Review paper

CHEMICAL COMPOSITION, NUTRITIONAL FUNCTIONS, AND ANTIOXIDANT ACTIVITIES OF HONEYS IN AFRICA

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Abstract

Honey production in Africa is considered an integral part of folk medicine and provides an opportunity for poor rural communities to increase their economic sustainability. In this review, we provide and discuss the data available on the positive nutritional value and health properties of honey harvested from Africa. Besides sugar, honey contains protein and amino acids, with proline which is about 50% of the total amino acids, vitamins, enzymes, some minerals (Na, K, Mg, Ca, Zn, Cu, Mn, Fe, P, S), trace elements (Mn, Ni, Li, F, I, Cl, Sr, Co) and polyphenol compounds. The paper reviewed studies on the use of African honey with anti-inflammatory, antioxidant, antibacterial, antifungal, anti-breast cancer, antidiabetic and antimycotic properties and also its positive effects on infertility (asthenozoospermia), febrile neutropenia and diabetic foot ulcers.

Keywords: African regions, anticancer, antidiabetic, antimicrobial, honey, nutritional value

INTRODUCTION

Most developing countries including those in Africa are facing a double burden of prevailing malnutrition coupled with increasing epidemics of cancer, diabetes and communicable diseases. In recent years, the consumers, food industry and researchers have developed an enthusiastic interest in foods and their mechanisms to enhance human well-being and to manage two areas of public health, nutrition, and food safety. The increasing knowledge on honey, pure and contamination-free food, has been phenomenal over the years. The global market for honey continues to gain significant expansion due to modern uses of honey in health and food & beverage industries, with anticipated growth in the future. These advancements will further increase the applicability of honey and trigger a significant rise in business opportunities for honey product manufacturers.

Honey is composed of several sugars, flavonoids, phenolic acids, pigments, enzymes, amino acids, α-tocopherol, proteins and essential and trace elements. Its composition depends on the botanical origin (Tahir et al., 2016, 2015). Several societies use honey for its medicinal properties against cardiovascular diseases, diabetes, cancer, neurodegenerative diseases, pulmonary diseases, liver diseases, estrogenic and immunomodulatory activities (Abdulrhman et al., 2013; Ahmed & Othman, 2013; Hossen et al., 2017). Furthermore, honey is used to control such infectious diseases as tuberculosis, tetanus, influenza, hepatitis and human immune deficiency syndrome (Khan et al., 2018). A wide range of phenolic compounds in honey (such as quercetin, kaempferol, chrysin, caffeic acid, cinnamic, caffeic, syringic, vanillic and chlorogenic) have potential in the treatment of cardiovascular diseases (Khalil & Sulaiman, 2010) and anti-leukemic activities (Abubakar et al., 2012).

The antioxidant and antimicrobial properties of honey are due to the synergistic effect of its polyphenols, amino acids, vitamins and enzymes (Lachman et al., 2010; Liu et al., 2013; Meda et al., 2005). The essential and trace elements in honey affect biomedical exercises and have many both recognized and unknown biological functions (Alvarez-Suarez et al., 2010). Most African hive substances have household uses, while honey could give a cheap and easily accessible source of energy, minerals and polyphenols. Bogdanov et al. (2008), Jaganathan & Mandal (2009), El-Soud (2012), Ahmed & Othman (2013) and Eteraf-Oskouei & Najafi (2013) have published reviews on North American, Australian and European honey based on available information. Alvarez-Suarez et al. (2010) and Solayman et al. (2016) cover the nutritional antioxidant activities and health properties of honeys from these continents. There is no comprehensive database on African honey, and this article summarizes its nutritional and health benefits and assesses the studies on laboratory or clinical experiments which show honey produced in Africa has a beneficial effect on human or experimental animals.

Sources of African honey

The chemical composition of honey is strongly affected by both natural and human-caused factors, which differ based on its botanical and geographical origins. In Africa, reports show that the information on the botanical origin of honey and bee species are limited and relatively insufficient. Tab. 1. Summaries of available information on the botanical origin of African honey samples and species of the bee.

Carbohydrates

Carbohydrates, mainly glucose and fructose, are the main components of honey and constitute approximately 95% of honey dry weight (Alvarez-Suarez et al., 2010). The carbohydrate content of honey harvested in Africa differs and ranges from as low as 62.80% in Algeria up to 90.8% in Tanzania (Murray et al., 2001) on a dry basis. In general, the range of carbohydrates in African honey is higher than in honeys from other continents (Escuredo et al., 2013). The details of carbohydrate in some African honey are presented in Tab. 2.

Lipids

The lipid content of honey depends on the amount and sources of pollen collected by honeybees, so the lipid content of honey from different floral regions in Africa ranged between 0.01 and 8.10%. The smallest fat content was reported in Nigerian honey (Buba, Gidado, & Shugaba, 2013; Ndife & Fagbemi, 2014) while the highest in Tanzanian honey (Murray et al., 2001). The high lipid content in honey could be due to the incorporation of honeybee larvae (Buba et al., 2013). These results demonstrate that the contribution of honey to the recommended daily lipid intake is minor. Generally, there is little published data on the lipid content of African honey (Tab. 2).

Proteins and amino acids

Protein and amino acid in honey are not only dependent on the amount of pollen grain content but also on the enzymes. Generally, the protein content of African honey is about 0.08 to 3.8%, which can be interpreted to mean very low (Tab. 2). However, honey harvested from Tanzania showed a high protein content of 1.70-3.80% on a dry basis (Murray et al., 2001), and low protein content was detected in Libyan honey (Owayss, 2005) and Sudanese honey (Idris, Mariod, & Hamad, 2011). The content of total free amino acids in honey is between 10 and 200 mg/100g, with proline as their main contributor, which is about 50% of all amino acids (Iglesias et al., 2003).

