMPOSITION (%)			
Palmitic acid	13	13.5	13.5
Stearic acid	5.5	5.5	5.5
Oleic acid	46	47	48
Linoleic acid	35	33	34
Linolenic acid	<0.5	<0.5	<0.5

Cosmetic Argan Oil

Cosmetic argan oil is prepared by solvent-extraction. Cosmetic argan oil is directly used for application on the skin or as a hair lotion. Its content of volatile components is lower than that of edible argan oil (Pauly et al., 2001) and its shelf life is also shorter, probably due to the formation of Millard compounds during the roasting step (El Monfalouti et al., 2010; Harhar et al., 2010). Cosmetic argan oil contains approximately one percent of unsaponifiable matters that also have antioxidant properties and participate in oil preservation (Guillaume and Charrouf, 2011a, 2011b).

Beauty Argan Oil

The preparatory time of beauty argan oil is normally less than that of edible oil, because roasting is not carried out during preparation. Four steps are necessary for its manufacturing including fruit picking, fruit peeling, nut breaking, and kernel pressing. Non-roasted argan kernels deliver beauty oil in 40–45% yield (Guillaume and Charrouf, 2011a, 2011b).

Enriched Argan Oil

Enriched argan oil can be prepared by removing free fatty acids by steam distillation at 150–200°C under pressure of 1.5–8.5 Pa (Fabre et al., 1991). However, enrichment in fatty acids is detrimental for cosmetic argan oil. High levels of fatty acids lead to an odorant oil that can be irritant to the skin (Guillaume and Charrouf, 2011a, 2011b).

Table 3 Fatty acid composition of argan oil determined by different scientists

Fatty acid	Fellat-Zarrouck et al., 1987	Charrouf et al., 1990	Khallouki et al., 2003	Hilali et al., 2005	Charrouf & Guillaume, 2008	Gharby et al., 2011	Range of values
Myristic C14:0	0.12–0.18	0.16	–	0–0.2	<0.1	–	0–0.18
Palmitic C16:0	14.4–15.6	14.3	13.4	–	11–15	13–14	11–15.6
Stearic C18:0	4.5–5.9	5.9	5.1	5.6	4–7	5–6	4–7
Oleic C18:1	43.3–48.8	42.8	44.8	45.2–46.9	43–49	47–48	42.8–49
Linoleic C18:2	30–34.1	36.9	35.7	31.6–34.6	29–36	31–33	29–36.9
Linolenic C18:3	0.1–0.26	0.15	0.1	0–0.1	<0.2	–	0–0.26
Arachidonic C20:4	–	0.39	–	0–0.4	–	–	0–0.4
Eicosaenoic C20:1	0–0.1	0.15	–	0–0.1	<0.5	–	0–0.5

CHEMICAL COMPOSITION OF ARGAN OIL

Triglycerides and Fatty Acid Profile

Essential fatty acids (EFA) are long-chain polyunsaturated fatty acids, which play an important role on human health promotion, and as they cannot be synthesized by the human body they must be obtained through diet. They are "good fats" that compete with "bad fats", such as *trans* fats and cholesterol, and they increase the levels of high-density lipoprotein (HDL), or "good cholesterol", and decrease the levels of low-density lipoprotein (LDL), the "bad cholesterol".

Triacylglycerols (TAG) are the major constituent of argan oil. Over 99% of argan oil consists of mixtures of TAGs, that is, glycerol molecules, each esterified with three fatty acids. During oil extraction from the kernal, the hydrophobic TAGs attract other fat- or oil-soluble cellular components. These are the minor components of argan oil such as, triterpenes, sterols, pigments, tocopherols, and trace metals. Other components in argan oil are the metabolites from the biosynthesis of TAGs and products of lipolytic activity. These include the monoacylglycerols, diacylglycerols, and free fatty acids. 13C NMR methodologies, which are used to characterize oils (Mannina et al., 1992) have been conducted to locate the triglyceridic regiospecificity of the profile of argan oil, and the results of this study indicated that the method is more convenient and less time consuming. It shows that saturated fatty acids (palmitic or stearic) generally substitute the glycerol extremities (Sn-1 and Sn-3), while oleic acid generally esterifies the glycerol secondary alcohol (Sn-3).

The compositions of fatty acid profile of argan oil determined by different scientists are presented in (Table 3). The major fatty acids in argan oil are oleic, linoleic, stearic, and palmitic acids (Charrouf and Guillaume, 1999; Khallouki, 2003; Khallouki et al., 2005). The oil has a high content (45%) of oleic acid (C-18:1) with respect to other seed oils, and it is also rich (35%) in polyunsaturated linoleic acid (C-18:2; refs. Charrouf and Guillaume, 1999; Khallouki, 2003; Khallouki et al., 2003). Argan oil has a fatty acid composition similar to that of sesame and peanut oil, marketed in Western Europe. The comparative fatty acid composition of argan oil with *Moringa olerifera* oil and olive oil are presented in (Table 4). The comparison indicates high-quality composition of argan oil. Chemical analysis of this oil highlighted a glyceride fraction (99%) that is rich in polyunsaturated fatty acids like oleic (47.7%) and 29.3% linoleic acid (Chimi et al., 1994).

