Special Article

Bioactive compounds and nutritional significance of virgin argan oil – an edible oil with potential as a functional food

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This review compiles recently published scientific reports on the bioactive compounds present in virgin argan oil along with their possible beneficial effects on human health, which could justify consideration of this oil as a new functional food. Virgin argan oil is characterized by high levels of linoleic and oleic acids, tocopherols (especially γ-tocopherol), and minor compounds such as sterols, carotenoids, and squalene. The total antioxidant capacity of virgin argan oil is higher than that of other vegetable oils. Recent studies suggest that this edible oil, as a functional food, may play a role in disease prevention. For example, some authors have found it to have hypolipidemic, hypocholesterolemic, hypoglycemic, and antihypertensive effects as well as a possible role in cancer prevention. This review demonstrates the need for further studies in order to fully characterize argan oil from bromatological, nutritional, culinary, and technological perspectives. In particular, the scarcity of clinical data hampers relevant conclusions from being drawn regarding the therapeutic effects of virgin argan oil.

INTRODUCTION

Virgin argan oil is harvested from the fruit of the argan tree *Argania spinosa* [L.] Skeels, a species that is endemic to southwest Morocco and the Algerian province of Tindouf in the western Mediterranean region. The argan tree is protected by the United Nations Educational, Scientific and Cultural Organization (UNESCO),[1] because of the ecological and socioeconomic benefits it provides. Able to survive even in extreme drought and poor soil, it provides environmental protection by slowing desertification.[2] The tree bears a plum-sized fruit that contains a stone-like structure encasing one to three kernels (nuts) with a high oil content. For centuries, the production of virgin argan oil has played an invaluable economic role in Morocco, and today total annual production reaches approximately 4,000 tons per year.[3,4] Argan oil is currently used for culinary purposes in southwest Morocco, representing 25% of the total dietary fat intake in this region.[5] The oil, which has a delicate flavor with notes of hazelnut and toasted almond,[6,7] has recently extended into the European oil market and is readily found in gourmet stores in Japan and the United States. Selling for approximately €100 per liter in Europe, argan oil is considered a luxury food.[7] However, exports will likely increase in the near future, particularly as the unique properties of this oil become more widely known.

Virgin argan oil is characterized by high levels of linoleic and oleic acids and is rich in polyphenols and tocopherols, which exhibit significant antioxidant activity.[8] In addition, the presence of minor compounds such as sterols, carotenoids, xanthophylls, and squalene contributes to its nutritional value and health properties, its dietetic and organoleptic characteristics, and its preservative properties.[3,5,8–12] The geographical origin of the argan tree is limited and specific, and as a result, the chemical composition (major as well as minor components) of virgin argan oil is highly reproducible.[13] Despite this,

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Table 1 **Distinctive quality criteria for virgin argan oil, according to the *Norme Marocaine 08.5.090* standard (2003).[14]**

Parameter	Limit value	
Density (g/mL)		0.906–0.919
Saponification index		189.0–199.1
Iodine index		92.0–102.0
Refraction index (at 20°C)		1.463–1.472
Unsaponifiable fraction		≤1.1%
Fatty acid composition (%)	Myristic acid	≤0.2
	Pentadecaenoic acid	≤0.1
	Palmitic acid	≤11.5–15
	Palmitoleic acid	≤0.2
	Heptadecaenoic acid	–
	Stearic acid	4.3–7.2
	Oleic cid	43.49.1
	Linoleic acid	29.3–36.0
	Linolenic acid	≤0.2
	Arachidonic acid	≤0.5
	Gadoleic acid	≤0.5
	Behenic acid	≤0.2
Sterol content	Total	≤180 mg/100 g
	Scotenol	44–49%
	Spinasterol	34–44%
	Delta-7-avenasterol	4–7%
	Stigmata 8-22-dien-3β-ol	3.2–5.7%
	Campesterol	≤0.14%
Tocopherol composition	Total	60–70 mg/100 g
	α-tocopherol	2.4–4.8%
	β-tocopherol	0.1–0.2%
	γ-tocopherol	81.89%
	δ-tocopherol	6.2–8.2%
Trans fatty acids	C18:1T	<0.05%
	C18:3T	<0.05%
Triacylglycerides with palmitic acid in position 2	≤0.5%	

there is very little information available about the composition and antioxidant properties of virgin argan oil, with variable data reported thus far.

Under Moroccan jurisdiction, a regulation[14] was introduced in 2003 (known as the *Norme Marocaine*) to define the quality specifications for virgin argan oil (Table 1) and the classification of argan oils into different categories. Extra virgin argan oil is the highest quality level and refers to an oil with an acidity value lower than 1.0 (Table 2).

Traditionally, argan oil is recommended as a skin moisturizer and anti-flaking agent, as a treatment for juvenile acne, and as a nourishing hair conditioner.[15,16] It is also prescribed in traditional medicine for its presumed cosmetic, bactericidal, and fungicidal properties.[2] More recently, studies suggest that it may have a relevant role to play in disease prevention due to its antioxidant potential and its hypolipidemic, hypocholesterolemic, and antihypertensive effects.[10,17–19]

This review compiles recently published scientific reports on the bioactive compounds present in virgin argan oil along with their possible beneficial effects on human health, which could justify consideration of this oil as a new functional food.

METHODS OF VIRGIN ARGAN OIL EXTRACTION

For centuries, virgin argan oil was prepared exclusively by Berber women who used a process handed down from generation to generation.[20] Currently, this traditional method (hand pressure), carried out by indigenous women solely for the purposes of domestic consumption, coexists with a semi-industrialized or semiautomated method (mechanical cold pressure) applied in recently developed cooperatives to produce and commercialize virgin argan oil of certified quality (Figures 1 and 2). In both cases, the fruits of the tree are harvested between May and August and allowed to sun dry before the pericarp is removed to obtain the argan nuts. An average of 100 kg of dried fruits and 15 person-hours are necessary to obtain 60 kg of argan nuts,[20] which, once cracked opened and air dried in clay containers, will yield just

Table 2 **Quality criteria for virgin argan oil, according to the *Norme Marocaine 08.5.090* standard (2003).[14]**

Quality criteria	Extra virgin argan oil	Fine virgin argan oil	Ordinary virgin argan oil	Lampante argan oil
Quality criteria				
Acid value (% oleic acid)	≤1.0	≤2.0	≤3.3	>3.3
Peroxide value (meq of active O_2 per kg oil)	≤20	≤20	≤20	unlimited
K_{270}	≤0.25	≤0.25	≤0.30	unlimited
ΔK	≤0.01	≤0.01	≤0.01	unlimited
Organoleptic criteria				
Color	Characteristic of the designated product			
Smell and taste	Free of odor, uncommon flavor or rancidity			
Food additives	No additives are permitted for virgin argan oil			
Pollutants				
Humidity + volatile sludges (%)	≤0.2	≤0.2	≤0.2	≤0.3
Insoluble sludges in petroleum ether (%)	≤0.3	≤0.3	≤0.3	≤0.4
Trace metals (mg/kg)				
Iron	≤3.0	≤3.0	≤3.0	≤3.0
Copper	≤0.1	≤0.1	≤0.1	≤0.1
Lead	≤0.1	≤0.1	≤0.1	≤0.1
Arsenic	≤0.1	≤0.1	≤0.1	≤0.1
Halogenated solvents	≤0.1	≤0.1	≤0.1	≤0.1
Each solvent detected	≤0.1	≤0.1	≤0.1	≤0.1
Amount of solvents detected	≤0.2	≤0.2	≤0.2	≤0.2

6.5 kg of kernels.[20] To prepare edible argan oil, the kernels must be slowly roasted for a few minutes, during which overheating must be avoided as it negatively influences the final taste. During roasting, temperatures in excess of 100°C are used, resulting in significant changes in the structure of the seed material and disruption of oil-bearing cells. Such temperatures are also sufficient for the formation of Maillard reaction products. Several of these compounds are known to have a high antioxidant activity.[21,22] Thus, oils prepared from roasted seeds are more stable due to better extractability of antioxidant compounds from the kernels and the formation of compounds such as Maillard reaction products during the roasting process.[20]

In the traditional method, the roasted kernels are crushed, kneaded into a paste or dough with hot water, and then hand-pressed, after which the oil/water mixture is separated by decantation.[3,4] This method, however, is very slow, leading to oil batches with variable organoleptic properties and significant differences in chemical composition, mainly due to nonreproducible roasting conditions. In addition, and because of the extraction conditions, the oils obtained by this method are often of poor sanitary quality.