Several authors have reported that antioxidant assays and proline contributed substantially to the antioxidant activity of honeys (Beretta et al., 2005; Meda et al., 2005). Tab. 4 summarizes

Table 1.
Summaries the available information on the botanical origin of African honey samples and species of the bee

Countries	Botanical origin	Place of collection	Species	References
Tanzania	Baobab tree, multifloral, Commiphora tree	Beekeeper	*Apis mellifera scutellata, Trigona erythra junodi, Trigona rispolii*	Murray et al. (2001)
Tunisia	Mint, eucalyptus, rosemary, horehound, thyme, orange, rape, sunflower, multifloral.	Beekeeper	N.R	Boussaid et al. (2018); Martos et al. (1997)
Sudan	*Acacia nilotica*, *Acacia seyal*, *Ziziphus spina-christi*, *Amaranthus graecizan*, eucalyptus, multifloral, *Azadarichta indica*, *Helianthus annuus*, sun flower, *Cucurbita maxima* Duch., *Balanites aegyptiaca*	N.R	N.R	Dafalla et al. (2014); El-Toum et al. (2007); Idriset al. (2011); Makawi et al. (2009); Tahir et al. (2017)
Egypt	Sesame, clover, orange, marjoram, cotton, citrus, eucalyptus, *Cassia javanica*, *Citrus reticulata*, Ziziphus tree	Beekeepers Market-sourced	N.R	Abdulrhman (2013); Abdulrhman et al. (2013; 2016); Alqarni et al. (2012); Badawy et al. (2004); El-Gendy (2010); Hamdy et al. (2008); Hegazi et al. (2014); Moghazy et al.(2010); Rashed et al. (2004);Rashed et al. (2004); Wasfi et al. (2016)
Nigeria	Palm, multifloral	N/A	N.R	Adeonipekun et al. (2016)
Ethiopia	*Schefflera abyssinica,* multifloral	Farm gates	N.R	Adgaba et al. (2017); Mulu et al. (2010)
Cameroon	Manuka-mountain	Supermarket	N.R	Ndip et al. (2007)
Morocco	Honeydew, eucalyptus, citrus, Lythrum flower, *Euphorbia officinarum* subsp, *Euphorbia regis-jubae*, carob	Beekeeper	N.R	Bettar et al. (2015); El-Haskoury et al. (2018); Terrab et al. (2002; 2003a)
Algeria	Honeydew, *Myrtus communis*, Rubus, Capparis spp, hedysarum, coronarium, eucalyptus, *Erica arborea*	beekeepers	N.R	Ouchemoukh et al. (2007).
South Africa	Goldcrest, lemon, sinesis, eucalyptus, orange, *Leucospermum cordifolium*, wild shrub, Fynbos, *Eucalyptus cladocalyx*	Producer	N.R	Basson et al. (2008); Manyi-Loh et al. (2010); Serem et al. (2012)
Burkina Faso	Combretaceae, Vitellaria, acacia, Lannea, honeydew, multifloral, strawberry, chestnut, sulla, clover, dandelion, chicory, honeydew	Beekeeper, Research center and market	N.R	Beretta et al. (2005); Meda et al. (2005)
Libyan	*Ceratania siliqua,* multiflora, *Arbutus pavari, Thymus capitatus,* eucalyptus, *Ziziphus lotus, Tamarix aphylla*	Beekeepers	*Apis meliffera ligustica*	Ahmida et al. (2013)

N.R., not reported

Table 2.
Summary of studies on macronutrients composition of honeys produced in some African countries

Nutrients	g/100 g of honey	Origin	References
Protein	1.7-3.8 dw	Tanzania	Murray et al.(2001)
	0.0-0.1	Libya	Owayss (2005)
	0.4-0.9	Algeria	Ouchemoukh et al. (2007)
	0.6-1.3	South Africa	Serem et al. (2012)
	0.2-1.2	Nigeria	Buba et al. (2013); Ndife et al. (2014)
	0.2-0.3	Sudan	Idris et al. (2011)
	0.6-1.0	European Atlantic area	Escuredo et al. (2013)
	0.1-0.2	Tunisia	Boussaid et al. (2018)
Fat	1.3-8.1 dw	Tanzania	Murray et al. (2001)
	0.1-0.2	Nigeria	Ndife et al. (2014)
	72.3	Ethiopia	Belay et al. (2013)
Carbohydrate	68.7-75.0	Sudan	Musa et al. (2014)
	87.7-90.8 dw	Tanzania	Murray et al. (2001)
	62.8-84.3	Algeria	Khalil et al. (2012); Ouchemoukh et al. (2007; 2010)
	79.9-82.7	Nigeria	Ndife et al. (2014)
	64.9-73.1	European Atlantic area	Escuredo et al. (2013)

dw - dry weight

the various contents of proline in honey from different countries. Apart from proline, more than fifteen amino acids were detected in honey harvested from different botanical sources in Sudan: aspartic acid (Asp), glutamic acid (Glu), phenylalanine (Phe), histidine (His), threonine (Thr), serine (Ser), glycine (Gly), cysteine (Cys), alanine (Ala), valine (Val), methionine (Met), isoleucine (Ile), leucine (Leu), tyrosine (Tyr), lysine (Lys), and arginine (Arg) (Mohammed & Babiker, 2010).

Minerals

The determination of minerals and heavy metals in honey provides information on its botanical and geographical sources and the degree of contamination which helps consumers to avoid possible contamination when purchasing honey and enable. Tab. 3 contains the mineral values of some African honeys. The minerals Na, K, Mg, Ca, Fe, Zn, Cu and Mn were detected in Moroccan honeys (Bettar et al., 2015; Terrab et al., 2002, 2003a, 2003b). In Egyptian honey, the major minerals were Na, K, Mg, Ca, Zn, Cu, P and Fe and trace elements Mn, Ni, Li, F, I, Cl, Sr and Co (Alqarni, Owayss, & Mahmoud, 2016; Rashed & Soltan, 2004). According to Tab. 3, the highest Mg (8.07-30.00 mg/100g) and Fe (6.80-20.20 mg/100g) characterize Egyptian honey. The mineral content of honey collected during a whole year from different regions in Tunisia was Na, K, Ca, Mg, Fe, P, Zn, Cu and Ni (Amel et al., 2018).