Minor Constituents of Argan Oil

The minor constituents of argan oil can be divided into two broad groups. The first group consists of fatty acid derivatives, like glycerides (mono and diacylglycerols), phytosterols, triterpenes, and alcohols. The second group includes classes of compounds not related chemically associated to fatty acids. These

Table 4 Comparison of argan, olive, and Moringa oleifera oil (Khallouki et al., 2003; Tsaknis et al., 1999)

	Virgin argan oil	Virgin olive oil	Moringa olifera oil
Fatty acid		%age	
C16:0	13.4	10.4	6.04
C18:0	5.1	2.76	4.14
C18:1	44.8	71	73.6
C18:2	35.7	12.9	0.73
C18:3	0.1	1.04	0.22
Sterols		mg/100 g oil	
Schottenol	142	0	–
Spinasterol	115	0	–
β-Sitosterol	0	156	50.07
Campestrol	0	12	15.13
Stigmasta-8,22-dien-3β-ol	9	0	16.87
Others	29	151	–
Total	295	319	–
Tocopherols		mg/kg oil	
Alpha	35	190	98.82
Beta	122	42	27.9
Gamma	480	26	71.16
Total	637	358	
Phenolic compounds		μg/kg oil	
Vanillic acid	67	359	–
Syringic acid	37	0	–
Ferulic acid	3147	51	–
Tyrosol	12	19,573	–
Others	–	773,000	–
Total	3,263	792,983	–

include the hydrocarbons, aliphatic alcohols, tocopherols, pigments, phenolics, and trace metals. Most of the minor components found in the unsaponifiable fraction of argan oil are phytosterols, triterpene alcohols, tocopherols, and xanthophylls (Charrouf and Guillaume, 1999; Khallouki, 2003; Khallouki et al., 2003). The comparison of fatty acids and other minor compounds in Israeli and Moroccan argan oil is presented in Table 5.

Table 5 Comparison of fatty acid profile of Israeli and Moroccan argan oils (Yaghmur et al., 1999)

	Range (wt%)	
Fatty acid profile	Israeli oil	Moroccan oil
Myristic acid (14:0)	0.2	0.2–0.3
Palmitic acid (16:0)	13–15	12–14
Palmitoleic acid (16:1)	–	0–1
Stearic acid (18:1)	2–4	5–7
Oleic acid (18:1)	46–55	42–47
Linoleic acid (18:2)	28–35	31–37
Linolenic acid (18:3)	0–0.5	0–1
Arachidonic acid (20:4)	0–0.3	0–1
Gadoleic acid (20:1)	–	trace
Behenic acid (22:0)	0	trace
TUFA/TSFA[1]	4.93	4.29

[1]TUFA, total unsaturated fatty acids; TSFA, total saturated fatty acids

Triterpene Alcohols

The unsaponifiable matter in argan oil contains a proportion of approximately 20% of triterpene alcohols (Charrouf and Guillaume, 1999). These are a complex group of plant constituents which consist mainly of five condensed cyclohexane rings with 30 carbon atoms. They can be separated from the sterols by chromatography and the few identified in crude argan oil include lupane, ursane, and oleanane derivatives which include β-amyrin, butyrospermol, and tirucalol as major triterpenic alcohols (Fig. 2) and represent 27.3, 18.1, and 27.9% of the triterpenic fraction, respectively (Khallouki et al., 2005).

Methyl Sterols and Sterols

Sterols and stanols are present in fruits, vegetables, nuts, seeds, cereals, legumes, and vegetable oils, among others, being stanols present in much smaller amounts than sterols. Both are

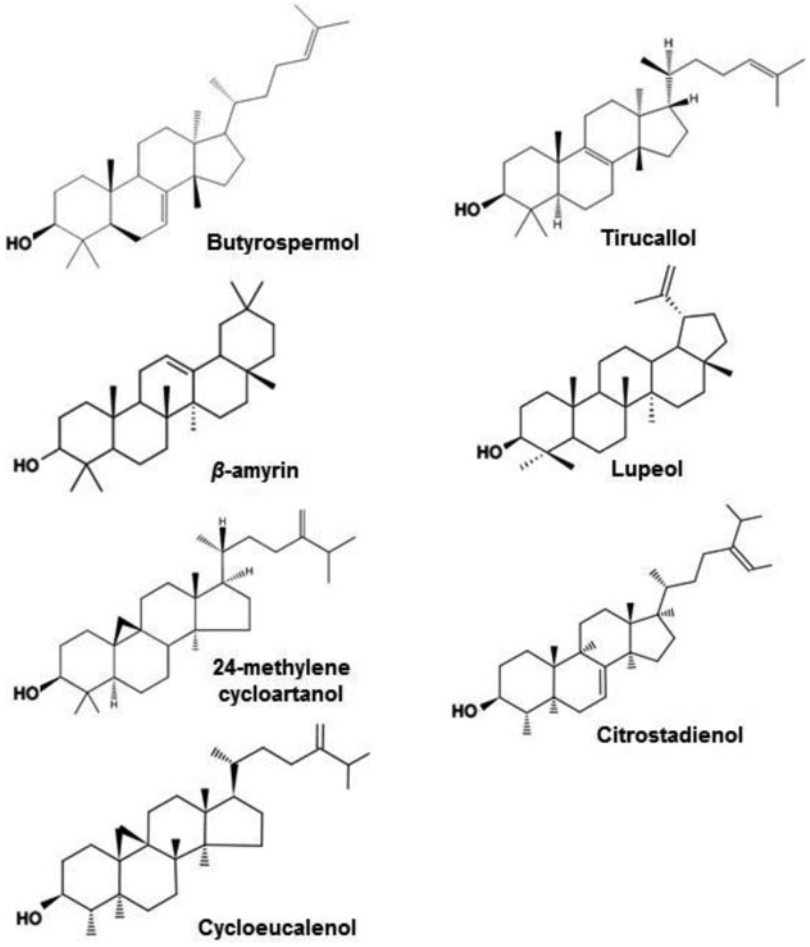

Figure 2 Triterpene alcohols in argan oil (Charrouf & Guillaume, 2002).