The main difference between this approach and the semi-industrialized method is that, in the latter, the oil is extracted with a mechanical cold press without the addition of water.[3,8,23] Thanks to the semi-industrialized method, high-quality argan oil can now be produced on a large scale.[20] Whichever production method is used, the quality of the raw material and oil processing directly impact the quality of the final product, influencing considerably such variables as the acidity value, the peroxide index and other quality parameters, the physicochemical composition, the nutritional value, and sensorial properties.[11,12,20,24]

COMPOSITION OF VIRGIN ARGAN OIL

Fatty acid profile

High levels of unsaturated fatty acids have long been considered the main parameter linking argan oil consumption to its observed nutritional effects. Several studies have indicated that argan oil is rich in oleic, linoleic, stearic, and palmitic acids.[2,3] Oleic acid is the predominant fatty acid in argan oil. A recent study by Marfil et al.[25] indicates the oleic acid content of virgin argan oil ranges between 36.50% and 47.70%. This is higher than the oleic acid content described by Lopez and Lopez[26] for other seed oils such as sunflower (15–85%) and soybean oils (20–35%), but lower than that of rapeseed oil (60.7%), canola oil (50–65%),[26] peanut oil (58.3%), and olive oil (67.2%)[27] (Table 3). The nutritional value of oleic acid and the clinical relevance of this fatty acid to major risk factors for cardiovascular disease have been described extensively.[28] It is widely known that oleic acid (*cis* 18:1 n-9) significantly reduces levels of low-density lipoproteins (LDL) and even slightly increases levels of high-density lipoproteins (HDL).[9,29] Furthermore, recent studies indicate that oleic acid has hypotensive effects.[30]

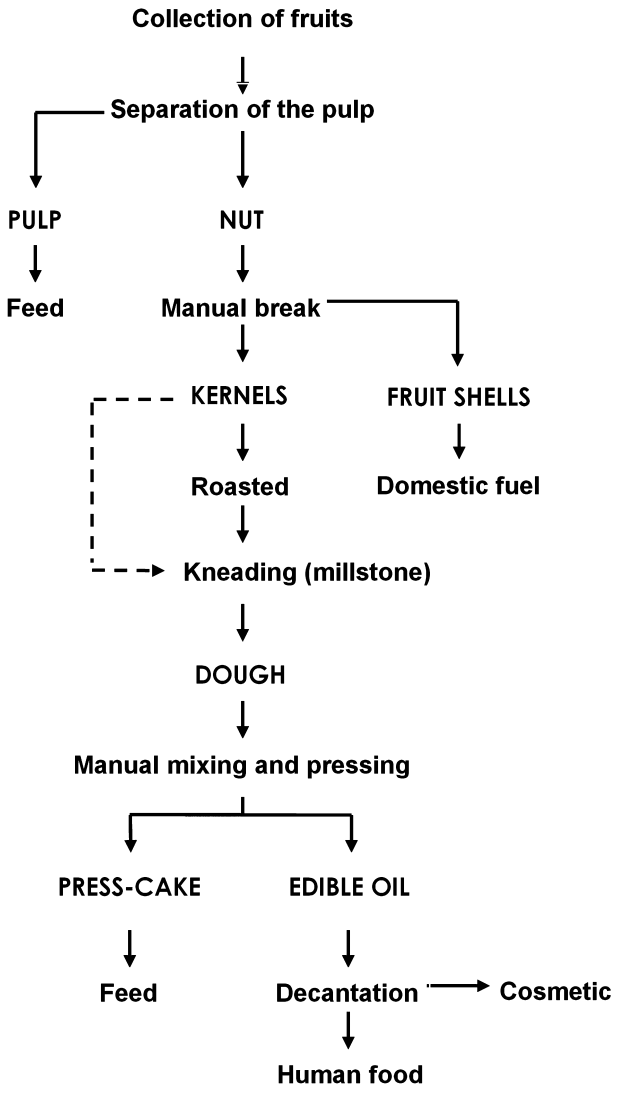

Figure 1 **Traditional method of argan oil extraction.**

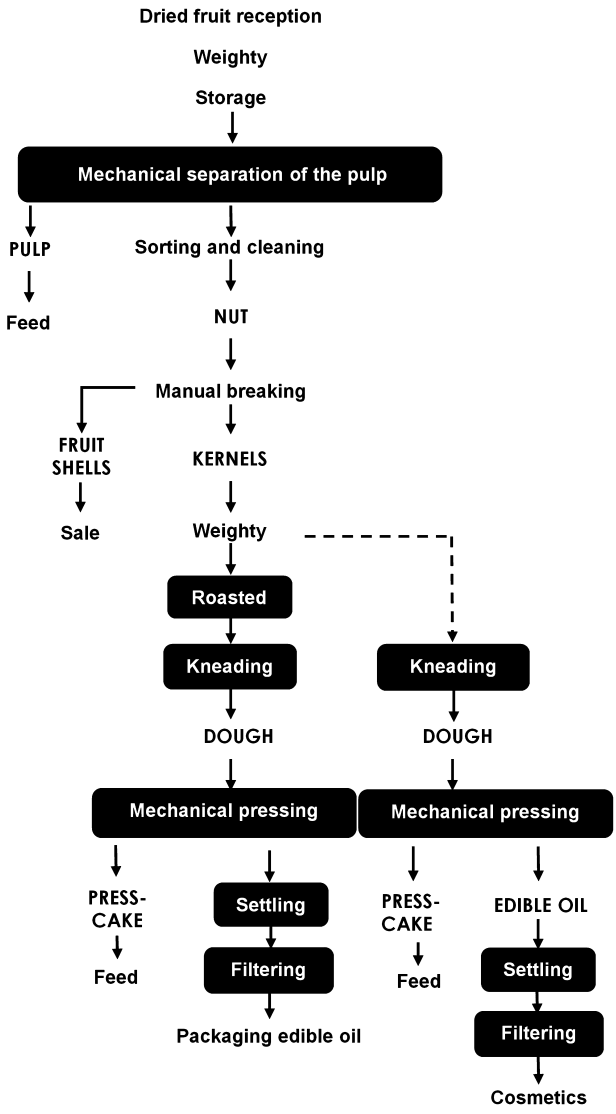

Figure 2 **Semi-industrialized method of argan oil extraction.** The process can be performed with roasting (oil for human consumption) or without roasting (oil for cosmetics). The steps in solid black denote operations that can be mechanized in the semi-industrialized extraction process.

Argan oil consumption appears to promote a proper supply of essential omega-6 polyunsaturated fatty acids, thereby improving the lipid profile, which may help protect against conditions related to oxidative damage, such as cardiovascular disease, diabetes, and cancer.[2,3] Argan oil is rich in polyunsaturated fatty acids (35%), of which linoleic acid represents the largest proportion. Marfil et al.[25] found the linoleic acid content in argan oil to range between 31.26% and 40.41%, while Charrouf and Guillaume[13] reported a linoleic acid content of at least 29%. This level is high compared to that found in olive oil (Table 3), although some varieties of olive oil may contain up to 20%.[31] Linoleic acid possesses several pharmacological properties. For instance, diets comprising 0.1% linoleic acid have recently been shown to inhibit metastasis of colon cancer cells.[32] Only traces of α-linolenic acid are present in virgin argan oil. Hilali et al.[24] reported proportions of 0.030–0.10% and Marfil et al.[25] reported 0.09–2.63%. On the other hand, saturated fatty acids are found in argan oil in similar or slightly higher quantities (19.6%)[17] compared with those found in other vegetable oils such as palm oil and coconut oil. According to Marfil et al.,[25] palmitic acid (11.74–13.94%) and stearic acid (4.91–8.29%) represent the greatest proportion of saturated fatty acids in argan oil.

The fatty acid composition of virgin argan oil, together with components of the unsaponifiable fraction of this oil (representing approximately 1.1%), make it a fat with unique properties that are potentially beneficial for human health. Following a similar line of argument, a recent review compared the nutritional properties of argan oil with those of olive oil. Interestingly, the authors

Table 3 **Comparative fatty acid profiles of virgin argan oil versus other edible oils, expressed in percentages.**