In similar sample collections, Na, K, Mg, Ca, Fe, Zn, Cu, Mn, Ni and P were detected in Libyan honey (Mohamed, Ahmed, & Mazid, 1981; Owayss, 2005). In Ethiopian honey, several essential and trace elements were determined and Na was the major compound with values of 29.79-59.06 mg/100g

Table 3.
Summary of the concentrations of the major elements and trace elements of honey produced in some African countries

Origin	mg/100g of honey									
	Na	K	Mg	Ca	Fe	Zn	Cu	Mn	Ni	P
Nigeria	3.70-4.60	37.28-50.10	2.60-3.12	4.05-6.81	0.52-1.12	0.20-3.10	0.025-1.03	1.38-3.18	0.10-0.70	-
Cameroon	0.43-0.81	11.13-28.91	0.58-1.26	4.24-41.12	-	-	0.01-0.03	0.01-0.05	-	1.47-2.13
Egypt	1.71-47.80	30.69-150.00	8.07-30.00	6.29-6.44	6.80-20.20	0.35-0.93	0.10-0.18	0.05-0.44	0.02-0.041	3.00-3.31
Libya	2.95-38.10	2.95-41.40	0.003.29	0.34-2.00	0.00-0.74	0.16	0.00-0.01	000-0.31	0.00-0.26	0.00-4.00
Morocco	2.60-70.02	1.40-188.13	0.48-15.52	5.10-68.84	0.17-3.13	0.05-1.25	0.01-0.47	0.01-1.15	0.002-0.015	-
Ethiopia	29.79-59.06	26.78-66.18	0.51-0.34	0.81-1.85	0.63-1.36	0.04-0.11	0.04-1.40	0.10-0.15	0.20-0.25	-
Tunisia	25.13-52.12	17.25-97.67	3.73-7.81	11.38-22.11	0.08-0.35	0.0-0.21	0.00-0.03	-	0.00-0.04	2.63-7.27
Ghana	0.00-6.17	40.92-266.48	7.57-28.97	5.01-20.23	0.05-2.76	-	0.006-12.00	0.32-0.56	-	4.03-37.26
Sudan	1.41–2.82	1.76–7.47	2.37–17.72	3.56–8.29	0.21-3.36	0.49-0.96	0.29–5.81	0.01-0.10	N.D.-0.41	2.81–20.46
European Atlantic	3.00-15.10	101.00-239.70	2.00-21.30	10.1-15.90	0.30-1.10	0.16-0.23	0.16-0.23	-	-	3.90-16.30

Not reported (-), N.D, not detected

(Adgaba et al., 2017; Nigussie, Subramanian, & Mebrahtu, 2012). The major elements in Nigerian honeys were Zn (0.20-3.10 mg/100g), Mn (1.38-3.18 mg/100g) and Ni (0.10-0.70 mg/100g) (Iwegbue et al., 2015; Ndife & Fagbemi, 2014). Among the minerals reported, halogen elements were only found in Egyptian honeys, and these were chlorine (772-1800 μg/g), fluorine (4.80-12.50 μg/g) and iodine (0.62-0.87 μg/g) (Rashed & Soltan, 2004). Low concentrations of such toxic metals as lead and cadmium were detected in Egyptian, Libyan and Sudanese honey (not shown in Table) (Alqarni, Owayss, & Mahmoud, 2016; Owayss, 2005). In this review, high calcium content (4.24-41.12 mg/100g) was reported in Cameroonian honey (Solayman et al., 2016; Tchoumboue et al., 2007), and Ghanaian raw honey showed the highest potassium content (40.92-266.48 mg/100g) (Yeboah-Gyan & Marfo, 1998). Among the investigations reported, chromium (1.93-3.65 mg/100g) and sulfur (0.0-0.03 mg/100g) were identified only in Tunisian honey (not shown in Table) (Amel et al., 2018). Based on the reports studied, honey samples produced in Africa contained more minerals than those produced in the European Atlantic area (Escuredo et al., 2013).

Phenolic compounds

Studies report quite differences between total phenolic content (TPC) and total flavonoid content (TFC) in African honey. Algerian honey TFC and TPC were 2.71-7.18 mg catechin equivalents (CE)/100g and 41.11-49.82 mg Gallic acid equivalents (GAE)/100g respectively (Khalil et al., 2012). Ahmed et al. (2013) reported that honeys from different locations contained a TPC of 63.00-95.00 mg GAE/100g and a TFC of 5.41-9.94 mg CE/100g. While Ouchemoukh, Louaileche, & Schweitzer (2007) found a high TPC in the range of 79.00 and 1304.00 mg GAE/100g. From the above-mentioned results, the antioxidant activity of honey obviously does not only depend on the floral source but also on the geographical origin and the environments. Sudanese honey was distinctive with a high TPC (Mohammed & Babiker, 2010; Tahir et al., 2015) while Benin honey with TFC (Azonwade et al., 2018). Tab. 4 presents the detailed content of TPC and TFC in various African honeys.