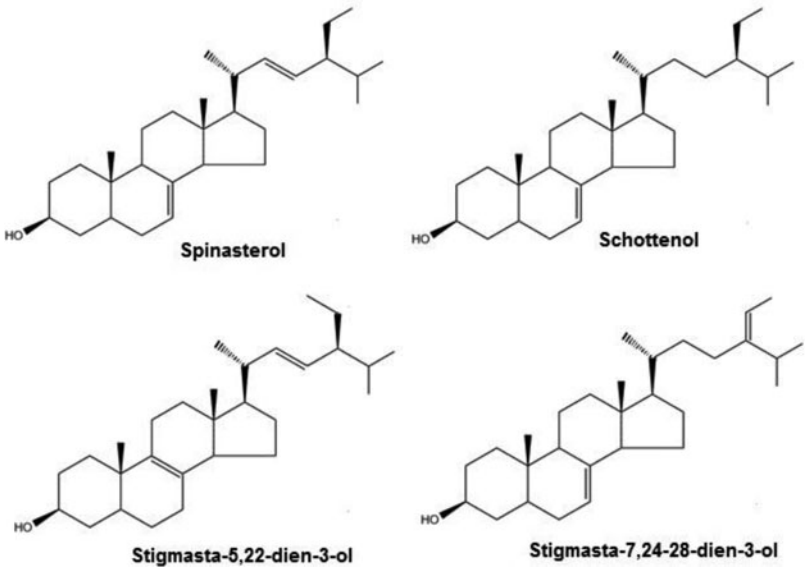

Figure 3 Sterols present in argan oil (Charrouf & Guillaume, 2002).

essential components of plant cell membranes and structurally resemble cholesterol, which is also a sterol. However, cholesterol is predominately of animal origin, being synthesized in the human liver, and has an essential role in the human body, either for the cell walls or as a building block for steroid hormones, such as testosterone and estrogen. Cholesterol is carried from the liver to the cells by the LDLs, through the blood, and these may originate fat deposits in the arteries, increasing the risk of coronary heart disease (CHD), and leading ultimately to heart attack or stroke (Law et al., 1994). On the contrary, the HDLs exert a protective effect to the heart, because they carry the excess of bad cholesterol back to the liver, where it is eliminated.

Four sterols have been isolated from argan oil (Farines et al., 1984), spinasterol, schottenol, (3β,22*E*, 24*S*)-stigmasta-5,22-dien-3- ol, and (3β,24*Z)*-stigmasta-7,24–28-dien-3-ol (Fig. 3). 24-methylene cycloartanol in plants represents the biosynthetic origin of 4-methyl sterols. These sterols are present in small quantities in the triterpenic fractions of the oil. Charrouf and Guillaume (1999) and Khallouki (2003) reported the presence of cycloeucatenol and citrostadienol in argan oil. These methyl sterols do not appear to play any specific biological role and are probably biosynthetic intermediates in the evolution of triterpenic alcohols and sterols.

Sterols are tetracyclic compounds with generally 27, 28, or 29 carbon atoms. They constitute a sizeable proportion of the unsaponifiable matter in oil. Four types of sterols have been found in argan oil. The two major are named spinasterol and schottenol (44 and 48%, respectively), the two minor [stigmasta-8, 22-dien-3β-ol (22-*E*, 24-*S*) and tigmasta-7,24–28-dien-3β-ol (24-Z)] have been both isolated in four percents yield. No D-5 type of sterols have been identified in argan oil; however, this is repeatedly encountered in vegetable oils (Charrouf and Guillaume, 2008).

The total content of sterols in the unsaponifiable fraction of argan oil is approximately 20%. Farines and colleagues (1981), Charrouf and Guillaume (1999), Khallouki (2003), Khallouki and colleagues (2003) report that argan oil contains spinasterol (40%) and its dihydrospinasterol (schottenol, 48%) as major sterols, respectively, together with Δ-7-avenasterol and stigmasta-8,22-diene-3-β-ol in lower concentrations. Spinasterol and schottenol are rarely found in vegetable oils. Spinasterol has been described as the characteristic phytosterol of the sapotaceae family (Gunasekera et al., 1977). Contrary to the composition of fatty acids, the phytosterol composition is very different from that of sesame and peanut oils in which β-sitoterol dominates.

Antioxidants

Antioxidants such as vanillic, ferulic, and syringic acids together with tyrosol in argan oil have also been observed (Khallouki, 2003; Khallouki et al., 2003). *p*-Hydroxybenzoic acid and vanillin are also identified in trace amounts, and a number of unidentified compounds with UV spectra similar to phenolics were also detected, and these warrant further investigations.

Vitamin E is a fat-soluble vitamin, which comprises two major homologous series of compounds (tocochromanols), known as tocopherols and tocotrienols. The tocopherols are structurally characterized by a saturated side chain on the chromatin ring, whereas the tocotrienols possess an unsaturated phytyl side chain (Fig. 4). Four homologs of each type are known to exist in nature, and they have different degrees of antioxidant and vitamin E activities. Vegetable oils, especially the seed oils, are rich sources of tocopherols. The vitamin E content in crude argan oil ranges between 629 to 660 mg/kg