Fatty acid	Lauric acid	Myristic acid	Palmitic acid	Palmitoleic acid	Stearic acid	Oleic acid	Linoleic acid	Linolenic acid	Arachic acid	Erucic acid	Behenic acid	Lignoceric acid	Reference
Virgin argan oil	–	–	11.5–15	–	4–7	43–49	29–36	–	–	–	–	–	Charrouf and Guillaume (2010)[13]
	–	0.10–0.16	11.7–13.9	0.01–0.14	4.9–8.3	36.6–47.7	31.3–40.4	0.09–2.63	0.33–0.43	–	0.12–0.23	0.06–0.28	Marfil et al. (2009)[25]
Virgin olive oil	–	–	11.5–17.3	0.9–3.4	1.4–3.4	61.9–78.9	3.8–19.2	1.1–1.8	0.28–0.5	–	–	–	López and López (2005)[26]
	–	–	7.5–15.6	0.3–1.9	1.4–3.4	60.9–82.1	4.5–16.1	0.4–1.2	0.3–0.5	0.2–0.5	0.0–0.2	0.0–0.1	Ollivier et al. (2003)[78]
Sunflower oil	–	–	3–10	–	1–10	14–65	20–75	0.7	0.05	–	–	–	López and López (2005)[26]
	–	0.08	7.4	0.09	4.56	25.17	60.15	0.3	–	–	–	0.34	Filip et al. (2011)[79]
Soybean oil	–	–	6.0	0.4	2.2	26.1	50.1	14.5	–	–	–	–	Ayorinde et al. (2000)[80]
	–	–	9.78	–	3.08	26.12	53.98	5.67	0.49	0.23	0.48	0.16	Araujo et al. (2010)[81]
Safflower oil	–	–	6–11	–	1–10	4–12	55–81	1	0.5	–	–	–	López and López (2005)[26]
Almond oil	–	0.06	6.85	0.63	1.29	69.24	21.52	0.16	0.16	–	0.05	–	Maguire et al. (2004)[82]
		0.03	5.9–6.7	0.18–0.82	–	72.5–79.9	13.5–19.8	–	–	–	–	–	Ozcan et al. (2011)[83]
Cottonseed oil	–	–	17–31	–	1–4	13–44	33–59	0.1–2.1	0.7	–	–	–	López and López (2005)[26]
	–	–	22.96	0.90	2.3	16.8	55.42	0.02	–	–	–	–	Pasias et al. (2009)[84]
	–	0.6–0.9	20.6–25.1	0.4–.0.5	2.1–2.8	15.2–18.2	51.9–56.4	0.1–0.2	0.2–0.3	–	0.1–0.2	0.1–0.2	Lukonge et al. (2007)[85]
Canola oil	–	–	3.1	0.4	–	61.4	25.8	9.5	–	–	–	–	Ayorinde et al. (2000)[80]
	–	0.1	5.0	0.3	2.0	63.1	19.8	7.2	0.6	1.1	0.3	–	Moser (2011)[86]
Peanut oil	–	–	2–10	–	2–7	9–20	1.4–6.6	–	–	–	–	–	López and López (2005)[26]
	–	–	7.5–14.4	–	3.1–4.6	40.3–64.7	11.3–37.1	1.0–1.4	–	–	–	–	Sundaram et al. (2010)[87]
Corn oil	–	–	8–19	0.5	0.5–4	19–50	34–62	2	1	–	–	–	López and López (2005)[26]
	–	–	13.4	<0.1	1.5	27.4	56.0	0.9	0.2	–	–	–	Karoui el al. (2010)[88]
Grape seed oil			5.5–11	1.2	3–6	12–28	58–78	1	1	–	–	–	López and López (2005)[26]
	–	0.06	8.3–9.3	0.10–0.12	3.2–4.3	12.2–18.7	67.6–72.9	0.3–0.9	0.2–0.3	0.1	0.02–0.06	0.01–0.02	Rubio et al. (2009)[89]
Sesame oil	–	–	7–12	0.5	3.6–6	35–50	35–8	0.1	0.5	–	–	–	López and López (2005)[26]
	<0.01	0.5–1.8	3.9–8.7	<0.01	3.8–9.5	31.7–37.6	42.4–51.61	3.8–9.4	0.2	–	–	–	Azeez and Morakinyo (2011)[90]
Palm kernel oil	51.3	22.8	12.1	–	1.3	10.7	–	–	–	–	–	–	Ayorinde et al. (2000)[80]
	35.8	38.0	5.6	–	1.67	8.19	1.67	0.02	0.07	–	–	–	Siang et al. (2010)[91]
Palm oil	–	0.97	37.42	0.19	4.79	43.37	11.75	0.37	0.22	0.15	0.05	fatty acid	Man and Rohman (2011)[92]
	0.21–0.61	4.48–4.90	45.9	0.20–0.25	4.9–6.6	31.4–32.4	10.1–10.5	0.2–0.62	0.31–0.42	–	–		Siang et al. (2010)[91]
Palm olein oil	–	–	38.27	–	4.09	40.51	9.37	0.24	–	–	–	–	Enríquez-Fernández et al. (2011)[93]
	0.28–0.33	1.5–4.46	40.3–43.9	0.26–0.28	4.3–4.9	35.0–38.0	10.8–12.5	0.18–0.30	0.25–0.44	–	–	–	Siang et al. (2010)[91]
Coconut oil	49.1	21.8	8.4	–	2.8	6.1	1.2	–	–	–	–	–	Bhatnagar et al. (2009)[94]

indicated that the nutritional qualities of both oils are likely to be identical, given that both oils contain high levels of oleic acid, both contain linoleic acid as the second major fatty acid, and both contain the saturated fatty acids palmitic acid and stearic acid.[28]

Polyphenol content

According to Valavanidis et al.,[33] polyphenols present in edible oils are advantageous because their antiradical activity can protect against the degradation of tocopherols during storage and cooking. Moreover, polyphenols are bioactive molecules that act as free radical scavengers. As such, they are chiefly responsible for preventing the auto-oxidation of unsaturated fatty acids, thereby increasing an oil's shelf life. In recent years, scientists have been particularly interested in the preventive effects of polyphenols against reactive oxygen species (ROS) damage involved in the pathology of diseases such as diabetes, Alzheimer's disease, dementia, and Parkinson's disease or muscular degeneration.

The putative pharmacological properties of virgin argan oil are generally attributed to the phenolic compounds in the oil. The polyphenols in argan oil are present at a level of approximately 56 ppm, and their chemical composition has recently been reviewed.[34] Not all the phenolic compounds contained in argan oil or in other dietary oils have been identified. Therefore, it is very important to distinguish between the known absence of a given compound and a lack of information regarding that compound.[13] To date, caffeic, vanillic, ferulic, syringic, and p-hydroxybenzoic acids have been identified in virgin argan oil.[13] Oleuropein, a derivative whose aglycone strongly reduces breast cancer cell viability, is also a minor constituent of virgin argan oil.[13] Marfil et al.[35] applied the Folin-Ciocalteau method to evaluate the total amount of phenolic compounds present in virgin argan oil, reporting a range of 6.07–152.04 mg of gallic acid equivalents (GAE) per kilogram of oil. The high variability between different samples (coefficient of variation = 54.87%) could be explained by the influence of genetic, environmental, and technological factors (such as seed roasting temperature and time, the amount of water added during the oil extraction process, and storage conditions) on the antioxidants in the oil. According to bibliographic data, the polyphenol content of virgin argan oil is lower than that of virgin olive oil but higher than that of other edible vegetable oils. Pellegrini et al.[36] reported data on the polyphenol content of extra virgin olive oils, virgin olive oils, and refined olive oils (73–265 mg, 14–24 mg, and 4 mg GAE/kg oil, respectively). Sanchez et al.[37] found a polyphenol content in virgin olive oils of 1,085.92–1,406.40 mg GAE/kg oil. However, it must be borne in mind that the chemical composition of virgin oils such as virgin argan oil will show large variations. For comparative purposes, Valavanidis et al.[33] analyzed the total phenolic content of different edible oils and reported data of 170–210 mg GAE/kg in extra virgin olive oils, 60 mg–80 mg GAE/kg in soybean oil, 3 mg–4 mg GAE/kg in sunflower oil, and less than 1 mg GAE/kg in corn oil.

Tocopherol content

Tocopherols belong to the vitamin E group of substances and display strong and specific nutritional properties. The total tocopherol content is a purity criterion for argan oil, as established by the *Norme Marocaine 08.5.090* standard,[38] with the reference limits of this parameter ranging between 60 mg and 90 mg of tocopherols per 100 g of oil. Tocopherol content represents the main difference between the minor constituents of olive oil and argan oil. Marfil et al.[35] determined the total tocopherol content of 22 samples of virgin argan oil and encountered values ranging from 427.0 mg/kg to 654.0 mg/kg (mean, 518.90 mg/kg). Khallouki et al.[3] and Cayuela et al.[11] reported similar values, but Charrouf and Guillaume[13] reported higher values (600–900 mg/kg). Cayuela et al.[11] indicated that artisan-extracted argan oils have significantly higher total tocopherol content than oils derived by the semi-industrialized extraction method, which can be attributed to the thermal degradation of tocopherols caused by the higher temperatures used in the semi-industrialized method. Tocopherols are of great importance to the stability of argan oil, but they are degraded when exposed to unsuitable storage conditions. Thus, it is possible that the tocopherol content of argan oil may be improved by ensuring good storage procedures. In fact, Matthaus et al.[20] have reported that the amount of vitamin E active compounds in mechanically extracted argan oil generally ranges between 400 mg/kg and 775 mg/kg, while, during storage at 60°C, the total tocopherol content varies between 224 mg/kg and 457 mg/kg.

