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## Review

# Honey for Nutrition and Health: A Review

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**Key words:** honey, nutrition, composition, glycemic index

Due to the variation of botanical origin honey differs in appearance, sensory perception and composition. The main nutritional and health relevant components are carbohydrates, mainly fructose and glucose but also about 25 different oligosaccharides. Although honey is a high carbohydrate food, its glycemic index varies within a wide range from 32 to 85, depending on the botanical source. It contains small amounts of proteins, enzymes, amino acids, minerals, trace elements, vitamins, aroma compounds and polyphenols. The review covers the composition, the nutritional contribution of its components, its physiological and nutritional effects. It shows that honey has a variety of positive nutritional and health effects, if consumed at higher doses of 50 to 80 g per intake.

### Key teaching points:

- About 95% of the honey dry matter is composed of carbohydrates, mainly fructose and glucose. 5–10% of the total carbohydrates are oligosaccharides, in total about 25 different di- and trisaccharides.
- The Glycemic Index of honey varies from 32 to 85, depending on the botanical source. Fructose-rich honeys such as acacia honey have a low GI.
- Besides, honey contains small amounts of proteins, enzymes, amino acids, minerals, trace elements, vitamins, aroma compounds and polyphenols.
- Honey has been shown to possess antimicrobial, antiviral, antiparasitary, anti-inflammatory, antioxidant, antimutagenic and antitumor effects.
- Due to its high carbohydrate content and functional properties honey is an excellent source of energy for athletes.
- Most of the health promoting properties of honey are only achieved by application of rather high doses of honey such as 50 to 80 g per intake.

## INTRODUCTION

As the only available natural sweetener honey was an important food for Homo sapiens from his very beginnings. Indeed, the relation between bees and man started as early as Stone Age [1]. In order to reach the sweet honey, man was ready to risk his life (Fig. 1). The first written reference to honey, a Sumerian tablet writing, dating back to 2100–2000 BC, mentions honey's use as a drug and an ointment [2]. In most ancient cultures honey has been used for both nutritional and medical purposes [2–5]. According to the bible, King Solomon has said: "Eat honey my son, because it is good" (Old Testament, proverb 24:13). The belief that honey is a nutrient, a drug and an ointment has been carried into our days.

For a long time in human history it was an important carbohydrate source and the only largely available sweetener until industrial sugar production began to replace it after 1800 [2]. In the long human tradition honey has been used not only as a nutrient but also as a medicine [3]. An alternative medicine branch, called apitherapy, has developed in recent years, offering treatments based on honey and the other bee products against many diseases. The knowledge on this subject is compiled in various books [e.g. 6,7] or on relevant web pages such as [www.apitherapy.com](http://www.apitherapy.com), [www.apitherapy.org](http://www.apitherapy.org). The major use of honey in healing today is its application in the treatment of wounds, burns and infections which is not a subject of this review since it is reviewed elsewhere [8].

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Abbreviations: CHO = carbohydrate, GI = glycemic index, GL = glycemic load, ORAC = oxygen radical absorbance capacity, PGE = prostaglandin E, PGF = prostaglandin F, RDI = recommended daily intake.

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**Fig. 1.** Prehistoric man gathering honey. A rock painting, made around 6000 BC. La Arana shekter, Bicorp, Eastern Spain.

At present the annual world honey production is about 1.2 million tons, which is less than 1% of the total sugar production. The consumption of honey differs strongly from country to country. The major honey exporting countries China and Argentina have small annual consumption rates of 0.1 to 0.2 kg per capita. Honey consumption is higher in developed countries, where the home production does not always cover the market demand. In the European Union, which is both a major honey importer and producer, the annual consumption per capita varies from medium (0.3–0.4 kg) in Italy, France, Great Britain, Denmark and Portugal to high (1–1.8 kg) in Germany, Austria, Switzerland, Portugal, Hungary and Greece, while in countries such as USA, Canada and Australia the average per capita consumption is 0.6 to 0.8 kg/year [see <http://www.apiservices.com/>].

Different surveys on nutritional and health aspects of honey have been compiled [8–13]. However, as they are not complete and comprehensive, we undertook the task to review all the available relevant sources on this topic.