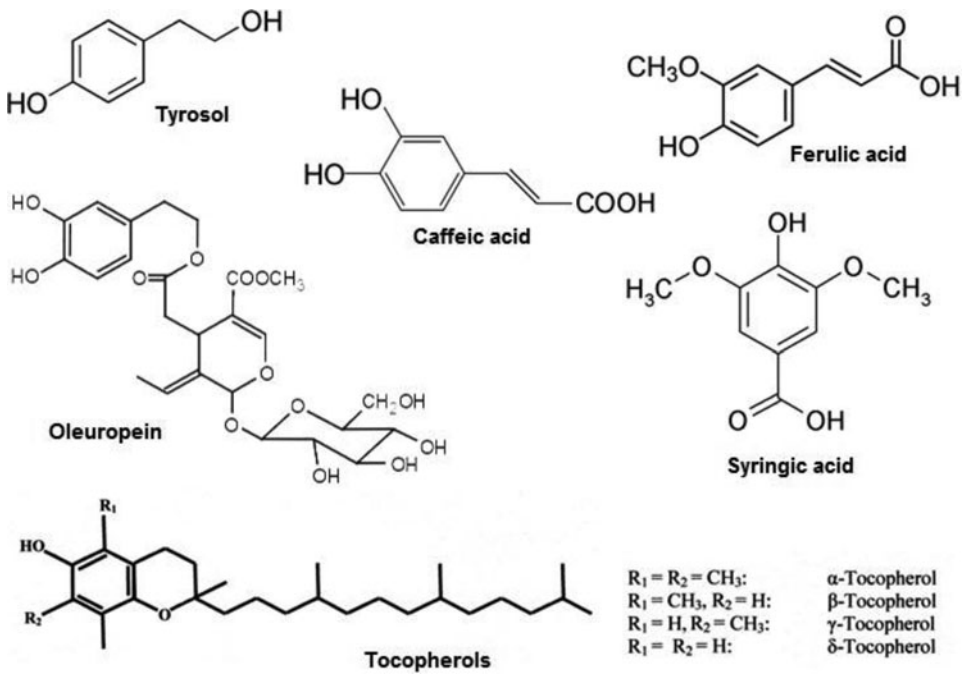

Figure 4 Antioxidants present in argan oil (Charrouf & Guillaume, 2002; Khallouki et al., 2005).

and the major tocopherol (500 mg/kg) is the γ-analogue (75%) (Khallouki, 2003; Khallouki et al., 2003). Similarly, studies with the unsaponifiable fraction revealed that argan oil is rich in tocopherol (620 mg/kg vs. 320 mg/kg in olive oil and 400 mg/kg in sunflower oil), particularly α and β-tocopherol (Khallouki, 2003; Aguilera et al., 2004). Argan oil is almost twice as rich in tocopherol as olive oil (620 vs. 320 mg/kg). α-Tocopherol as well as β- and γ -tocopherol have been identified in argan oil (Charrouf, 1984). The presence of these tocopherols (Vitamin E), together with polyphenols (caffeic acid and oleuropein; ref. Chimi et al., 1988), probably plays a part in the good preservation qualities of argan oil. Recently, Marfil and colleagues (2011) determined the tocopherol and antioxidant content of argan oil. They concluded that total tocopherols varied between 427.0 and 654.0 mg/kg. The antioxidant activity of argan virgin oils determined by the ABTS method in *n*-hexane oils dilution ranged between 14.16 and 28.02 mmol Trolox/kg, and by the ABTS, DPPH, and FRAPS methods in methanolic oil extracts, it ranged between 2.31 and 14.15, 0.19 and 0.87, and 0.62 and 2.32 mmol Trolox/kg, respectively. A high correlation was found between ABTS and DPPH methods applied to a methanolic oil extract. Virgin argan oil presents a higher tocopherol content, and total antioxidant activity in comparison with any other edible vegetable oils.

In general, vegetable oils contain a large variety of bioactive compounds with interesting properties, which include free radical scavengers, reducing agents, potential chelators of metal ions, and quenchers of the singlet oxygen formation (Gorinstein et al., 2003). Published data show that the total tocopherol content in virgin argan oil is higher than the content reported for extra virgin olive oil but is lower than for other edible vegetable oils (Marfil et al., 2011). For example, Pellegrini and colleagues (2003) reported data on the α-tocopherol content in extra virgin olive oil is 251–369 mg/kg; α-tocopherol represents the major fraction of total tocopherols in olive oil. Tuberoso and colleagues (2007) found values of 1618.4 and 1797.6 mg/kg of total tocopherols in corn and soybean oils, respectively. Szydlowska–Czerniak and colleagues (2008) reported data that total tocopherols ranged between 555 and 690 and 80 and 190 mg/kg in rapeseed and olive oils, respectively. Cayuela and colleagues (2008) analyzed different argan oils produced by the traditional and the semiautomatic extraction methods, and reported a total tocopherols content ranging from 389 to 503 mg/kg; γ-tocopherol was the major tocopherol (84.4–86.4%). These authors reported that the low tocopherol content they found could be due to inadequate oil storage conditions. These authors also indicated that traditionally extracted argan oils show significantly higher total tocopherols content than the oils from semi-industrial extraction method. The total tocopherol content is a purity criterion, as established by Ministry of Industry, Trade, Energy and Mines (MITEM), the Moroccan standard is 08.5.090 (MITEM, 2002) with the reference limits of this parameters being between 600 and 900 mg/kg.

Carotenoid Pigments

*O*f the various classes of pigments in nature, the carotenoids are among the most widespread and important ones, particularly due to their varied functions. These are fat-soluble pigments found mostly in plants, fruits, flowers, algae, and photosynthetic bacteria, but they also occur in some non-photosynthetic