In general, the total tocopherol content of virgin argan oil is higher than that of extra virgin olive oil but lower than that of other edible vegetable oils (Table 4). This is in line with the positive tocopherol/linoleic acid ratio generally found in different oils (Tables 4 and 5).[39,40]

Among tocopherols present in virgin argan oil, γ-tocopherol was found in the greatest proportion (84.68% of the total content), whereas α-, δ-, and β-tocopherols represented 7.75%, 7.29%, and 0.33% of the total pool, respectively.[35] It is well known that tocopherols have different efficiencies as antioxidants: δ-tocopherol > γ-tocopherol ≈ β-tocopherol > α-tocopherol.[33,41] Moreover, γ-tocopherol is a potent antioxidant with a powerful anti-inflammatory effect, and

Table 4 **Tocopherol content in virgin argan oil versus that in other edible vegetable oils.**

Edible oil	Total content	α	β	γ	β + γ	δ	Reference
Virgin argan oil	427–654 mg/kg	7.75%	0.33%	84.68%		7.29%	Man and Rohman (2011)[92]
	Mean: 518.9 mg/kg						
	400–775 mg/kg						Matthaus et al. (2010)[20]
	660 mg/kg	7%	–	76%		17%	Khallouki et al. (2003)[3]
	600–900 mg/kg						Charrouf and Guillaume (2007)[34]
	389–503 mg/kg			84.4–86.4%			Cayuela et al. (2008)[11]
Extra virgin olive oil		251–369 mg/kg					Pellegrini et al. (2003)[36]
	177 ± 3 mg/kg	163 ± 3 mg/kg					Gliszcynska-Swiglo et al. (2007)[95]
	130–190 mg/kg	130–190 mg/kg			12.3 ± 0.4 mg/kg	1.6 ± 0.3 mg/kg	Szydlowska-Czerniak et al. (2008)[60]
		96 ppm				–	Kamal-Eldin and Andersson (1997)[40]
Virgin olive oil			6 ppm	12 ppm			
Corn oil	1,618.4 mg/kg						Tuberoso et al. (2007)[27]
		222 ppm	1 ppm	570 ppm		3 ppm	Kamal-Eldin and Andersson (1997)[40]
		207 ± 11 mg/kg			592 ± 20 mg/kg	30.0 ± 1.0 mg/kg	Gliszcynska-Swiglo et al. (2007)[95]
	829 ± 23 mg/kg	23–573 mg/kg	0–356 mg/kg	268–2,468 mg/kg		23–75	Codex Alimentarius FAO-WHO (2003)[96]
Soybean oil	1,797.6 mg/kg						Tuberoso et al. (2007)[27]
		116 ppm	17 ppm	578 ppm		263 ppm	Kamal-Eldin and Andersson (1997)[40]
	829 ± 12 mg/kg	152 ± 1 mg/kg			494 ± 12 mg/kg	182 ± 3 mg/kg	Gliszcynska-Swiglo et al. (2007)[95]
		90–352 mg/kg	0–356 mg/kg	89–2,307 mg/kg		154–932 mg/kg	Li et al. (1996)[97]
	236.7 ± 5.3 ppm	211.5 ± 5.5 ppm	–	25.2 ± 1.2 ppm		0.0 ppm	Codex Alimentarius FAO-WHO (2003)[96]
Sunflower oil		671 ppm	23 ppm	4 ppm		0 ppm	Kamal-Eldin and Andersson (1997)[40]
	535 ± 8 mg/kg	490 ± 8 mg/kg			30.8 ± 0.5 mg/kg	10.1 ± 0.1 mg/kg	Gliszcynska-Swiglo et al. (2007)[95]
		403–935 mg/kg	0–45 mg/kg	0–34 mg/kg		0–7 mg/kg	Codex Alimentarius FAO-WHO (2003)[96]
Palm oil		377 ppm	1 ppm	4 ppm		–	Kamal-Eldin and Andersson (1997)[40]
	110.2 ± 11 ppm	102.3 ± 9.7 ppm	–	7.9 ± 1.7 ppm		0.0 ppm	Li et al. (1996)[97]
Linseed oil		–	–	588 ppm		6 ppm	Kamal-Eldin and Andersson (1997)[40]
	367 ± 8 mg/kg	–			363 ± 7 mg/kg	5.2 ± 0.8 mg/kg	Gliszcynska-Swiglo et al. (2007)[95]
Sesame oil		4 ppm	–	584 ppm		9 ppm	Kamal-Eldin and Andersson (1997)[40]
		0–3.3 mg/kg	0 mg/kg	521–983 mg/kg		4–21 mg/kg	Codex Alimentarius FAO-WHO (2003)[96]
Rapeseed oil	83.9–173.8 mg/kg	19.3–68.5 mg/kg		0.0–2.6 mg/kg		44.2–118.9 mg/kg	Seker et al. (2008)[98]
	434 ± 9 mg/kg	181 ± 5 mg/kg			244 ± 7 mg/kg	9.3 ± 0.1 mg/kg	Gliszcynska-Swiglo et al. (2007)[95]
	555–690 mg/kg	180–300 mg/kg		370–390 mg/kg		5–10 mg/kg	Szydlowska-Czerniak et al. (2008)[60]

Table 5 **Antioxidant capacity (AC) of virgin argan oil versus that of other edible oils according to the AC analytical method applied.**

AC analytical method and type of edible oil	AC (mmol Trolox/kg oil)	Reference
ABTS-n-hexane dilution		
Virgin argan oil	14.16–28.02	Marfil et al. (2011)[35]
Extra virgin olive oil	1.53–2.69	Pellegrini et al. (2003)[36]
Extra virgin olive oil	1.79	Pellegrini et al. (2003)[36]
Corn oil	1.29	Pellegrini et al. (2003)[36]
Soybean oil	2.20	Pellegrini et al. (2003)[36]
Sunflower oil	1.17	Pellegrini et al. (2003)[36]
Peanut oil	0.61	Pellegrini et al. (2003)[36]
ABTS-methanolic extract		
Virgin argan oil	2.31–14.15	Marfil et al. (2011)[35]
Virgin olive oil	0.78–2.64	Gorinstein et al. (2003)[99]
Extra virgin olive oil	0.56–1.00	Sánchez et al. (2007)[100]
DPPH-methanolic extract		
Virgin argan oil	0.19–0.85	Marfil et al. (2011)[35]
Soybean oil	0.41	Tuberoso et al. (2007)[27]
Olive oil	0.42	Tuberoso et al. (2007)[27]
Corn oil	0.45	Tuberoso et al. (2007)[27]
Peanut	0.08	Tuberoso et al. (2007)[27]
Sunflower oil	0.16	Tuberoso et al. (2007)[27]
Safflower oil	0.25	Tuberoso et al. (2007)[27]
Rapeseed oil	0.26	Tuberoso et al. (2007)[27]
Linseed oil	0.19	Tuberoso et al. (2007)[27]
Extra virgin olive oil	0.20–0.59	Sánchez et al. (2007)[100]
Extra virgin olive oil	0.69–0.75	Gómez-Alonso et al. (2003)[101]
FRAP-methanolic extract		
Virgin argan oil	0.62–2.32	Marfil et al. (2011)[35]
Refined safflower oil	0.95–1.86	Szydlowska-Czerniak et al. (2008)[60]
Virgin safflower oil	2.84–5.52	Szydlowska-Czerniak et al. (2008)[60]
Olive oil	0.32–1.03	Szydlowska-Czerniak et al. (2008)[60]
Extra virgin olive oil	0.62–1.67	Szydlowska-Czerniak et al. (2008)[60]

Abbreviations: ABTS, 2,2′-azobis-(3-ethylbenzothiazoline-6-sulfuric acid; DPPH, 2,2′-diphenyl-1-picrylhydrazyl; FRAP, ferric-reducing antioxidant power.

plasma levels of this tocopherol are inversely associated with cardiovascular diseases.[42] In general, it is proposed that diets providing substantial amounts of γ-tocopherol could protect against ROS-mediated inflammation. Consequently, γ-tocopherol consumption has been recommended and is associated with a reduced risk of clinically relevant diseases.[43] In addition, γ-tocopherol has marked cancer-preventive properties, possibly being the most effective form of vitamin E in cancer prevention.[44]

It is important to note that γ-tocopherol is the main tocopherol in virgin argan oil, while α-tocopherol is the major tocopherol in olive oil (Table 4). Different activities can be expected from α- or γ-tocopherol-rich foods because γ-tocopherol, but not α-tocopherol, has anti-inflammatory properties,[45] and the former can be more effective in cancer prevention.[44] Furthermore, supplementation with α-tocopherol results in a decrease in plasma and tissue levels of γ-tocopherol.[46,47]

Wax content

Wax content in olive oil is used as a parameter of quality assessment; hence, the maximum wax content is regulated. The maximum level of wax permitted in olive oil, 250 mg/kg, was set to prevent tampering through the addition of olive-pomace oils and/or lampante oils. There is no report on the wax content of different types of virgin argan oil included in the *Norme Marocaine 08.5.090* standard. Marfil et al.[25] found that wax levels in argan oil ranged between 7.0 mg/kg and 95 mg/kg, with a mean of 26.4 mg/kg, indicating a wide variability in results. Moreover, in that study there was a significant difference between oils extracted by traditional methods and those extracted by semi-industrialized methods. Nota et al.[48] reported the wax content in virgin olive oils as ranging between 94 mg/kg and 203 mg/kg. Several studies have related the increase in wax content of oils to an increased

temperature during storage.[49] Waxes increase substantially over 20°C. Other factors, such as the processing temperature and the packaging material, also influence the wax content of oil. In general, the presence of wax does not alter the nutritional properties of olive oil. Furthermore, if the wax content is within the established regulatory limits, the presence of wax should not be considered a deficiency but rather the result of thermal phenomena that affect the product temporarily. Nevertheless, it is recommended that oils be stored at temperatures below 20°C, in a completely dark, oxygen-free environment.