## COMPOSITION AND NUTRITIONAL REQUIREMENTS

The overall composition of honey is shown in Table 1. The carbohydrates are the main constituents, comprising about 95% of the honey dry weight. Beyond carbohydrates, honey contains numerous compounds such as organic acids, proteins, amino acids, minerals, polyphenols, vitamins and aroma compounds. Summarising the data shown in Tables 1 and 2, it can be concluded that the contribution of honey to the recommended daily intake is small. However, its importance with respect to nutrition lies in the manifold physiological effects [16]. It should be noted that the composition of honey depends greatly on the botanical origin [17], a fact that has been seldom considered in the nutritional and physiological studies.

**Table 1.** Honey Composition (Data in g/100 g) [14,15]

	Blossom honey		Honeydew honey	
	average	min.–max.	average	min.–max.
Water	17.2	15–20	16.3	15–20
Monosaccharides				
fructose	38.2	30–45	31.8	28–40
glucose	31.3	24–40	26.1	19–32
Disaccharides				
sucrose	0.7	0.1–4.8	0.5	0.1–4.7
others	5.0	2–8	4.0	1–6
Trisaccharides				
melezitose	<0.1		4.0	0.3–22.0
erlose	0.8	0.5–6	1.0	0.1–6
others	0.5	0.5–1	3.0	0.1–6
undetermined				
oligosaccharides	3.1		10.1	
Total sugars	79.7		80.5	
Minerals	0.2	0.1–0.5	0.9	0.6–2.0
Amino acids, proteins	0.3	0.2–0.4	0.6	0.4–0.7
Acids	0.5	0.2–0.8	1.1	0.8–1.5
pH-value	3.9	3.5–4.5	5.2	4.5–6.5

## Carbohydrates

The main sugars are the monosaccharides fructose and glucose. Additionally, about 25 different oligosaccharides have been detected [18,19]. The principal oligosaccharides in blossom honey are the disaccharides sucrose, maltose, trehalose and turanose, as well as some nutritionally relevant ones such as panose, 1-kestose, 6-kestose and palatinose. Compared to blossom honey honeydew honey contains higher amounts of the oligosaccharides melezitose and raffinose. In the process of digestion after honey intake the principal carbohydrates fructose and glucose are quickly transported into the blood and can be utilized for energy requirements by the human body. A daily dose of 20 g honey will cover about 3% of the required daily energy (Table 2).

## Proteins, Enzymes and Amino Acids

Honey contains roughly 0.5% proteins, mainly enzymes and free amino acids. The contribution of that fraction to human protein intake is marginal (Table 2). The three main honey enzymes are diastase (amylase), decomposing starch or glycogen into smaller sugar units, invertase (sucrase,  $\alpha$ -glucosidase), decomposing sucrose into fructose and glucose, as well as glucose oxidase, producing hydrogen peroxide and gluconic acid from glucose.

## Vitamins, Minerals And Trace Compounds

The amount of vitamins and minerals is small and the contribution of honey to the recommended daily intake (RDI) of the different trace substances is marginal (Table 2). It is known that different unifloral honeys contain varying amounts of minerals and trace elements [26]. From the

**Table 2.** Honey Nutrients (Values Compiled from Different Authors [12,14,20–27] and Recommended Daily Intake [28])

Ingredient	Amount in 100 g	Recommended Daily Intake <sup>1</sup>		
		1–4 years old	4–15 years old	After 15 years old
Energy (kcal)				
Carbohydrates (kcal)	300	1000–1100	1400–2700	2400–3100
Proteins (g)	0.5	13–14	17–46	44–59
Fats (g)	0	—	—	—
Minerals (mg)				
Sodium (Na)	1.6–17	300	410–550	550
Calcium (Ca)	3–31	600	700–1200	1000–1200
Potassium (K)	40–3500	1000	1400–1900	2000
Magnesium (Mg)	0.7–13	80	120–310	300–400
Phosphorus (P)	2–15	500	600–1250	700–1250
Zinc (Zn)	0.05–2	3	5–9.5	7–10
Copper (Cu)	0.02–0.6	0.5–1	0.5–1	0.5–1
Iron (Fe)	0.03–4	8	8–15	10–15
Manganese (Mn)	0.02–2	1–1.5	1.5–5	2–5
Chromium (Cr)	0.01–0.3	0.02–0.06	0.02–0.1	0.03–1.5
Selenium (Se)	0.002–0.01	0.001–0.004	0.001–0.006	0.003–0.007
Vitamins (mg)				
Phyllochinon (K)	ca. 0.025	15	20–50	60–70
Thiamin (B <sub>1</sub> )	0.00–0.01	0.6	0.8–1.4	1–1.3
Riboflavin (B <sub>2</sub> )	0.01–0.02	0.7	0.9–1.6	1.2–1.5
Pyridoxin (B <sub>6</sub> )	0.01–0.32	0.4	0.5–1.4	1.2–1.6
Niacin <sup>2</sup>	0.10–0.20	7	10–18	13–17
Panthenic acid	0.02–0.11	4	4–6	6
Ascorbic acid (C)	2.2–2.5	60	70–100	100