Table 4.
Summary of studies on total phenolic, total flavonoid and proline contents of honey produced in some African countries

Origin	TPC GAE mg/100g	TFC mg/100g	Proline mg/100g	References
Egypt	44.0-59.0	-	168.0-183.0	Alqarni et al. (2016)
Algeria	41.1-49.8	2.7-7.2*	169.2-271.2	Khalil et al. (2012)
southern Africa	68.2-167.9	19.4-51.6*	15.6-45.2	Serem et al. (2012)
Burkina Faso	28.7-114.8	0.2-8.4**	43.8-216.9	Beretta et al. (2005); Meda et al. (2005)
Nigeria	9.0-130.0	11.0-66.0*	38.0-243.0	Alisi et al. (2012); Buba et al. (2013)
Algeria	63.0-95.0	5.4-9.9*	-	Ahmed et al. (2013)
Algeria	79.0-1304.0		20.2-68.0	Ouchemoukh et al. (2007)
Morocco	75.5-245.2	2.3-4.8	25.0-227.0	El-Haskoury et al. (2018); Terrab et al. (2002)
Libya	49.0-91.0	-	-	Ahmida et al. (2013)
Sudan	79.4-232.7	2.9-13.2	37.9-75.4	Mohammed et al. (2010); Tahir et al. (2015)
Tunisia	32.2-119.4	0.9-2.2*	5.91-10.3	Boussaid et al. (2018)
Kenya	-	-	2.1 – 67.3	Muli et al. (2007)
Benin	63.1-2245.9	1.4-52.8		Azonwade et al. (2018); Lokossou et al. (2017)
European Atlantic area	78.4-181.0	4.3-9.6**	-	Escuredo et al. (2013)

Not reported (-); Gallic acid equivalent (GAE); **= Qurecitin equivalent (QE); *=Catechin equivalent (CE)

Polyphenol profiles

Phenolic acid and flavonoid profiles in African honeys are actually the less parameters analyzed for assessing honey quality, while the total polyphenols, TPC and TFC, are more reported. Several components have been reported in Tunisian honeys (Martos et al., 1997), and the most abundant flavonoid was chrysin with 2.23-1258.05 µg/100g and ellagic acid was 2.81-848.89 µg/100g. They are known to have high antioxidant activity and could be utilized in pharmacology, medicine and the food industry (Kilic, Yeşiloğlu, & Bayrak, 2014). Makawi et al. (2009) and Tahir et al. (2017) investigated the phenolic profiles of Sudanese honey, and found kaempferol 9.90-535.3 µg/100g to be the predominant flavonoid and syringic acid the main phenolic acid 1530-5030 µg/100g. Several phenolic compounds including hesperetin, quercetin, cinnamic acid, and *p*-hydroxybenzoic acid were detected in Egyptian honeys. Cinnamic acid 570.00-1350.00 µg/100g and *p*-hydroxybenzoic acid 70.00-1100.00 µg/100g were the main phenolics (Tab. 5) (Hamdy et al., 2008). Table 5 depicts the detailed concentrations of major polyphenols identified in honey produced in African.

Various constituents

There are reports available on the various beneficial components of honey produced in Africa. All of the water-soluble vitamins are usually present in honey with vitamin C the most abundant (Mijanur Rahman, Gan, & Khalil, 2014), but it is difficult to determine them due to their instability and traditional methods of extraction from hives. The ascorbic acid of various Algerian honey was 0.39-16.05 mg/100g (Khalil et al., 2012; Mouhoubi-Tafinine, Ouchemoukh, & Tamendjari, 2016), and 18.52-25.16 mg/100g for Nigerian honey (Buba et al., 2013). Alisi et al. (2012) in Nigeria reported on the amount of Vitamin E (15.4 - 18.4 µg/100g), which is known for its antioxidant capacity and multiple health benefits (Kamal-Eldin & Appelqvist, 1996).

The color of honey reflects the content of such

Table 5.
Summary of pigments, phenolic, and flavonoid profiles of honeys produced in some African countries

Honey origin	Pigments content	μg/g honey	References
Egypt	Total chlorophylls	12.1-12.1	Alqarni et al. (2016)
	Total carotenoids	44.7-46.9	
	Xanthophylls	9.9-11.0	
	Total anthocyanins	8.0-8.9	
Tunisia	Total carotenoids	1.2-4.7	Boussaid et al. (2018)
Sudan	Total carotenoids	2.0-7.7	Tahir et al. (2015)
Tunisia	Phenolic and flavonoid contents	μg/100g honey	Martos et al. (1997)
	Kaempferol	9.8-248.2	
	Apigenin	2.0-579.1	
	Hesperetin	3.7-18.1	
	Quercetin	13.6-123.2	
	Luteolin+3-methylquercetin	4.0-11.5	
	8-methoxykaempferol	9.3-94.6	
	Pinobanksin	56.7-132.5	
	Ellagic acid	2.8-848.9	
	Isorhamnetin	1.4-122.4	
	pinocembrin	2.5-129.1	
	Phenylethyl caffeate	1.2-19.8	
	Pinobanksin 3-acetate	8.7-17.9	
	Dimethylallyl caffeate	8.5-37.3	
	Quercetin 3,7-dimethyl ether	0.0-37.3	
	chrysin	2.2-1258.1	
	Galangin	1.3-383.9	
	Galangin 3-methyl ether	29.9-93.5	
	Myricetin 3,7,4',5'-methylether	4.7-61.8	
	Pinocembrin 7-methyl ether	11.8-29.2	
	Tecthochrysin	8.5-68.7	
Sudan	Kaempferol	39.9-535.3	Makawi (2009); Tahir et al. (2017)
	Isorhamnetin	32.2-36.6	
	Apigenin	38.3-52.6	
	Hesperetin	391.4-640.6	
	Quercetin	1.8-320.5	
	Catechin	200-4500	
	Chlorogenic acid	110-2000	
	Syringic acid	1530-5030	
	Caffeic acid	0-960	
	p-hydroxybenzoic acid	0-10050	
	Vanillic acid	220-970	
	p-coumaric acid	0-3900	
	Ferulic acid	0-12740	
	Cinnamic acid	90-6190	
Egypt	Hesperetin	0.0-1080	Hamdy et al. (2008)
	Quercetin	200 -600	
	Cinnamic acid	570 -1350	
	p-hydroxybenzoic acid	70 -1100	

pigments such as carotenoids and anthocyanin. Alvarez-Suarez et al. (2010), Escuredo et al. (2013), Serem & Bester (2012) suggested a strong relationship between honey color and antioxidant activities. Alqarni et al. (2016) studied the pigments of Egyptian honey and found that total chlorophylls was 12.07-12.12 µg/g and xanthophylls 9.93-11.04 µg/g and total anthocyanin 8.00-8.92 µg/g. Total carotenoid content in Tunisian honey ranged from 1.16 to 4.72 µg/g (Amel et al., 2018), Algerian honey 3.0 to 10.1 µg/g (Mouhoubi-Tafinine et al., 2016), Egyptian honey carotenoid 44.69-46.92 µg/g (Alqarni et al., 2016), and Sudanese honey from 2.0 to 7.7 µg/g (Tahir et al., 2015). Catalase is produced in plants and a recognized antioxidant, and in honey it specifies the amount of peroxide (Weston, 2000). The catalase concentration in southern African honey was 4.35-38.48 µmol H_2O_2/g (Serem & Bester, 2012).