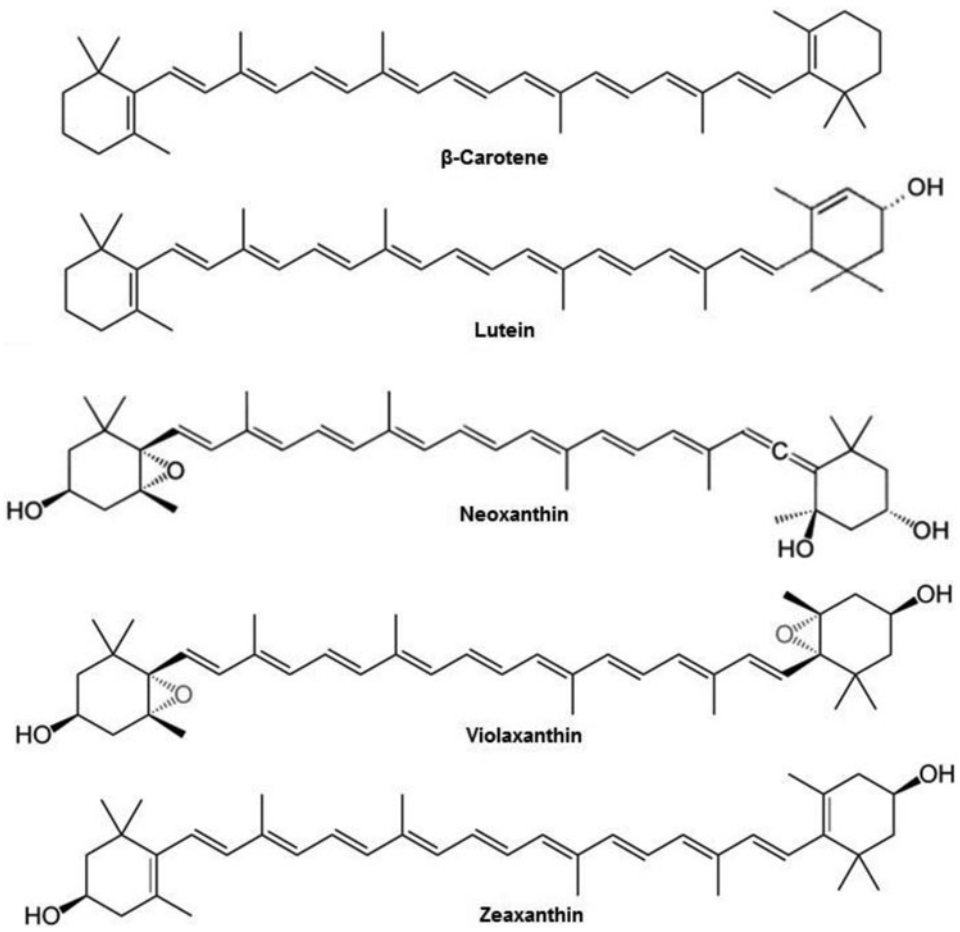

Figure 5 Xanthophylls present in argan oil (Croce et al., 1999).

bacteria, yeasts, and molds. The most abundant carotenoids in naturally consumed foods are β-carotene, α-carotene, γ-carotene, lycopene, lutein, β-crpytoxanthin, zeaxanthin, and astaxanthin (Fig. 5).

Carotenoids are highly unsaturated tetraterpenes, biosynthesized from eight isoprene units. Their more favored state is the all-trans. Carotenoids are divided into two main classes: carotenes which are strictly polyene hydrocarbons, and xanthophylls, which contain oxygen. The oxygen in xanthophylls may be in the form of hydroxy (e.g., zeaxanthin and lutein), keto, epoxy, or carboxyl groups. Xanthophylls occur in crude argan oil at a level of 42% of the unsaponifiable fraction (Charrouf and Guillaume, 1999).

Carotenoids are important for human health, but its structure ultimately determines the potential biologic functions. The essential role of β-carotene and others as the main dietary source of vitamin A has been known for many years (Carlier et al., 1993). More recently, protective effects of carotenoids against serious disorders such as cancer (Donaldson, 2004; Kantoff, 2006) heart disease (Lonn and Yusuf, 1999; Sesso et al., 2003) and degenerative eye disease (Mozaffarieh et al., 2003) have been recognized, and have stimulated intensive research into the role of carotenoids as antioxidants and as regulators of the immune response system.

Squalene

Similar to olive oil Owen and colleagues (2000) and other vegetable oils, argan oil contains, high contents of squalene (up to 3.2 g/kg; refs. Khallouki, 2003; Khallouki et al., 2003). Hydrocarbons, mainly squalene, in vegetable oils are present in quantities generally lower than 0.15%; the exceptions are olive and argan oils, which exceed 0.3% (Khallouki et al., 2005).

Phenolic Compounds

Argan oil is rich in phenolic content. Nine phenols (i.e., 3-hydroxypyridine (3-pyridinol), 6-methyl- 3-hydroxypyridine, catechol, resorcinol, 4-hydroxybenzyl alcohol, vanillyl alcohol, 4-hydroxy-3-methoxyphenethyl alcohol, epicatechin, and catechin) are determined by GC-MS analysis in alimentary and cosmetic argan oil. The analysis of the press cake revealed 16 phenols, among which six new ones not present in oils were identified (vanillin, 4-hydroxyphenylacetic acid, 3,4-dihydroxybenzyl alcohol, methyl 3,4-dihydroxybenzoate, hydroxytyrosol, and protocatechuic acid). Marfil and colleagues (2011) pointed that total polyphenolic contents in argan oil ranged between 6.07 and 152.04 mg GAE/kg. Virgin argan oil

contains higher polyphenols in comparison with any other edible oil.

NUTRITIONAL PROPERTIES AND HEALTH BENEFITS OF ARGAN OIL

Argan oil has been used as a food, food ingredient, and cosmetics ingredient for centuries. It has been applied to the skin, thereby proving no toxicity either in acute or chronic form. Argan oil has a long, significant, and tasty lineage in Morocco. It is used for cooking Tagine, couscouss, and other meals. It may be served alone as a dip for bread at breakfast time or in combination with honey, or with butter, or also with blended almonds to make a mixture called Amlou. Its flavor is similar to that of peanut butter. Combined with oat, it is considered as a good meal for babies and children. The main traditional use of argan oil is by far for nutritional purposes. Natives either directly eat the oil on toasts, generally for breakfast, or use it for frying. Argan oil consumers have lower levels of plasma LDL and cholesterol compared with the non-consumers (Drissi et al. 2004). There are many patents that confirm the use of argan oil in many cosmetics products (Table 6).