\* Only major components considered.

<sup>1</sup> From the German Nutrition Society [28].

<sup>2</sup> Niacin equivalents: 1 mg nicotinamide = 1 mg niacin = 60 mg tryptophan (= niacin-precursor).

nutritional point of view chromium, manganese and selenium are important, especially for 1 to 15 years old children. The elements sulphur, boron, cobalt, fluoride, iodide, molybdenum and silicon can be important in human nutrition too, although there are no RDI values proposed for these elements (Table 3).

Honey contains 0.3–25 mg/kg choline and 0.06 to 5 mg/kg acetylcholine [12]. Choline is essential for cardiovascular and brain function as well as for cellular membrane composition and repair, while acetylcholine acts as a neurotransmitter.

**Table 3.** Other Trace Elements in Honey [14,20–27]

Element	mg/100 g	Element	mg/100 g
Aluminium (Al)	0.01–2.4	Lead (Pb)*	0.001–0.03
Arsenic (As)	0.014–0.026	Lithium (Li)	0.225–1.56
Barium (Ba)	0.01–0.08	Molybdenum (Mo)	0–0.004
Boron (B)	0.05–0.3	Nickel (Ni)	0–0.051
Bromine (Br)	0.4–1.3	Rubidium (Rb)	0.040–3.5
Cadmium (Cd)*	0–0.001	Silicon (Si)	0.05–24
Chlorine (Cl)	0.4–56	Strontium (Sr)	0.04–0.35
Cobalt (Co)	0.1–0.35	Sulfur (S)	0.7–26
Fluoride (F)	0.4–1.34	Vanadium (V)	0–0.013
Iodide (I)	10–100	Zirconium	0.05–0.08

\* Elements regarded as toxic, can be partially of man-made origin.

### Aroma Compounds, Taste-Building Compounds And Polyphenols

There is a wide variety of honeys with different tastes and colours, depending on their botanical origin [29]. The sugars are the main taste-building compounds. Generally, honey with a high fructose content (e.g. acacia) are sweeter compared to those with high glucose concentration (e.g. rape). The honey aroma depends also on the quantity and type of acids and amino acids present. In the past decades extensive research on aroma compounds has been carried out and more than 500 different volatile compounds were identified in different types of honey. Indeed, most aroma building compounds vary in the different types of honey depending on its botanical origin [30]. Honey flavour is an important quality for its application in food industry and also a selection criterion for the consumer's choice.

Polyphenols are another important group of compounds with respect to the appearance and the functional properties of honey. 56 to 500 mg/kg total polyphenols were found in different honey types [31,32]. Polyphenols in honey are mainly flavonoids (e.g. quercetin, luteolin, kaempferol, apigenin, chrysin, galangin), phenolic acids and phenolic acid derivatives [33]. These are compounds known to have antioxidant properties. The main polyphenols are the flavonoids, their content can

vary between 60 and 460  $\mu\text{g}/100\text{ g}$  of honey and was higher in samples produced during a dry season with high temperatures [34].

### Contaminants and Toxic Compounds

The same as any other natural food, honey can be contaminated by the environment, e.g. by heavy metals, pesticides, antibiotics etc. [35]. Generally, the contamination levels found in Europe do not present a health hazard. The main problem in recent years was the contamination by antibiotics, used against the bee brood diseases, but at present this problem seems to be under control. In the European Union antibiotics are not allowed for that purpose, and thus honey containing antibiotics is also not permitted to be traded on the market.