Antioxidant capacity

A number of African honey samples possess high antioxidant activities, but comparing results from different countries is a challenge due to variations in the assays used for measurement, units, extraction technique and floral origin. From literature, numerous analytical techniques have been used to assess the antioxidant activities of honey. In Southern African honey, the range of Trolox equivalent (TE) antioxidant capacity was 0.42-3.72 µmoL TE/g, 2,2-diphenyl-picrylhydrazyl (DPPH) was 0.42-3.72 and µmoL TE/g and oxygen radical absorbance capacity (ORAC) was 3.71-49.26 µmoL TE/g (Serem & Bester, 2012). In Burkina Faso honey, Meda et al. (2005) and Beretta et al. (2005) investigated the antioxidant activities of twenty-seven honey samples using quercetin equivalent antioxidant content (QEAC), ascorbic acid equivalent antioxidant capacity (AEAC), DPPH, ORAC, ferric reducing antioxidant power (FRAP) methods. The results obtained were 4.27-33.34 mg QEAC/100g, 10.20-65.86 mg AEAC/100g, DPPH (IC50=1.37-29.13 mg/mL), 11.07-18.23 µmoL TE/g and 38.10-80.81 µM Fe(II)./100g, respectively. The water extracts of Algerian honeys have been shown to exhibit very high antioxidant activity by FRAP 287.45-403.54 µMFe^{+2} /100g, moderate AEAC 23.68-31.59 mg AEAC/100g and DPPH 35.39-43.75% (Khalil et al., 2012). Alisi et al. (2012) found that the methanolic extracts of Nigerian honeys had good antioxidant activity in DPPH (IC50=0.71-13.70), 0.90-10.40 mg QEAC/100g and 1.78-22.00 mg AEAC/100g of honey. Sudanese honey showed good antioxidant activity (20.1-27.0 mg AEAC/100g), FRAP (556.9-1237.1 mM), DPPH (50.4-70.5%), ferrous ion chelating activity (52.40-87.88%) and thiobarbituric reactive substances (TBARS, IC_{50}=317-6247 µg) (Idris et al., 2011; Tahir et al., 2015). When Dzomba et al. (2012) investigated the antioxidant capacity of different methanolic concentrations of Zimbabwean honeys, 0.1 mg/ml showed high DPPH% and ranged from 10.05 to 99.95%. The antioxidant capacity of Tunisian honeys was DPPH (IC_{50}=11.08 to 93.26 mg/ml) (Amel Boussaid et al., 2018). Honey harvested from various areas in Benin showed a good antioxidant activity (IC_{50} 27. 6 to 47. 5 µg/µl) (Azonwade et al., 2018). Many kinds of honey produced in African regions exhibited higher antioxidant activities than those reported in the European Atlantic area (Escuredo et al., 2013).

Biological and cellular protection of southern Africa honeys was examined by means of the erythrocyte haemolysis, the pBR322 plasmid, and the dichlorofluorescein diacetate (DCFH-DA) assays in SC-1 and Caco-2 cells. Results showed that all the tested honeys had the potential to protect DNA, erythrocytes, and cells *in vitro* (Serem & Bester, 2012). El-Haskoury et al. (2018) investigated the antioxidant activity of Moroccan carob honey samples collected from various geographical locations. The total antioxidant activity of carob honey ranged from 35.03 mg AAE/g to 60.94 mg AAE/g. The highest value was achieved in carob honey from the Taounate area, and the lowest was detected in samples from the Marrakech region. DPPH and FRAP values ranged from 12.54 mg/mL to 23.10 mg/mL and 1.87 mg/mL to 4.40 mg/mL, respectively. In this study, Benimellal honey showed the highest DPPH while honey from Taounate exhibited the highest FRAP value. This review showed that differences in African honeys depend on the botanical and geographical sources.

Anti-inflammatory

Nooh & Nour-Eldien (2016) and Yaghoobi, Kazerouni, & kazerouni (2013) proved that honey mitigates skin inflammation and oedema, stimulates wound curing and promotes tissue regeneration. Owoyele et al. (2014) investigated the analgesic and anti-inflammatory properties of Nigerian honey and the impacts of simultaneous administration of autonomic nervous system blocking drugs. In these studies, a hotplate was utilized for formalin-induced paw oedema while anti-inflammatory drugs for carrageenan paw oedema. Thirty male albino rats were randomly allocated to equal six groups. They were treated with saline, honey (600 mg/kg), indomethacin (5 mg/kg), autonomic blockers (3 μg/kg of tamsulosin, 20 mg/kg (intraperitoneally) of propranolol, 2 ml/kg of atropine or 10 mg/kg (intramuscularly) of hexamethonium) or honey (200 and 600 mg/kg) with one of the blockers. The outcome of the test confirmed that honey diminished pain recognition particularly inflammatory.