In southern Morocco, argan forests are precious to the indigenous Berber tribes who rely on the peculiar tree for firewood and charcoal for heating and cooking; wood for carpentry and construction; fodder for livestock; and oil for culinary, cosmetic, and medicinal purposes. The argan oil is traditionally indicated to cure all kind of pimples on the skin and, more particularly, juvenile acne and chicken pox pustules (Charrouf et al., 2002a, 2002b). It is also recommended to reduce dry skin problems and slow down the appearance of wrinkles (Charrouf and Guillaume, 1999). In addition, it is used in rheumatology. For these indications, the oil is used as a skin lotion and applied on the area to be cured. In addition, and as olive oil, argan oil is also used by mouth and is traditionally prescribed as hepatoprotective agent, or in case of hypercholesterolemia or atherosclerosis (Bellakhdar, 1997; Moukal and L'arganier, 2004). Argan oil would also prevent miscarriage. Cosmetic-grade oil cures skin pimples, juvenile acne, and chicken pox pustules. It also reduces the rate of appearance of wrinkles and is used to fight dry skin and dry hair. The complete list of all pharmacologic properties of argan is presented in Table 7.

Table 6 Some recent patents relative to the use of argan oil

Patent number	Statements
EP 1958 614 A1	Composition comprising argan oil (up to 40 wt.%) and a plant-based product of the aloe genus, and its cosmetic use
US 7871766 B2	Cosmetic and/or dermopharmaceutic preparations containing native proteins from the plant *Argania spinosa*
WO 01/37792	Dermatologic compositions which comprise rice starch, coconut products, shea butter, borage oil, avocado oil, jojoba oil, and optionally 1.5% by weight of argan oil
FR 2756183	Pharmaceutical or cosmetic composition which comprises a combination of argan oil and argan peptides
FR 2553788	Method for preparing a lipidic extract of argan fruit
EP 1764085	Cosmetic composition which comprises at least 10% by weight of argan oil

Table 7 Overview of nutritional and pharmacologic benefits of argan oil

References	Pharmacologic role
(Drissi et al., 2004)	Reduction of LDL cholesterol
(Charrouf et al., 2002)	Cure of pimples, acne, and chicken pox pustules
(Charrouf and Guillaume, 1999)	Solution of skin wrinkles and dryness
(Semerano et al., 2011)	Solution of rheumatologic problems
(Charrouf and Guillaume, 1999)	Help in joint movement and arthritis
(Bellakhdar, 1997)	Hepatoprotective agent
(Moukal and L'arganier, 2004)	Atherosclerosis reduction
(Derouiche et al., 2005; Richard et al., 2011)	Reducing in plasma cholesterol
(Perdomo et al., 2011)	Increase efficiency of prostaglandins
(Ames and Shiegenaga, 1992)	Reduction of aging process
(Bennani et al., 2007; Drissi et al., 2006)	Controlling prostate cancer
(Dobrev, 2007)	Sebum control properties
(Charrouf and Guillaume, 2008)	Softness and protection of hairs
(Yaqqob, 2004)	Anti-inflammatory properties
(Berrougui et al., 2004)	Reduction in hypertension
(Cherki et al., 2005)	Antiatherogenic activity
(Mekhfi et al., 2008)	Reduction in platelet aggregation
(Newmark, 1997)	Protection against skin cancer
(Bellahcen et al., 2011; Bnouham et al., 2008)	Antidiabetic properties
(Astier et al., 2010)	Argan oil triggers allergic reaction
(Benzaria et al., 2006)	Argan oil does not influence immune system
(Derouiche et al., 2005)	Argan oil has no impact on thyroid hormone profile

Antioxidant Properties

Argan oil is rich in essential fatty acids and vitamin E. The fat component of argan oil is divided into the following fatty acid types: saturated (16–20%), monounsaturated (45–50%), and polyunsaturated (32–40%). There is also a significant concentration of oleic acid and omega-6 fatty acids. Compared with olive oil, argan oil is approximately equal in saturated fatty acid content, lower in monounsaturated fatty acid content, and high in polyunsaturated fatty acid content. Mono- and polyunsaturated fatty acids, when consumed instead of saturated fatty acids, are capable of reducing plasma cholesterol (Richard et al., 2011).

Argan oil contains, in small amounts, other fatty acids, such as linoleic acid, that produce prostaglandins, which are key in immune system and circulatory functions (Perdomo et al., 2011). Consumption of linoleic acid will lead to an increased production of prostaglandins, which helps with rheumatoid arthritis and problems of the cardiovascular system (Semerano et al., 2011). The triglycerides content of argan oil may have too

cholesterol-lowering effects (Derouiche et al., 2005). Because argan oil is processed using a cold press, it retains a much larger amount of its natural nutritive qualities than oils pressed using a heated process.

Argan oil induces an increase in antioxidant activity of the cell because ingestion of argan oil by rats induces a change in the polyunsaturated fatty acids of the membranes (Belcadi, 1994) and presence of vitamin E could decrease the membrane susceptibility to peroxidation that could be at the origin of elderly processes (Ames and Shiegenaga, 1992).

Recent epidemiologic, experimental, and mechanistic evidence suggests that γ-tocopherol may be a more potent cancer chemopreventive agent than α-tocopherol (Gao et al., 2002; Huang et al., 2003). It was found that γ-tocopherol is more potent than α-tocopherol in its interaction with reactive nitrogen oxide (NO) species (Cooney et al., 1993). Helzlsouer and colleagues (2000) have examined the effects of α-tocopherol, γ-tocopherol, and selenium on incident prostate cancer, and statistically significant protective associations for high levels of selenium and α-tocopherol were found only when γ -tocopherol levels were high. Moreover, the role of γ -tocopherol as a colorectal cancer preventive agent is well reviewed by Campbell and colleagues (2003). γ-Tocopherol inhibits proliferation of colon cancer cell lines more potently than α-tocopherol and prevents cell-cycle progression through reduction in the levels of cyclin D1 and cyclin E and inhibits DNA synthesis more efficiently than α-tocopherol (Gysin et al., 2002). Argan oil contains higher content of γ-tocopherol in comparison with any other edible oil. Argan oil is highly effective in controlling prostate cancer (Khallouki et al., 2003; Drissi et al., 2006; Bennani et al., 2007).