A few plants used by bees are known to produce nectar containing toxic substances. Diterpenoids and pyrazolidine alkaloids are two main toxin groups relevant in nectar. Some plants of the *Ericaceae* family belonging to the sub-family *Rhododendron*, e.g. *Rhododendron ponticum* contain toxic polyhydroxylated cyclic hydrocarbons or diterpenoids [36]. The substances of the other toxin group, the pyrazolidine alkaloids, found in different honey types and the potential intoxication by these substances is reviewed [37]. Cases of honey poisoning have been reported rarely in the literature and have concerned individuals from the following regions: Caucasus, Turkey, New Zealand, Australia, Japan, Nepal, South Africa, and also some countries in North and South America. Observed symptoms of such honey poisoning are vomiting, headache, stomach ache, unconsciousness, delirium, nausea and sight weakness. In general the poisonous plants are known to the local beekeepers and honey, which can possibly contain poisonous substances, is not marketed. To minimise risks of honey born poisoning in countries where plants with poisonous nectar are growing tourists are advised to buy honey in shops and not on the road and from individual beekeepers.

### Glycemic Index and Fructose

The impact of carbohydrates on human health is discussed controversially, especially the understanding of how the carbohydrates of a given food affect the blood glucose level. Today, the dietary significance of carbohydrates is often indicated in terms of the glycemic index (GI). Carbohydrates with a low GI induce a small increase of glucose in blood, while those with a high GI induce a high blood glucose level. The only comprehensive data on honey GI are the one presented in Table 4, based mainly on data of different Australian honeys [38,39]. There is a significant negative correlation between fructose content and GI, probably due to the different fructose/glucose ratios of the honey types tested. It is known that unifloral honeys have varying fructose content and fructose/glucose ratios [17]. Some honeys, e.g. acacia and yellow box, with relatively high concentration of fructose, have a lower GI than other honey types (Table 4). There was no significant correlation between GI and the other honey sugars. The GI values of 4 honeys found in one study varied between 69 and 74 [40], while in another one the value of a honey unidentified botanical origin was found to be 35 [41]. As the GI concept claims to predict the role of carbohydrates in the development of obesity [42], low GI honeys might be a valuable alternative to high GI sweeteners. In order to take into consideration the quantity of ingested food, a new term, the glycemic load, was introduced. It is calculated as follows: the GI value is multiplied by the carbohydrate content in a given portion and divided by 100. Values lower than 10 are considered low, between 10 and 20 are intermediate and above 20 belong to the category high. For an assumed honey portion of 25 g the glycemic load of most honey types is low and some types are in the intermediate range (Table 4).

The GI concept was developed to provide a numeric classification of carbohydrate foods, assuming that such data are useful in situations where the glucose tolerance is impaired.

**Table 4.** Glycemic Index (GI) and Glycemic Load (GL) for a Serving (25 g) of Honey [38,39]

	honey origin	Fructose g/100 g	GI	AC g/serving	GL (per serving)
Acacia (black locust)*	Romania	43	32	21	7
Yellow box	Australia	46	35 $\pm$ 4	18	6
Stringy bark	Australia	52	44 $\pm$ 4	21	9
Red gum	Australia	35	46 $\pm$ 3	18	8
Iron bark	Australia	34	48 $\pm$ 3	15	7
Yapunya	Australia	42	52 $\pm$ 5	17	9
Pure Australia	Australia		58 $\pm$ 6	21	12
Commercial blend	Australia	38	62 $\pm$ 3	18	11
Salvation June	Australia	32	64 $\pm$ 5	15	10
Commercial blend	Australia	28	72 $\pm$ 6	13	9
Honey of unspecified origin	Canada		87 $\pm$ 8	21	18
Average		55	55 $\pm$ 5	18	10
Sucrose (mean of 10 studies)			68 $\pm$ 5		
Glucose			100		

AC = available carbohydrate.