Nooh & Nour-Eldien (2016) investigated the impact of multi-floral honey on chronically induced ulcerative colitis (UC). Forty healthy male albino Wistar rats were randomly allocated into equal four groups: (1) negative control group did not receive any treatment; (2) sham control group took 1.0g/rat of raw honey orally once a day for three weeks; (3) colitis induced group prompted by the addition of dextran sulfate sodium to drinking water for twenty-one days, 5% for seven days after that 3% for fourteen days; (4) treated group took the above-outlined dose of honey once a day for three weeks after the induction of colitis. According to the biochemical assessment of colonic tissue, the dextran sulfate sodium colitis group exhibited considerably lower superoxide dismutase (SOD) and decreased Glutathione (GSH) amounts than those shown by the control group. The colitis group which received honey presented a substantial increase in tissue antioxidant enzyme (i.e. GSH and SOD) levels. Conversely, the rates of the inflammatory cytokines IL-1β and IL-6 in colonic tissues were significantly superior in the colitis group than in the other groups. Al-Seeni, El Rabey, & Al-Solamy (2015) studied the function of Egyptian honey against the toxic impact of melamine in the male rat kidney. They reported that melamine toxicity in the kidneys of male albino rats obviously decreased with the application of Egyptian honey at a dose of 2.5 g/kg body weight for twenty-eight days. In this study, honey intervention enhanced kidney functioning increased antioxidant enzymes and reduced lipid peroxide values. The authors attributed the protective action of honey to the synergistic effect of various antioxidant substances such as polyphenols and vitamins.

Infertility (asthenozoospermia)

Abdelhafiz & Muhamad (2008) reported that honey ingestion influenced the treatment of male infertility as a result of asthenozoospermia. In this study, ninety-nine couples affected by asthenozoospermia took part. One group was administered midcycle pericoital vaginal applications of Egyptian honey or royal jelly and the other standard intrauterine insemination for three cycles or until pregnancy occurred for both groups. The results showed that honey administered intravaginally could be used as an easy and relatively effective procedure for asthenozoospermia treatment. The study indicated that natural honey (2%, 3%, 4%) added to semen extender enhanced post-thaw sperm motility and protected membrane integrity in the cryopreserved Arab stallion spermatozoa through its unique nutritive value, energy, antibacterial and antioxidant properties (El-Sheshtawy et al., 2016).

Another study on applied to rats showed that persistent consumption of Nigerian honey (i.e 5 ml/kg and 7.5 ml/kg body weight) had a negative impact on sperm parameters and fertility potential of male Wistar rats (Dare, Igbigbi, & Avwioro, 2013). Oyelowo et al. (2014) also studied the protective potential of Nigerian honey on sperm indices and testis in sucrose-fed rats. They found that the high sucrose diet had adverse impacts on male reproductive function while honey feeding showed a protective impact on reproductive dysfunction.

The effect of honey on infertility has been reported worldwide. Sharifah (2011) studied the effect of nicotine and Malaysia Gelam honey on testis parameters and sperm qualities of juvenile rats. The results showed that i.p. injection of nicotine had a negative impact on sperm quality, while Gelam honey improved the fertility of the subject of study by increasing sperm motility and the number of morphologically normal sperm. In Iran, Hemadi et al. (2013) studied the impacts of honey and vitamin E on the germinative and somatic cells of testes of rats exposed to noise stress, and the outcome revealed that 5% of honey supplementation could contribute to spermatozoa enhancement. Fakhrildin & Alsaadi (2014) in Iraq studied how various concentrations of natural honey supplementation affected the semen freezing solution. Cryopreservation was completed at -196°C in liquid nitrogen and thawing done after six months. The outcome of this study revealed that the addition 10% of honey to cryoprotectant medium resulted in improved sperm quality after thawing. A similar result was observed with Spain rosemary honey (5%) used as a supplementation for freezing medium (Jerez-Ebensperger et al., 2015). The results of the study suggested that rosemary honey could be an alternative to fructose in Fiser extender without affecting the quality of sperm after freezing.

Effect of honey on febrile neutropenia

Febrile neutropenia is a common negative result of chemotherapy, and the present treatment for it is costly and may prompt adverse effects. Abdulrhman et al. (2016) investigated the influence of Egyptian honey on febrile neutropenia in children with acute lymphoblastic leukemia. Forty patients male and female aged 2.5–10 years with acute lymphoblastic leukemia were randomly allocated into two equal groups, intervention to control (I/C) and control to intervention (C/I). Patients in the I/C received 2.5g honey/kg body weight/ dose twice weekly during the first 12-week period (period 1), whereas the patients in the C/I group did not take honey as a control in period 1. Following period 1, the approach was substituted for each group for the following 12-week period (period 2). In this study, the body weight, hemoglobin (Hb), total leucocyte count, absolute neutrophil count and platelet count (PLT) were measured before treatment and at week 24. The potential positive impact of honey on Hb percentage and PLT were obvious in this experiment. However, because of the honey intervention, substantial increases in Hb% and PLT were observed in the C/I group. On the other hand, great decreases in Hb% and PLT were found after honey secession in the I/C group. These authors concluded that honey mediation might diminish the incidence of febrile neutropenia in a group of children with acute lymphoblastic leukemia and the period of their hospital stay.

Effects of honey on diabetic foot ulcers

Moghazy et al. (2010) investigated Egyptian honey as cost-effectiveness bandages in the treatment of diabetic foot ulcers, particularly in developing countries. The results showed rapid reduction of the inflammatory symptoms (e.g. edema, hotness, and redness) within 10 days in all patients, which was attributed to the anti-edema and antimicrobial effects of Egyptian honey. Similar findings were observed when several honey samples were tested on more than 787 patients from the nine following countries: Malaysia (Shukrimi et al., 2008), China (Guo & Fu, 2013), Pakistan (Jan et al., 2012), Greece (Kamaratos et al., 2014), Iran (Siavash et al., 2015), Saudi Arabia (Imran et al., 2015), India (Gulati et al., 2014), Yemen (Mohamed et al., 2014) and Russia (Mohamed et al., 2015).