Dermocosmetologic Properties

It is believed that argan oil skin-protective properties such as moisturizing, antiaging, and repair, results from its high level in polyphenols, a class of compounds known to prevent UV-B–induced wrinkle formation and photo-aging caused by collagen destruction and inflammatory responses (Guillaume and Charrouf, 2011a, 2011b). In addition, argan oil possesses sebum-control properties (Dobrev, 2007). This has led to the preparation of argan oil-containing compositions aimed at correcting or preventing disorders associated with greasiness by reducing the sebum secretion. Cosmetic-grade argan oil can be introduced crude or after trans-esterification with polyglycerin-6 in shampoos or hair conditioners, because it nourishes and revitalizes the scalp, it also restores hair natural softness and silky (Charrouf and Guillaume, 2008).

The anti-sebum activity of argan oil was showed on 17- to 50-year-old 20 volunteers having oily facial skin. A twice daily facial application of an argan oil-containing cream for four weeks revealed significant anti-sebum activity that reduced greasiness and improved appearance of oily facial skin (Dobrev, 2007; Guillaume and Charrouf, 2011a, 2011b).

Prevention of Cardiovascular Diseases

The rich composition of argan oil in term of tocopherols, mono-unsaturated fatty acid (MUFA), and polyunsaturated fatty acid (PUFA) makes it a very interesting oil with regard to its potential actions on risk factors for cardiovascular diseases (CVD), such as hyperlipidemia, hypercholesterolemia, and hypertension.

The fatty acid composition of argan oil has been the focus of attention in determining its nutritional adequacy in relation to CHD, atherosclerosis, inflammation, and cancer risk factors. As indicated earlier, fatty acids in argan oil are balanced by almost 80% unsaturated oleic and linoleic acids and 20% saturated fatty acids. Dietary fatty acids are known to modulate plasma lipids and lipoproteins. This concept has been extensively researched since the early 1950s, and evidence has steadily accumulated showing a positive correlation between intake of saturated fat and increased levels of plasma total cholesterol (TC) in humans. Oils rich in oleic acid are currently touted to be the healthiest of the edible fats in the human diet (Bartsch et al., 1999). Whereas olive, rapeseed, and canola contain in excess of 60% of their composition as *cis*-oleic acid, argan oil has approximately 45% of this monounsaturated fatty acid. The question of whether this level of oleic acid in argan is adequate to result in a lipoprotein-cholesterol profile that protects against CHD and cancers must be examined in a series of human trials.

The anti-inflammatory properties of n-3 PUFA in the arterial wall may contribute to the protective effects of n-3 PUFA in CVD, as suggested by epidemiologic and secondary prevention studies. Some studies showed that dietary n-3 PUFA can be incorporated into plaque lipid in human subjects, where they may influence the morphology and stability of the atherosclerotic lesion (Yaqqob, 2004).

Berrougui and colleagues (2003) investigated the effect of dietary argan oil on serum lipids composition. Hyperlipidemia was induced by high-calorie and cholesterol (HCC) diet administration in 16 rats (Meriones shawi). Eight rats were treated with argan oil (10 ml/1 kg weight) daily by oral route during seven weeks (treated group). Control animals were also fed the HCC diet for seven weeks. After a seven-week treatment with argan oil, blood lipoproteins were significantly reduced. Total cholesterol decreased in 36.67%, LDL-cholesterol in 67.70%, triglycerides in 30.67%, and body weight in 12.7% of the treated group. Furthermore, HDL-cholesterol concentration remained unaltered (Berrougui et al., 2003). These findings indicate the beneficial effect of argan oil in the treatment of the hyperlipidemia and hypercholesterolemia.

Hypertension is one of risk factors of CVD (Simon et al., 1996). Berrougui and colleagues (2004) investigated the effects of seven weeks of treatment with argan oil (10 ml/kg) on the blood pressure and endothelial function of spontaneously hypertensive rats (SHR) and normotensive Wistar–Kyoto rats. Argan oil administration reduced the mean blood pressure of SHR after the fifth week of treatment and increased the endothelial responses of arteries from SHR. A high concentration of linoleic

acid and α-tocopherol could contribute to explaining this effect that was dependent on both cyclooxygenase products and nitrogen oxide (Berrougui et al., 2004). Drissi and colleagues (2004) reported that argan oil consumers have lower levels of plasma LDL and cholesterol compared with non-consumers, suggesting that argan oil may reduce cardiovascular risk factors, thus retarding the onset of the atherosclerosis process.

Human group studies have provided evidence for the hypolipidemic activity of argan oil (Derouiche et al., 2005). In this strict lipid-controlled study, for baseline measurement, 60 men were initially fed 25 g/day of butter on toasted bread as a source of lipids for two weeks. Thereafter, butter was replaced with 25 ml/day of virgin argan oil for one half of the group, while the other half received the same amount of virgin olive oil. After three weeks, body mass index (BMI), systolic (SBP) and diastolic blood pressure (DBP), serum total cholesterol, HDL, LDL, apolipoproteins A-I and B, and triglyceride levels were measured and compared with baseline values. BMI, SBP, DBP, and total cholesterol levels did not significantly change during the three-week study. In the argan oil group, HDL cholesterol and triglyceride levels significantly increased and decreased, respectively.

Antiatherogenic activity of argan oil has recently been studied by Cherki and colleagues (2005). They concluded that argan oil consumption has positive effect on oxidative stress plasma markers and HDL paraoxonase 1 (PON1). In their study (25 ml/day), subjects were fed argan oil for three weeks and plasma PON1 activity, antioxidant vitamins, and LDL susceptibility to oxidation were measured. A significant increase in PON1 activity was observed that consequently reduce the LDL level in blood. In addition, argan oil has the ability to reduce platelet aggregation and, therefore, minimize the risk of thrombosis in cardiovascular events (Mekhfi et al., 2008).