Therefore, food with a low GI should provide benefits with respect to diabetes and to the reduction of coronary heart disease [43]. The consumption of honey types with a low GI, e.g. acacia honey might have beneficial physiological effects and could be used by type-2 diabetes patients. An intake of 50 g honey of unspecified type by healthy people and diabetes patients led to smaller increases of blood insulin and glucose than the consumption of the same amounts of glucose or of a sugar mixture resembling to honey [44,45]. It was shown that consumption of honey has a favourable effect on diabetes patients, causing a significant decrease of plasma glucose [46–48]. Honey was well tolerated by patients with diabetes of unspecified type [49] and by diabetes type-2 patients [50–52]. According to recent studies, long term consumption of food with a high GI is a significant risk factor for type-2 diabetes patients [53]. However, the GI concept for the general population is still an object of discussions [54].

Fructose is the main sugar in most honey types (Table 1). A surplus consumption of fructose in today's American diet, mainly in the form of high-fructose corn syrup, is suspected to be one of the main causes for overweight problems [55]. By reviewing clinical studies these authors found that fructose ingestion causes a rise of de-novo lipogenesis, which has an unfavourable effect on energy regulation and on body weight. In rat feeding experiments the hypertriglyceridemic effect observed after intake of fructose does not take place after feeding of honey [56]. Compared to rats fed with fructose, honey-fed

**Table 5.** List of Bacteria That Were Found to Be Sensitive to Honey [60,61]

<i>Actinomyces pyogenes</i>
<i>Bacillus anthracis</i>
<i>Corynebacterium diphtheriae</i>
<i>Epidermophyton floccosum</i>
<i>Escherichia coli</i>
<i>Haemophilus influenzae</i>
<i>Helicobacter pylori</i>
<i>Klebsiella pneumoniae</i>
<i>Microsporium canis, M. gypseum</i>
<i>Mycobacterium tuberculosis</i>
<i>Nocardia asteroides</i>
<i>Proteus sp.</i>
<i>Pseudomonas aeruginosa</i>
<i>Salmonella sp.</i>
<i>Salmonella cholerae-suis</i>
<i>Salmonella typhi</i>
<i>Salmonella typhimurium</i>
<i>Serratia marcescens</i>
<i>Shigella sp.</i>
<i>Staphylococcus aureus</i>
<i>Streptococcus agalactiae, Str. dysgalactiae, Str. uberis</i>
<i>Streptococcus faecalis</i>
<i>Streptococcus mutans</i>
<i>Streptococcus pneumoniae</i>
<i>Streptococcus pyogenes</i>
<i>Trichophyton rubrum, T. tonsurans, T. mentagrophytes var.</i>
<i>Vibrio cholerae</i>

**Table 6.** Effect of Heat, Light and Storage Time on the Antibacterial Activity of Honey; the Antibacterial Activity Is Expressed in % of the Untreated Controls [63]

	Non-peroxide activity		Peroxide activity	
	light	dark	light	dark
Storage: 15 months rt				
Blossom honey	76	86	19	48
Honeydew honey	78	80	63	70
Heat: 15 min 70°C				
Blossom honey		86		8
Honeydew honey		94		78

rt = room temperature 15–20°C.

rats had higher plasma  $\alpha$ -tocopherol levels, higher  $\alpha$ -tocopherol/triacylglycerol ratios, lower plasma  $\text{NO}_x$  concentrations and a lower susceptibility of the heart to lipid peroxidation. These data suggest a potential nutritional benefit of substituting fructose by honey in the ingested diets. Ingestion of both honey (2 g/kg body weight) and fructose prevented the ethanol-induced transformation of erythrocytes in mice [57]. In humans faster recovery from ethanol intoxication after honey administration has been reported while a higher ethanol elimination rate has also been confirmed [58,59].

## DIFFERENT PHYSIOLOGICAL EFFECTS

### Antimicrobial, Antiviral and Antiparasitic Activity

Honey inhibits the growth of micro-organisms and fungi. The antibacterial effect of honey, mostly against gram-positive bacteria, is well documented [60–63]. Both bacteriostatic and bactericidal effects have been reported for many strains, many of them pathogenic (Table 5). Further, it was reported that honey has also been shown to inhibit *Rubella* virus in vitro [64], three species of the *Leishmania* parasite [65] and *Echinococcus* [66].