Effects of honey on diabetes (antidiabetic activity)

Abdulrhman et al. (2013) studied the impact of sucrose and glucose in Egyptian honey on blood glucose and C-peptide in type 1 diabetes mellitus patients. The study consisted of fifty patients (aged 1-18) with type1 diabetes mellitus and thirty patients as a control. Using honey and other sugars, the researches determined the oral sugar tolerance of patients. The fasting and postprandial serum C-peptide values were assessed for all the groups of study, and then the glycemic index (GI) and the peak incremental index (PII) were computed for each group. Honey showed lower GI and PII in both patients and control when compared with sucrose. In both groups, the C-peptide values after honey ingestion increased significantly. Both study subjects had substantially increased C-peptide levels after honey ingestion was when compared with sugars. These results could be due to the stimulatory effect of honey on infected beta cells, but further therapeutic studies targeting beta cells of the pancreas are needed to properly explain the above phenomenon.

Abdulrhman (2013) examined the impact of Egyptian honey on type 2 diabetes mellitus. Although this was a single test case, the results serve as a guide for properly designed randomized controlled trials to assess if the ingestion of honey as a supplementary agent, alongside with anti-diabetic medicine has the perspective to halt or diminish both macro-and micro-vascular drawbacks of diabetes. In this study, an Egyptian man born in 1956 with hypertension and type 2 diabetes mellitus was employed. For eleven years from October 2002 to April 2013 he consumed only honey in a dose of 2 g/kg/day; he weighed 75 kg and consumed 150g of honey twice daily. The daily dose was split into 60g mixed with water and consumed before meals twice daily and 30g was used as the sweetening agent. During the study, the blood pressure was controlled and the patient did not develop cerebral strokes and diabetic ketoacidosis or hyperosmolar coma. Conversely, he developed microvascular complications (i.e. peripheral neuritis, non-proliferative retinopathy) after six and eight years, respectively.

Anticancer

There is now considerable evidence that honey is a natural anticancer agent through the course of treatment proposed methods. The proposed treatment effects include cell enlargement suppression, apoptosis prompting, and cell-cycle capture (Othman, 2012). Honey contains the components of a “natural cancer vaccine” as it diminishes chronic inflammatory developments, enhances the immune status and decreases infections. Several such polyphenols as caffeic acid, chrysin, galangin, quercetin and kaempferol found in honey have evolved as good pharmacological components in the inhibition and treatment of cancer (Jaganathan & Mandal, 2009).

El-Gend (2010) assessed the *in vitro* anticancer activity of raw and purified honeys *Cassia javanica, Citrus reticulata* and *Ziziphus spina-christi* with reference to colon, breast, and liver tumor cell line (HCT-116, HTB-26 and HepG2). They observed that Cassia honey had important cytotoxic activity with reference to cell line of colon and breast cancer whereas the weakest cytotoxic activity with reference to cell line of liver cancer. Raw Citrus honey displayed the most noteworthy cytotoxic activity against breast cancer. However, crude Ziziphus honey demonstrated strong proficiency against colon, liver and breast cancer with tumor development inhibition of 100 ± 0.1, 99.2 ± 0.4 and 88.14± 0.1%, respectively. Hanaa & Shaymaa (2011) studied the antitumor effect of Egyptian honey and found it to be a promising antitumor agent with obvious antimetastatic and antiangiogenic properties. The chemopreventive impact of Egyptian coriander honey (500 mg/kg/mouse) was investigated in Ehrlich Ascites Carcinoma (EAC) in both *in-vivo* and *in-vitro.* The administration of honey to EAC-bearing mice induced a reduction in Ascitic fluid volume and viable tumor cell count and also increased their nonviable tumor cell count and life span. Additionally, compared to the control group it reduced levels of lipid peroxidation and superoxide dismutase but increased the glutathione level, demonstrating that the anticancer influence of honey is attributable to its high bioactive compounds content (Hegazi et al., 2014). Various concentrations (10, 100 or 1000 mg/100g body weight of mice) of Egyptian honey were orally administered to mice (0.20 ml/mouse) every other day for four consecutive weeks. An observed increase in the number of bone marrow cells and peritoneal macrophages shows that the protective effect of honey occurs through activation of the immune system in addition to macrophages and T and B cell functions were also increased (Gabry & Othman, 2008).

Recently, Hegazi et al. (2015) demonstrated the potential of Egyptian Coriander honey (500 mg/kg) for activation of the immune system during treatment of EAC-bearing mice by and observed decreased tumor volume, packed cell volume and viable cell count. Several studies have been conducted on the effect of honey samples collected from various countries on human or experimental animals (Badolato et al., 2017; Hossen et al., 2017). In Malaysia, the potential of Tualang honey as an anticancer agent against breast (MCF-7 and MDA-MB-231) and cervical (HeLa) cancer cell lines has been investigated (Fauzi et al., 2011). The outcome of the study (EC50= 2.4–2.8% showed that Tualang honey has significant anticancer activity against all cancer types, which was proved by non–cytotoxic influence on the normal breast epithelial cell line (MCF-10A). In Japan, Swellam et al. (2003) investigated the *in vivo* and *in vitro* antineoplastic activity of honey on a bladder cancer implantation model. According to the results, bee honey can be used as an effective agent for preventing the growth of T24, RT4, 253J and MBT-2 bladder cancer cell lines *in vitro* as well as in MBT-2 bladder cancer implantation models when it is administered intralesionally or orally.

Antibacterial and antifungal activities

In Egypt, honey samples presented antibacterial activities against common bacteria- inducing respiratory diseases including *Klebsiella pneumonia, Staph. aureus*, *Streptococcus pyogenes*, *S. pneumonia* and *Pseudomonas aeruginosa* with varied sensitivity (Ahmed et al., 2013; El-Kased, 2016). Another study on Egyptian sesame and eucalyptus honey types showed antibacterial against strains *Clostridium acetobutylicum* (DSM1731) and *Clostridium perfringens* (KF383123) (Hegazi et al., 2014). Other authors also reported on the effect of Egyptian citrus, clover and marjoram honeys on *Escherichia coli* (E. coli ATCC 8739), *E. coli* (O157: H7) and *Salmonella typhimurium* (Badawy et al., 2004; Wasfi, Elkhatib, & Khairalla, 2016). Elbanna et al. (2014) demonstrated the antibacterial effect of Egyptian citrus, clover and cotton honeys on pathogenic bacteria, and their findings showed that the *Salmonella enteritidis* was the most sensitive followed by *Staph. aureus, Listeria monocytogenes* and *E. coli*, respectively.