Cytoprotective and Anticarcinogenic Properties

Tocopherols and saponins derived from argan fruit exert an antiproliferative effect on human prostate cancer (Drissi et al., 2006). The unsaponifiable fraction of argan oil inhibits proliferation of several transformed cell lines in a dose-dependent manner through inactivation of extracellular-regulated kinase (ERK1/2; ref. Samane et al., 2006). This antiproliferative effect of argan oil was shown against HTC liver cells and two cell lines of tumorigenic origin, namely the human HT-1080 fibrosarcoma cell line and the transformed and invasive canine MSV-MDCK-INV cells (Samane et al., 2006).

The antiproliferative effect of polyphenols and sterols extracted from the virgin argan oil on three human prostatic cell lines (DU145, LNCaP, and PC3) was shown (Bennani et al., 2007). In a more recent study, Bennani (2009) investigated the effect of polyphenols extracted from argan oil on the proliferation of two human epithelial cell lines (PNT1A and PC3) and one epithelial cell lines from dog adenocarcinoma (DPC1). Their results showed that the polyphenols of argan oil exert a dose-dependent antiproliferative action on PC3 and DPC1 cell lines. However, no inhibition effect has been shown on PNT1A cell lines (Bennani, 2009). Furthermore, El Babili et al. (2010) showed that the ethyl acetate extract of argan fruits was cytotoxic at a dose of 42 mg/ml against human breast cancer cells (MCF7). Similarly, squalene in argan oil is suggested to be protective against skin cancer (Newmark, 1997) and enhances excretion of xenobiotics in rats and mice (Kamimura et al., 1992).

Antidiabetic Effects

Bnouham (2008) showed that the intraperitoneal administration of argan oil (2.5 ml/kg) 30 minutes before the oral glucose loading (1 g/kg) induced a significant reduction of glycemia in healthy and diabetic rats compared with controls. In the subchronic treatment, the results showed a significant improvement of body mass and a significant reduction of the glycemia at the end of experiment, when compared with untreated diabetic rats. Moreover, argan oil significantly reduced the amount of absorbed glucose in perfused jejunal segment. However, this effect was less than that of acarbose (an α-glucosidase inhibitor; ref. Bnouham et al., 2008), although, argan oil consumption may reduce hyperglycemia-induced pathogenesis. In a recent study, Bellahcen and colleagues (2011) confirmed the antidiabetic effect of virgin argan oil. Argan oil (2 ml/kg) was administered orally for seven consecutive days to rats before and during intraperitoneal alloxan administration (75 mg/kg for five consecutive days). An alloxan diabetic-induced untreated group and a group treated with table oil were used as control groups. The result indicated that argan oil prevented body mass loss, induced a significant reduction of blood glucose, and increased significantly the hepatic glycogen level compared with the untreated diabetic group (Bellahcen et al., 2011). The antidiabetic effect of argan oil has not be adequately studied as yet; further investigations in human subjects seem necessary to clarify the possible role of argan oil in reducing weight loss in diabetics, and even in inhibiting the development or progression of diabetes. Similarly, comparison of the metabolic response of rats to a free-access, high-fat/high-glucose diet in which six percent of the fat was replaced by either argan oil or fish oil showed that both oils resulted in the restoration of insulin signaling in fat and liver cells (Samane et al., 2009).

Immune System Enhancing Properties

Biochemical studies have shown that fatty acid profile of argan oil enhances immune responses (Yaqqob, 2004), particularly for lymphocyte proliferation, lymphocyte-derived cytokine production and cell mediated immunity. Rat studies confirms the dietary effect of argan oil on the immune system and these studies concluded that effects of argan and olive oil on immune cells

are similar, and that argan oil has no marked effects on immune cell function (Benzaria et al. 2006).

Anaphylaxis and Toxicity to Argan Oil

There are currently no reported acute or chronic toxicity to argan oil. Recently, a case of anaphylaxis to argan oil was reported (Astier et al., 2010). It is expected that new cases of allergy to argan oil could appear due to the expansion of argan oil consumption around the world, possibly, because of its unique fatty acid profile. The identified allergen is a protein of 10 kDa molecular weight, persistent in oil. This protein could belong to the family of oleosins, which are known to be potent allergens as described for peanut (Olszewski et al., 1998) and sesame (Leduc et al., 2006). The ability to induce severe reaction at low doses is underlined by the systemic reaction induced by prick-test and the low reactogenic dose. It must be taken in consideration by oil producers that allergenicity of argan oil could be suppressed by a step of refining (Zitouni et al., 2000).

CONCLUSIONS

Argan oil, extracted from argan-tree fruits, has been used in traditional medicine as a natural remedy for several centuries. Argan oil is traditionally used for skin, nail and hair care, cooking, massaging, and healing. Its chemical composition highlights the interest of many laboratories to use it in their best-selling products. The remarkable properties of the argan oil evaluated by numerous laboratories are: restoration of the skin water–lipid layer and an increase in nutrients in the skin cells, stimulation of intracellular oxygen, neutralization of free radicals, and protection of the conjunctive tissue. Recently, results of various studies were completed in vitro or on human and animal models suggest that argan oil could play a beneficial role in cardiovascular disease prevention and its consumption could protect against atherosclerosis through a variety of biologic mechanisms. It is because of its high contents of specific antioxidants and MUFAs and PUFAs, that argan oil could be useful in preventing cardiovascular diseases and cancer. Its consumption could also increase antioxidant compounds in the serum of healthy men. Experimental studies have shown the antiproliferative and proapoptotic effects of polyphenols and sterols extracted from argan oil on prostate cancer cell lines. The use of argan oil in diet will gives best results in combating diseases like cancer, diabetes, and CVDs. Comprehensive research is need for exploring all beneficial aspects and mechanism behind curing action of argan oil.

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