Other minor compounds

The presence of minor compounds such as sterols, carotenoids, xanthophylls, and squalene in virgin argan oil is significant. Squalene, a hydrocarbon intermediate in sterol synthesis in both plants and animals, is abundant in argan oil (up to 3.2 g/kg).[3] There is evidence suggesting that squalene protects against cancer[50] and increases xenobiotic excretion in rats and mice.[51] Phytosterols represent another group of molecules that are important to a healthy diet. It is widely known that plant sterols exert hypocholesterolemic effects.[52] One hundred grams of virgin argan oil contains 150–250 mg of sterols.[20,24] This sterol fraction contains five important compounds, namely stigmasta-8,22-diene-3-ol, spinasterol, schottenol, stigmasta-7,24-dien-3-ol, and campesterol. Campesterol is found at a low concentration, approximately 0.3%.[20] The possible influence of each of the different sterols on human health is poorly documented, but evidence suggests that phytosterols possess antiatherogenic and anticancerous properties.[53,54] An important characteristic of the argan tree is the presence of a triterpenoid saponin, generally named arganine, that has antinutritive and sensorial properties and must be eliminated from edible argan oils.[11] Arganine is eliminated by seed-roasting during the traditional process and by an analogous treatment during the modern semiautomated process. Cayuela et al.[11] indicated it is advisable to eliminate arganine by means of nonthermal methods, such as steam treatment, as such techniques are more likely to preserve the quality of the end product.

Trace elements

Lipid oxidation is a major deteriorative reaction affecting edible oils and fats; consequently, it is of primary concern to processors and, ultimately, consumers. Unsaturated lipids are particularly susceptible to oxidation during processing and storage via auto-oxidation and photosensitized oxidation. The most common mechanism of oxidation is free radical chain reaction.[55] This process is retarded by antioxidant compounds and accelerated by pro-oxidants such as trace metals. Marfil et al.[35] reported significant differences in iron content in virgin argan oils obtained by the traditional (0.8–4.0 mg/kg) and semi-industrialized (0.8–1.7 mg/kg) methods. Similar data were reported by Armenta et al.,[7] with levels of iron in virgin argan oil that ranged between 0.23 μg/g and 1.73 μg/g. Several reports have described the deleterious effects of iron on oil flavor and oxidative stability.[56–58]

Copper also acts as a pro-oxidant in the catalytic oxidation of oil hydroperoxides in the presence of oxygen, giving rise to ketones and aldehydes that change the taste of oils and resulting in the formation of new radicals that continue the oxidation process.[55] It has been shown that copper concentrations lower than 30 ppb can induce fatty acid oxidation.[55] The catalytic effect of copper is greater than that of iron. Thus, Romano et al.[58] estimated the catalytic effect of copper (II) on the kinetic oxidation of soybean oil under various experimental conditions to be higher than that of iron (III). Marfil et al.[12] measured copper concentrations in virgin argan oils obtained by the traditional method as well as by the semi-industrialized method, reporting values of 160.4–695.7 μg/kg for the former and 158.4–385.0 μg/kg for the latter. Armenta et al.[7] found concentrations that ranged between undetectable levels and 0.565 μg/g.

The technology used in oil processing can increase intrinsic levels of chromium and manganese due to transfer from apparatus, utensils, containers (i.e., ceramic containers), and packaging. Marfil et al.[12] reported chromium and manganese levels in virgin argan oil of 10.3–55.3 μg/kg (coefficient of variation = 54.8%) and 15.0–70.8 μg/kg (coefficient of variation = 40.7%), respectively; no significant differences related to the extraction method were observed. Manganese concentrations did not exceed the concentrations considered critical in the oil oxidation process; a manganese concentration close to 0.6 ppm induces a 50% decrease in the oil's resistance to the oxidation process. The catalytic activity of manganese varies between that of copper and iron.[59]

TOTAL ANTIOXIDANT CAPACITY OF VIRGIN ARGAN OIL

In general, vegetable oils contain a large variety of substances with antioxidant properties, including free radical scavengers, reducing agents, potential complexers of pro-oxidant metals, and quenchers of the singlet oxygen formation. Different methods based on electron or hydrogen atom transfer reactions between a free radical and an oxidant are applied to evaluate the antioxidant capacity of foods. Among them, electron-based methods such as 2,2′-diphenyl-1-picrylhydrazyl (DPPH), ferric reducing antioxidant power (FRAP), and 2,2′-azobis-(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) assays have been proposed for the evaluation of rapeseed and olive

oils[33,37,60] and, more recently, for virgin argan oils.[35] Methods for evaluating antioxidant capacity can be applied to an n-hexane oil dilution or to a methanolic oil extract. The methanol-soluble phase (methanolic extract) of vegetable oils contains most of the phenolic antioxidants (i.e., hydroxytyrosol, tyrosol, syringic acid, sinapic acid, protocatechine, caffeic acid, etc.), lignans, and secoiridoids (oleuropein aglycone). This phase is called the polar fraction. The nonsoluble or lipidic phase of edible oils, determined in the n-hexane dilution, contains mostly tocopherols, triglycerides, and phospholipids, so that the antioxidant capacity of this phase is due mainly to the type and concentration of tocopherols.[33,37] Because the methods for measuring antioxidant activity are extremely dependent on the conditions used and the substrates or products monitored, there is a great variability between the results obtained by different methods. The comparison of different methods enables the appropriate analytical procedure to be selected in order to determine antioxidant capacity. Table 5 summarizes data on the antioxidant capacity of edible vegetable oils according to similar studies reflected in the bibliography; data are expressed as mmol equivalents of Trolox per kilogram of oil, a commonly used unit for antioxidant assays. Data reported for the ABTS-n-methanolic extract and n-hexane solution in virgin argan oils indicate that the tocopherols present are mainly responsible for the antioxidant capacity of these oils.

The antioxidant capacity values of methanolic extracts from virgin argan oils, as determined by the ABTS radical scavenging assay and the DPPH free radical scavenging assay, are comparable to, or even higher than, those found in the literature for methanolic extracts from virgin olive oil and safflower, soybean, peanut, and sunflower oils, applying the same methodology. Using the FRAP assay, the antioxidant capacity values of the methanolic extract of virgin argan oil are quite similar to those of virgin olive oil. When the ABTS-n-hexane dilution method is used to measure antioxidant capacity, values for virgin argan oil are higher than those reported for virgin olive oils and other edible vegetable oils. Espin et al.[41] studied the antioxidant capacity of 57 edible oils from different sources and observed a decreasing order of antiradical activity in the methanolic fraction of the oil, as follows: sesame, safflower, rapeseed, walnut, olive, and linseed oils. In the rest of the oils (corn, sunflower, almond, hazelnut, soybean, and peanut oils), negligible antiradical capacity was observed. Recently, El Babili et al.[16] applied DPPH and ABTS assays to evaluate the high antioxidant activity of argan fruit extracts.

It is well known that process used to refine rapeseed oil decreases the total phenolic content and antioxidant capacity of the oil. According to Szydlowska-Czerniak,[60] the refining process causes a 60–80% decrease in antioxidant capacity. For example, phenolic compounds are polar substances, and many of them are weak acids, so they can be easily removed from the oils with aqueous solutions, especially when neutralized with sodium hydroxide. After neutralization, the phenolic components are markedly partitioned toward the water phase that is included in the sodium soap aggregates. Although seed oils are generally refined, argan oil is, in general, an unrefined virgin oil, which is a great advantage, since antioxidant compounds such as phenolic compounds are destroyed in refined edible oils.

EVIDENCE IN SUPPORT OF ARGAN OIL AS A FUNCTIONAL FOOD

Functional foods are foods and food components that provide a health benefit beyond basic nutrition. Argan oil has been studied as a functional food on the basis of its composition and its described antiproliferative, antidiabetic, and cardiovascular risk-preventive effects. The interest in argan oil as a functional food has resulted in several patents as well as claims to include this oil in lipid emulsions for parenteral nutrition,[61] in food preparations to reduce cholesterol levels,[62] and in functional foods for patients with inflammatory bowel disease.[63]

In terms of food safety, a case of allergic reaction was recently reported in a Moroccan man with no history of allergy who reported rhinitis and conjunctivitis as a result of smelling argan oil. The ingestion of argan oil induced epigastralgia and hypersalivation. Only 20 minutes after a positive prick-test with argan oil and argan paste, the patient developed a systemic reaction consisting of generalized erythema, beginning on the arms, followed by secondary urticaria. An analysis of the proteins extracted from the argan oil identified a 10 kDa protein as being responsible for the IgE-mediated anaphylactic reaction.[64] However, argan oil ingestion has generally been demonstrated to be safe.

Argan oil and cardiovascular disease

Of the several health benefits attributed to argan oil, the potential to reduce cardiovascular risk stands out.[29] Both the equilibrated proportions of polyunsaturated and monounsaturated fatty acids and the high content of antioxidants in argan oil are thought to be responsible for this effect. It is well known that hypertension and serum levels of LDL cholesterol, or saturated fatty acids, are positively correlated with the risk of cardiovascular disease, while serum levels of HDL cholesterol, or polyunsaturated fatty acids, and antioxidants are negatively correlated with the risk of cardiovascular disease.