In Nigeria, Adeoye-Isijola et al. (2017) tested honey samples against various microorganisms and proved that they contained antimicrobial agents and showed a promising antimicrobial effect against pathogenic bacteria. Similarly, Adeonipekun et al. (2014) demonstrated the antibacterial activity of Nigerian honeys against *Staph. aureus* and *P. aeruginosa*. Agbagwa & Frank-Peterside (2010) observed comparable results in Nigerian honey as well. In Algeria, honey samples were used against *P. aeruginosa* (Abdelmalek et al., 2012). Sudanese honey samples were not all found to contain significant levels of antibacterial activity (Abdallah, 2016), and some collected from various geographical areas in Sudan rather exhibited significant antibacterial activity (El-Toum & Yagoub, 2007; Farouk et al., 1988; Hamza, Aliyu, & Ibrahim, 2015). In Kenya, the honey samples were used also as an antibacterial agent (Orina, 2014). According to recent findings, Ghanaian honey samples were found to have the ability to inhibit the growth of *E. coli, Staphylococcus spp*. and *Shigella spp.* (Adadi & Obeng, 2017; Akpabli-Tsigbe & Kwaku, 2015) while their activities against *Bacillus spp*. were also confirmed (Darfour et al., 2015). Another study by Cockburn et al. (2013) indicated that *Meliponula bocandei* honey contains antimicrobial compounds that inhibit *P. aeruginosa* infections as an alternative to synthetic antibiotics.

In South Africa, polyfloral honey, citrus blossom and Goldcrest were examined for anti-*Helicobacter pylori* activity (Manyi-Loh et al., 2010). The positive control (clarithromycin) showed a zone diameter of 18.0±7.4 mm, which is not significantly different from honeys at 75% (v/v). The anti-*H. pylori* activity of honey seems to be due to the presence of phenolic and flavonoid compounds (Amaral et al., 2017). Another study showed that the South African honeys had a more inhibitory effect on *S. anginosus* (NCTC 10708) and *S. oralis* (NCTC 11427) (Basson & Grobler, 2008). Similarly, Khan et al. (2014) confirmed the positive effect of South Africa honey on various pathogenic bacteria: *Staph. aureus* American type culture collection (ATCC) 25923; *Staph. aureus,* clinical strain (6438300); methicillin-resistant *Staph. aureus* (ATCC 43300), methicillin-resistant *Staph. aureus* clinical strain 43300, methicillin and gentamycin-resistant *Staph. aureus* (ATCC 33592), *Staph. epidermidis* (ATCC 2223) and *P. aeruginosa*. Another study demonstrated that Ethiopian *Trigona* spp. honey has significant antimicrobial activity against fungal species *Aspergillus niger* (DSM 373), *Penicillium chrysogenum* (DSM 844) and *Trichoderma viride* (DSM 63065), as well as six species of bacteria *Bacillus subtilis* (DSM 347), *Micrococcus luteus* (DSM 348), *Bacillus megaterium* (DSM 90), *Bacillus brevis* (DSM 5609), *E. coli* (DSM 31) and *P. syringae* (DSM 5176*)* (Garedew et al., 2003).

In Ethiopia, honey was found to have the potential to be used against *Candida* species isolated from the oral cavity of acquired immunodeficiency syndrome patients (Mulu et al., 2010). The antifungal activity exhibited by the Ethiopian honey was suggested to be attributed to phytochemical, ascorbic acid and peroxidase. Similarly, Benin honey obtained from various sources were found to possess high antifungal activity against *Aspergillus parasiticus* (CMBB 20), *Aspergillus ochraceus* (CMBB 91), *Aspergillus fumigatus* (CMBB 89) and *Aspergillus clavatus* (NCPT 97) (Azonwade et al., 2018). More recently, Wasihun & Kasa (2016) have confirmed the antibacterial activity of red and white Ethiopian honey against multidrug-resistant pathogenic bacteria *Staph. aureus, E. coli, P. aeruginosa, Proteus mirabilis, coagulase-negative Staphylococcus, Streptococcus pyogenes* and *K. pneumonia.* Most studies focused on a wide range of geographical and botanical origins have been reported in Saudi Arabia (Ghramh et al., 2018), India (Kateel et al., 2018), China (Deng et al., 2018), Brazil (Bueno-Costa et al., 2016), Pakistan (Khalil et al., 2014), Australia (Wong et al., 2017), Spain (Osés et al., 2016), Malaysian (Tan et al., 2009), New Zealand (Lin et al., 2011), Mexican honey (Rodríguez et al., 2012). These studies provide an essential international perspective because the antimicrobial activity of honey obviously differs based on the composition, which is mainly dependent on geographical and botanical origins and post-harvest treatment (Deng et al., 2018; Kiriakou et al., 2018).

CONCLUSION

This paper provides a comprehensive assessment of honey from African countries based on nutritional value and health properties. The chemical composition depends on such factors as floral origin, climate condition, and locations. Thus, honey sourced from various African countries has different characteristics. Apart from carbohydrates, all-natural honeys of this type of ingredients in small and trace quantities that can be of anti-inflammatory, antioxidant, antimicrobial, anticancer, antidiabetic and antimitotic activities. This demonstrates that honey has a positive effect on the treatment of asthenozoospermia, febrile neutropenia and diabetic foot ulcers. The biological activities of African honeys are mainly attributed to phenolics, flavonoids and vitamins. Lastly, this review is an important contribution to the database and knowledge of the chemical composition of honey from Africa, since there is limited information on its nutritional and health properties.

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