Three important intervention studies in humans have shown the effects of argan oil on serum lipid profile and

oxidation.[17,18,29] In the first study, serum lipid parameters and antioxidant levels of 62 subjects who regularly consumed virgin argan oil were compared with those of 34 nonconsumers.[17] The mean daily intake of argan oil in the group of consumers was 15 g. Higher serum levels of polyunsaturated fatty acids and lower levels of LDL cholesterol were observed in the group of argan oil consumers. Furthermore, levels of plasma lipid peroxides were lower in the argan oil group, which also had higher levels of antioxidants. Argan oil intake was therefore concluded to result in a positive modification of the serum lipid profile and to provide protection against oxidation. In the other two intervention studies, the intake of virgin argan oil was compared with that of extra virgin olive oil, the "gold standard" in nutritional oils. The volunteers for these studies received 25 g of butter per day for 2 weeks and then the same amount of virgin argan oil or virgin olive oil for an additional period of 3 weeks. The oils and butter were taken in a single serving with bread at breakfast time. Both oils equally reduced the plasma levels of saturated fatty acids and increased the plasma levels of HDL and A-1 apolipoprotein.[18] Differences were observed in the levels of LDL, which were decreased only by virgin olive oil consumption, and in the levels of triglycerides, which were decreased only by virgin argan oil consumption.[18] The antioxidant status – as assessed by the measurement of lipid peroxide and conjugated diene formation as well as by the susceptibility of LDL to peroxidation – was also affected in both the argan oil group and the olive oil group. In conclusion, the findings from these two studies indicate that the effect of virgin argan oil on plasma lipids and oxidation is comparable to that of virgin olive oil, although argan oil has no effect on levels of LDL cholesterol.

In the three above-mentioned studies, it was shown that virgin argan oil decreases lipid peroxides and increases antioxidant status. This finding is interesting because an important fraction of virgin argan oil fatty acids is omega-6, and normally consumption of oils rich in this type of fatty acid increases plasma lipoperoxides. It is possible that the high vitamin E content of virgin argan oil (Table 4), together with its high antioxidant capacity (Table 5), prevents the increase in lipid peroxides. In fact, it has been shown that vitamin E supplementation in human subjects and animals decreases lipid peroxidation.[65] This explanation would be in line with the higher levels of vitamin E detected in the virgin argan oil group in the last two studies.[18,29] On the other hand, in vitro studies have shown that a phenolic extract from argan oil inhibits LDL oxidation in humans, indicating that phenolic compounds in virgin argan oil also contribute to the antioxidant effect.[19]

There are no studies on the effects of argan oil on blood pressure in humans. However, several studies carried out by Berrada et al.[66] and Berrougui et al.[9,67] assessed the effects of argan oil on blood pressure in spontaneously hypertensive rats[67] and in *Meriones shawi* rats fed either a hypercaloric diet[66] or a hypercaloric diet rich in cholesterol.[9] Argan oil was administered to the animals at a dosage of 5 mL/kg/day in the experiments by Berrada et al.[66] and a dosage of 10 mL/kg/day in the experiments by Berrougui et al.[9,67] In all studies, argan oil was shown to have a lowering effect on blood pressure. This effect was accompanied by a decrease in plasma glycemia, plasmatic cholesterol, LDL cholesterol, and insulinemia. Moreover, in the *Meriones shawi* rats fed a high-calorie or high-cholesterol diet, a reduction in body weight was also observed. In the latter study,[67] the antihypertensive effect of argan oil was attributed to decreased oxidative stress. Taken as a whole, the above data support the hypothesis that virgin argan oil could be used as a functional food to reduce cardiovascular risk.

Argan oil and diabetes

No human studies have been carried out to test the effect of argan oil on diabetes. However, a few animal studies indicate that this oil could have antidiabetic effects.[68,69] Among these, a recent study indicates that administration of virgin argan oil to rats has no effect on fasting blood glucose levels.[69] Nonetheless, in a model of diabetes induced by the administration of alloxan, the authors describe a decrease in blood glucose levels, an increase in hepatic glycogen, and prevention of weight loss in rats pretreated with virgin argan oil (2 mL/kg) for 7 days prior to the induction of type 1 diabetes mellitus.[69]

The observed antidiabetic effects of argan oil are thought to be attributable to its fatty acid profile and its high content of tocopherols that enhance the antioxidant status of tissues. In particular, low concentrations of circulating and dietary α-tocopherol have been correlated with the development of type 1 and type 2 diabetes,[70–73] while vitamin E supplementation is beneficial for diabetics, improving insulin sensitivity.[71,72] Recent studies indicate that both α- and γ-tocopherol can exert actions beyond their antioxidant capacity by increasing the expression of peroxisome proliferator-activated receptor gamma and adiponectin, which could result in an increase in insulin sensitivity.[72]

Ferulic acid could also be involved in the antidiabetic effect of argan oil. This phenolic compound has been shown to have beneficial effects in animal models of type I and type II diabetes, suppressing blood glucose levels and alleviating oxidative stress.[74]

Antiproliferative effects of argan oil

Several authors have pointed out the antiproliferative effects of argan oil in different cancer cell lines, evidence

that suggests this oil may have cancer chemoprotective properties.[3,10,16,75–77] Drissi et al.[76] and Bennani et al.[10] have shown that different compounds obtained from virgin argan oil (polyphenols, sterols, tocopherols, and saponins) exert antiproliferative and pro-apoptotic effects in prostatic cancer cell lines. Another study by Samane et al.[77] showed antiproliferative effects of the unsaponifiable fraction of argan oil using the fibrosarcoma HT-1080 cell line and MSV-MDCK-INV cells, an invasive variant of canine kidney cells. These effects were related to the inhibition of the MEK1/2-ERK1/2 signaling cascade. Finally, a recent study has shown that argan fruit extracts exert antimalarial activity.[16]

CONCLUSION

Virgin argan oil contains high levels of both oleic acid and linoleic acid, making it an excellent source of essential omega-6 polyunsaturated fatty acids. It is also particularly rich in polyphenols and tocopherols and has a high antioxidant capacity. Furthermore, the level of γ-tocopherol, a potent antioxidant with anti-inflammatory properties, is much higher in argan oil than in any other oil. This composition is of vital importance in elucidating the suggested protective effects of argan oil against cancer, diabetes, and coronary heart disease and, thus, its value as a functional food. Nevertheless, as reviewed here, there is limited information available about the functional properties of virgin argan oil. Therefore, greater efforts are needed to fully characterize the active compounds of argan oil as well as their mechanisms of action and their possible therapeutic effects in humans.

At present, a need exists for a comprehensive nutritional characterization of virgin argan oil. The chemical composition of argan oil is highly reproducible due to the restricted geographical origin of the argan tree, and this could prove advantageous for efforts to better characterize this oil. Nevertheless, there is a need for standardization of the extraction and storage processes in order to improve the quality of virgin argan oil and to preserve its chemical composition, flavor, and nutritional value. Finally, the present lack of information on the culinary and technological uses of argan oil is worth noting, providing an additional basis for further study.

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REFERENCES

1. United Nations Educational, Scientific and Cultural Organization (UNESCO). *Biosphere Reserve Information: 2007-10-11*. 2007. Available at: http://www.unesco.org/mabdb/br/brdir/directory/biores.asp?mode=all&code=MOR+01.
2. Charrouf Z, Guillaume D. Ethnoeconomical, ethnomedical, and phytochemical study of *Argania spinosa* (L.) Skeels. J Ethnopharmacol. 1999;67:7–14.
3. Khallouki F, Younos C, Soulimani R, et al. Consumption of argan oil (Morocco) with its unique profile of fatty acids, tocopherols, squalene, sterols and phenolic compounds should confer valuable cancer chemopreventive effects. Eur J Cancer Prev. 2003;12:67–75.
4. Chaussod R, Adlouni A, Christon R. The argan tree and argan oil in Morocco: towards a deep change in a traditional agroforestry system. Economic and scientific challenges. Cah Etud Rech Francoph. 2005;14:351–356.
5. Cherki M, Berrougui H, Drissi A, et al. Argan oil: which benefits on cardiovascular diseases? Pharmacol Res. 2006;54:1–5.
6. Lybbert TJ, Barrett CB, Narjisse H. Market-based conservation and local benefits: the case of argan oil in Morocco. Ecol Econ. 2002;41:125–144.
7. Armenta S, Gonzalvez A, de la Guardia M. Adulteration detection of argan oil by inductively coupled plasma optical emission spectrometry. Food Chem. 2010;121:878–886.
8. Yaghmur A, Aserin A, Mizrahi Y, et al. Evaluation of argan oil for deep-fat frying. Lebensm Wiss Technol-Food Sci Technol. 2001;34:124–130.
9. Berrougui H, Ettaib A, Herrera Gonzalez MD, et al. Hypolipidemic and hypocholesterolemic effect of argan oil (*Argania spinosa* L.) in *Meriones shawi* rats. J Ethnopharmacol. 2003;89:15–18.
10. Bennani H, Drissi A, Giton F, et al. Antiproliferative effect of polyphenols and sterols of virgin argan oil on human prostate cancer cell lines. Cancer Detect Prev. 2007;31:64–69.
11. Cayuela JA, Rada M, Perez-Camino MD, et al. Characterization of artisanally and semiautomatically extracted argan oils from Morocco. Eur J Lipid Sci Technol. 2008;110:1159–1166.
12. Marfil R, Cabrera-Vique C, Gimenez R, et al. Metal content and physicochemical parameters used as quality criteria in virgin argan oil: influence of the extraction method. J Agric Food Chem. 2008;56:7279–7284.
13. Charrouf Z, Guillaume D. Should the amazigh diet (regular and moderate argan-oil consumption) have a beneficial impact on human health? Crit Rev Food Sci Nutr. 2010;50:473–477.
14. Norme Marocaine 08.5.090. Huiles d'Argane. Specifications. In: Ministre de l'Industrie dC, de l'Energie et des Mines. Rabat, ed, 2003.
15. Moukal A. L'arganier, *Argania spinosa* L. skeels usage thérapeutique, cosmetike et alimentary [in French]. Phytothérapie. 2009;5:135–141.
16. El Babili F, Bouajila J, Fouraste I, et al. Chemical study, antimalarial and antioxidant activities, and cytotoxicity to human breast cancer cells (MCF7) of *Argania spinosa*. Phytomedicine. 2010;17:157–160.
17. Drissi A, Girona J, Cherki M, et al. Evidence of hypolipemiant and antioxidant properties of argan oil derived from the argan tree (*Argania spinosa*). Clin Nutr. 2004;23:1159–1166.
18. Derouiche A, Cherki M, Drissi A, et al. Nutritional intervention study with argan oil in man: effects on lipids and apolipoproteins. Ann Nutr Metab. 2005;49:196–201.
19. Berrougui H, Cloutier M, Isabelle M, et al. Phenolic-extract from argan oil (*Argania spinosa* L.) inhibits human low-density lipoprotein (LDL) oxidation and enhances cholesterol efflux from human THP-1 macrophages. Atherosclerosis. 2006;184:389–396.
20. Matthaus B, Guillaume D, Gharby S, et al. Effect of processing on the quality of edible argan oil. Food Chem. 2010;120:426–432.
21. Delgado-Andrade C, Rufian-Henares JA, Morales FJ. Assessing the antioxidant activity of melanoidins from coffee brews by different antioxidant methods. J Agric Food Chem. 2005;53:7832–7836.
22. Morales FJ, Jimenez-Perez S. Free radical scavenging capacity of Maillard reaction products as related to colour and fluorescence. Food Chem. 2001;72:119–125.
23. Rahmani M. The chemical composition of "virgin" argan oil. Cah Etud Rech Francoph. 2005;14:461–465.
24. Hilali M, Charrouf Z, Soulhi Ael A, et al. Influence of origin and extraction method on argan oil physico-chemical characteristics and composition. J Agric Food Chem. 2005;53:2081–2087.
25. Marfil R, Cabrera C, Gimenez R, et al. *Importancia nutricional, económica y natural del aceite de argán (Argania spinosa)*. Madrid: Fundación Euroárabe de Altos Estudios 2009.

26. López MC, López H. Grasas y Aceites. In: Ruiz-López MD, Gil A, eds. *Tratado de Nutrición*, Vol. 2. Madrid: Acción Médica; 2005:361–394.
27. Tuberoso CIG, Kowalczyk A, Sarritzu E, et al. Determination of antioxidant compounds and antioxidant activity in commercial oilseeds for food use. Food Chem. 2007;103:1494–1501.
28. Monfalouti HE, Guillaume D, Denhez C, et al. Therapeutic potential of argan oil: a review. J Pharm Pharmacol. 2011;62:1669–1675.
29. Cherki M, Derouiche A, Drissi A, et al. Consumption of argan oil may have an antiatherogenic effect by improving paraoxonase activities and antioxidant status: intervention study in healthy men. Nutr Metab Cardiovasc Dis. 2005; 15:352–360.
30. Teres S, Barcelo-Coblijn G, Benet M, et al. Oleic acid content is responsible for the reduction in blood pressure induced by olive oil. Proc Natl Acad Sci U S A. 2008;105:13811–13816.
31. Zarrouk M, Zarrouk W, Baccouri B, et al. Oil fatty acid composition of eighteen Mediterranean olive varieties cultivated under the arid conditions of Boughrara (southern Tunisia). Grasas y Aceites. 2009;60:498–506.
32. Soel SM, Choi OS, Bang MH, et al. Influence of conjugated linoleic acid isomers on the metastasis of colon cancer cells in vitro and in vivo. J Nutr Biochem. 2007;18:650–657.
33. Valavanidis A, Nisiotou C, Papageorgiou Y, et al. Comparison of the radical scavenging potential of polar and lipidic fractions of olive oil and other vegetable oils under normal conditions and after thermal treatment. J Agric Food Chem. 2004;52:2358–2365.
34. Charrouf Z, Guillaume D. Phenols and polyphenols from *Argania spinosa*. Am J Food Tech. 2007;2:679–683.
35. Marfil R, Gimenez R, Martinez O, et al. Determination of polyphenols, tocopherols, and antioxidant capacity in virgin argan oil (*Argania spinosa*). Eur J Lipid Sci Technol. 2011;113:886–893.
36. Pellegrini N, Serafini M, Colombi B, et al. Total antioxidant capacity of plant foods, beverages and oils consumed in Italy assessed by three different in vitro assays. J Nutr. 2003;133:2812–2719.
37. Sanchez CS, Gonzalez AMT, Garcia-Parrilla MC, et al. Different radical scavenging tests in virgin olive oil and their relation to the total phenol content. Anal Chim Acta. 2007;593:103–107.
38. Service de Normalisation Industrielle Marocaine. Huiles d'Argane. Specifications. In: *Norme Marocaine 08.5.090*. Rabat, Morocco: Ministre de l'Industrie, de l'Energie et des Mines; 2002.
39. Hove EL, Harris PL. Note on the linoleic acid-tocopherol relationship in fats and oils. J Am Oil Chem Soc. 1951;28:405–405.
40. Kamal-Eldin A, Andersson R. A multivariate study of the correlation between tocopherol content and fatty acid composition in vegetable oils. J Am Oil Chem Soc. 1997;74:375–380.
41. Espin JC, Soler-Rivas C, Wichers HJ. Characterization of the total free radical scavenger capacity of vegetable oils and oil fractions using 2,2-diphenyl-1-picrylhydrazyl radical. J Agric Food Chem. 2000;48:648–656.
42. Devaraj S, Jialal I. Failure of vitamin E in clinical trials: is gamma-tocopherol the answer? Nutr Rev. 2005;63:290–293.
43. Wright ME, Weinstein SJ, Lawson KA, et al. Supplemental and dietary vitamin E intakes and risk of prostate cancer in a large prospective study. Cancer Epidemiol Biomarkers Prev. 2007;16:1128–1135.
44. Yang CS, Ju J, Picinich SC, et al. Cancer-preventive activities of tocopherols and tocotrienols. Carcinogenesis. 2010;31:533–542.
45. Reiter E, Jiang Q, Christen S. Anti-inflammatory properties of alpha- and gamma-tocopherol. Mol Aspects Med. 2007;28:668–691.
46. Friedrich MJ. To "E" or not to "E," vitamin E's role in health and disease is the question. JAMA. 2004;292:671–673.
47. Devaraj S, Leonard S, Traber MG, et al. Gamma-tocopherol supplementation alone and in combination with alpha-tocopherol alters biomarkers of oxidative stress and inflammation in subjects with metabolic syndrome. Free Radic Biol Med. 2008;44:1203–1208.
48. Nota G, Naviglio D, Romano R, et al. Determination of the wax ester content in olive oils. Improvement in the method proposed by EEC regulation 183/93. J Agric Food Chem. 1999;47:202–205.
49. Garcia JM, Gutierrez F, Castellano JM, et al. Influence of storage temperature on fruit ripening and olive oil quality. J Agric Food Chem. 1996;44:264–267.
50. Newmark HL. Squalene, olive oil, and cancer risk: a review and hypothesis. Cancer Epidemiol Biomarkers Prev. 1997;6:1101–1103.
51. Kamimura H, Koga N, Oguri K, et al. Enhanced elimination of theophylline, phenobarbital and strychnine from the bodies of rats and mice by squalane treatment. J Pharmacobiodyn. 1992;15:215–221.
52. Gupta AK, Savopoulos CG, Ahuja J, et al. Role of phytosterols in lipid-lowering: current perspectives. QJM. 2011;104:301–308.
53. Moghadasian MH. Pharmacological properties of plant sterols in vivo and in vitro observations. Life Sci. 2000;67:605–615.
54. Woyengo TA, Ramprasath VR, Jones PJ. Anticancer effects of phytosterols. Eur J Clin Nutr. 2009;63:813–820.
55. Min DB, Choe E. Mechanisms and factors for edible oil oxidation. Comp Rev Food Sci Food Safety. 2006;5:169–186.
56. Martinpolvillo M, Albi T, Guinda A. Determination of trace-elements in edible vegetable-oils by atomic-absorption spectrophotometry. J Am Oil Chem Soc. 1994;71:347–353.
57. Karadjova I, Zachariadis G, Boskou G, et al. Electrothermal atomic absorption spectrometric determination of aluminium, cadmium, chromium, copper, iron, manganese, nickel and lead in olive oil. J Anal At Spectrom. 1998;13:201–204.
58. Romano R, Riccio F, Borriello I, et al. Catalytic effect of Cu (II) and Fe (III) on kinetic oxidation of fatty substances: the soybean oil case. Riv Ital Delle Sost Grass. 2007;84:25–32.
59. Roca A, Cabrera C, Lorenzo ML, et al. Levels of calcium, magnesium, manganese, zinc, selenium and chromium in olive oils produced in Andalusia. Grasas y Aceites. 2000;51:393–399.
60. Szydlowska-Czerniak A, Karlovits G, Dianoczki C, et al. Comparison of two analytical methods for assessing antioxidant capacity of rapeseed and olive oils. J Am Oil Chem Soc. 2008;85:141–149.
61. Bensouda Y, inventor; Bensouda Y, assignee. Formulation of argan oil-based lipid emulsion for parenteral nutrition. French patent WO 2008002116 (A1). January 3, 2008.
62. Ertus P, Leveugle C, inventors; Ertus P, assignee. Integration of the argan oil in food preparations, which is useful, e.g. as seasoning on green salads or compounds and to reduce cholesterol level, comprises adding argan oil extracted from kernels of the argan tree, to the food. French patent 2926441 (A1). July 24, 2009.
63. Moreno-Torres Herrera R, Alcala Torres J, Perez Moreno A, Perez Roca C, Romero de Soto D, inventors;Olifarma, S.L., assignee. Olive-oil-based functional oils. ES and US patent WO/2010/149815. December 29, 2010.
64. Astier C, Benchad Yel A, Moneret-Vautrin DA, et al. Anaphylaxis to argan oil. Allergy. 2010;65:662–663.
65. Singh U, Devaraj S, Jialal I. Vitamin E, oxidative stress, and inflammation. Annu Rev Nutr. 2005;25:151–174.
66. Berrada Y, Settaf A, Baddouri K, et al. Experimental assessment of antihypertensive and hypolipidemic effects of oil of argan, *Argania sideroxylon* [in French]. Therapie. 2000;55:375–378.
67. Berrougui H, Alvarez de Sotomayor M, Perez-Guerrero C, et al. Argan (*Argania spinosa*) oil lowers blood pressure and improves endothelial dysfunction in spontaneously hypertensive rats. Br J Nutr. 2004;92:921–929.
68. Bnouham M, Bellahcen S, Benalla W, et al. Antidiabetic activity assessment of *Argania spinosa* oil. J Complement Integr Med. 2008;5:1–12.
69. Bellahcen S, Mekhfi H, Ziyyat A, et al. Prevention of chemically induced diabetes mellitus in experimental animals by virgin argan oil. Phytother Res. 2012;26: 180–185.
70. Azar M, Basu A, Jenkins AJ, et al. Serum carotenoids and fat-soluble vitamins in women with type 1 diabetes and preeclampsia: a longitudinal study. Diabetes Care. 2011;34:1258–1264.
71. Gupta S, Sharma TK, Kaushik GG, et al. Vitamin E supplementation may ameliorate oxidative stress in type 1 diabetes mellitus patients. Clin Lab. 2011;57: 379–386.
72. Gray B, Swick J, Ronnenberg AG. Vitamin E and adiponectin: proposed mechanism for vitamin E-induced improvement in insulin sensitivity. Nutr Rev. 2011;69:155–161.
73. Salonen JT, Nyyssonen K, Tuomainen TP, et al. Increased risk of non-insulin dependent diabetes mellitus at low plasma vitamin E concentrations: a four year follow up study in men. BMJ. 1995;311:1124–1127.
74. Ohnishi M, Matuo T, Tsuno T, et al. Antioxidant activity and hypoglycemic effect of ferulic acid in STZ-induced diabetic mice and KK-Ay mice. Biofactors. 2004;21:315–319.
75. Benzaria A, Meskini N, Dubois M, et al. Effect of dietary argan oil on fatty acid composition, proliferation, and phospholipase D activity of rat thymocytes. Nutrition. 2006;22:628–637.
76. Drissi A, Bennani H, Giton F, et al. Tocopherols and saponins derived from *Argania spinosa* exert an antiproliferative effect on human prostate cancer. Cancer Invest. 2006;24:588–592.
77. Samane S, Noel J, Charrouf Z, et al. Insulin-sensitizing and anti-proliferative effects of *Argania spinosa* seed extracts. Evid Based Complement Alternat Med. 2006;3:317–327.
78. Ollivier D, Artaud J, Pinatel C, et al. Triacylglycerol and fatty acid compositions of French virgin olive oils. Characterization by chemometrics. J Agric Food Chem. 2003;51:5723–5731.
79. Filip S, Hribar J, Vidrih R. Influence of natural antioxidants on the formation of *trans*-fatty-acid isomers during heat treatment of sunflower oil. Eur J Lipid Sci Technol. 2011;113:224–230.
80. Ayorinde FO, Garvin K, Saeed K. Determination of the fatty acid composition of saponified vegetable oils using matrix-assisted laser desorption/ionization time-of-flight mass spectrometry. Rapid Commun Mass Spectrom. 2000;14: 608–615.
81. Araujo P, Zeng Y, Du ZY, et al. Discrimination of n-3 rich oils by gas chromatography. Lipids. 2010;45:1147–1158.

82. Maguire LS, O'Sullivan SM, Galvin K, et al. Fatty acid profile, tocopherol, squalene and phytosterol content of walnuts, almonds, peanuts, hazelnuts and the macadamia nut. Int J Food Sci Nutr. 2004;55:171–178.
83. Ozcan MM, Unver A, Erkan E, et al. Characteristics of some almond kernel and oils. Scientia Horticulturae (Amsterdam). 2011;127:330–333.
84. Pasias SA, Barakos NK, Papayannakos NG. Catalytic effect of free fatty acids on cotton seed oil thermal transesterification. Ind Eng Chem Res. 2009;48:4266–4273.
85. Lukonge E, Labuschagne MT, Hugo A. The evaluation of oil and fatty acid composition in seed of cotton accessions from various countries. J Sci Food Agric. 2007;87:340–347.
86. Moser BR. Influence of extended storage on fuel properties of methyl esters prepared from canola, palm, soybean and sunflower oils. Renew Energ. 2011; 36:1221–1226.
87. Sundaram J, Kandala CV, Holser RA, et al. Determination of in-shell peanut oil and fatty acid composition using near-infrared reflectance spectroscopy. J Am Oil Chem Soc. 2010;87:1103–1114.
88. Karoui IJ, Wannes WA, Marzouk B. Refined corn oil aromatization by *Citrus aurantium* peel essential oil. Ind Crop Prod. 2010;32:202–207.
89. Rubio M, Alvarez-Orti M, Alvarruiz A, et al. Characterization of oil obtained from grape seeds collected during berry development. J Agric Food Chem. 2009;57: 2812–2815.
90. Azeez MA, Morakinyo JA. Genetic diversity of fatty acids in sesame and its relatives in Nigeria. Eur J Lipid Sci Technol. 2011;113:238–244.
91. Siang GH, Makahleh A, Saad B, et al. Hollow fiber liquid-phase microextraction coupled with gas chromatography-flame ionization detection for the profiling of fatty acids in vegetable oils. J Chromatogr A. 2010;1217:8073–8078.
92. Man YBC, Rohman A. Palm oil analysis in adulterated sesame oil using chromatography and FTIR spectroscopy. Eur J Lipid Sci Technol. 2011;113:522–527.
93. Enríquez-Fernández BE, Álvarez de la Cadena y Yañez L, Sosa-Morales ME. Comparison of the stability of palm olein and a palm olein/canola oil blend during deep-fat frying of chicken nuggets and French fries. Int J Food Sci Technol. 2011;46:1231–1237.
94. Bhatnagar AS, Kumar PKP, Hemavathy J, et al. Fatty acid composition, oxidative stability, and radical scavenging activity of vegetable oil blends with coconut oil. J Am Oil Chem Soc. 2009;86:991–999.
95. Gliszcynska-Swiglo A, Sirkoska E, Kamelinskii I, et al. Tocopherol content in edible plant oils. Pol J Food Nutr Sci. 2007;57:157–161.
96. Codex Alimentarius (FAO/WHO). Codex Standard for named vegetable oils. 2003. CODEX STAN 210 1999. (revision and amendments: 2003).
97. Li SCX, Cherian G, Ahn DU, et al. Storage, heating, and tocopherols affect cholesterol oxide formation in food oils. J Agric Food Chem. 1996;44:3830–3834.
98. Seker M, Gul MK, Ipek M, et al. Screening and comparing tocopherols in the rapeseed (*Brassica napus* L.) and olive (*Olea europaea* L.) varieties using high-performance liquid chromatography. Int J Food Sci Nutr. 2008;59:483–490.
99. Gorinstein S, Martin-Belloso O, Katrich E, et al. Comparison of the contents of the main biochemical compounds and the antioxidant activity of some Spanish olive oils as determined by four different radical scavenging tests. J Nutr Biochem. 2003;14:154–159.
100. Sanchez CS, Gonzalez AMT, Garcia-Parrilla MC, et al. Different radical scavenging tests in virgin olive oil and their relation to the total phenol content. Anal Chim Acta. 2007;593:103–107.
101. Gomez-Alonso S, Fregapane G, Salvador MD, et al. Changes in phenolic composition and antioxidant activity of virgin olive oil during frying. J Agric Food Chem. 2003;51:667–672.