The antimicrobial effect of honey is due to different substances and depends on the botanical origin of honey [60–63]. The low water activity of honey inhibits bacterial growth. Honey glucose oxidase produces the antibacterial agent hydrogen peroxide [67], but the peroxide production capacity depends also on honey catalase activity [68]. There are also other non-peroxide antibacterial substances with different chemical origin, e.g. aromatic acids [69], unknown compounds with different chemical properties [63] and phenolics and flavonoids [70,71]. The low honey pH can also be responsible for the antibacterial activity [72].

Contrary to the non-peroxide activity, the peroxide one can be destroyed by heat, light and storage [63] (Table 6). These different factors had a bigger effect on the antibacterial activity of blossom honey than on honeydew honey. Thus, for optimum

antibacterial activity, honey should be stored in a cool, dark place and be consumed when fresh.

### Antioxidant Effects

The term “oxidative stress” describes the lack of equilibrium between the production of free radicals and the antioxidant protective activity in a given organism. Protection against oxidation is thought to prevent some chronic diseases [73]. The oxidative modification of the lipoproteins is considered to be an important factor for the pathogenesis of arteriosclerosis [74]. Honey has been found to contain significant antioxidant activity including glucose oxidase, catalase, ascorbic acid, flavonoids, phenolic acids, carotenoid derivatives, organic acids, Maillard reaction products, amino acids and proteins [31,75–84]. The antioxidative activity of honey polyphenols can be measured *in vitro* by comparing the oxygen radical absorbance capacity (ORAC) with the total phenolics concentration (Table 7). There is a significant correlation between the antioxidant activity, the phenolic content of honey and the inhibition of the *in vitro* lipoprotein oxidation of human serum [85]. Furthermore, in a lipid peroxidation model system buckwheat honey showed a similar antioxidant activity as 1 mM  $\alpha$ -tocopherol [83]. The influence of honey ingestion on the antioxidative capacity of plasma was tested in two studies [86,87]. In the first one, the trial persons were given maize syrup or buckwheat honeys with a different antioxidant capacity in a dose of 1.5 g/kg body weight. In comparison to the sugar control, honey caused an increase of both the antioxidant and the reducing serum capacity. In the second study humans received a diet supplemented with a daily honey serving of 1.2 g/kg body weight. Honey increased the body antioxidant agents: blood vitamin C concentration by 47%,  $\beta$ -carotene by 3%, uric acid by 12%, and glutathione reductase by 7% [87]. It should be borne in mind that the antioxidant activity depends on the

**Table 7.** Antioxidative Activity (ORAC) and Total Phenol Content of Different Unifloral Honeys [32]

Honey type	ORAC $\mu$ mol TE/g	total phenolics GAE mg/kg
Buckwheat Illinois	16.95 $\pm$ 0.76	796 $\pm$ 3.2
Buckwheat	9.81 $\pm$ 0.34	nd
Buckwheat New York	9.75 $\pm$ 0.48	456 $\pm$ 55
Buckwheat	9.34 $\pm$ 0.57	nd
Buckwheat	9.17 $\pm$ 0.63	nd
Buckwheat	7.47 $\pm$ 0.27	nd
Soy (2000)	9.49 $\pm$ 0.29	nd
Soy (1996)	8.34 $\pm$ 0.51	269 $\pm$ 22
Hawaiian Christmas berry	8.87 $\pm$ 0.33	250 $\pm$ 56
Clover (January 2000)	6.53 $\pm$ 0.70	nd
Clover (July 2000)	6.05 $\pm$ 1.00	128 $\pm$ 11
Tupelo	6.48 $\pm$ 0.37	183 $\pm$ 9
Fireweed	3.09 $\pm$ 0.27	62 $\pm$ 6
Acacia	3.00 $\pm$ 0.16	46 $\pm$ 2

ORAC = oxygen radical absorbance capacity, TE = Trolox equivalent, GAE = gallic acid equivalent, nd = not determined.

botanical origin of honey and varies to a great extent in honeys from different botanical sources [31,77,78,88–90].

The impact of heat and storage time on the antioxidant capacity of clover and buckwheat honey was analysed recently [91]. While processing of clover honey did not significantly influence its antioxidant capacity, storage during 6 months reduced it by about 30%. After a given storage period the antioxidant capacity of processed and raw honeys was similar. In another study both antioxidant activity and brown pigment formation increased upon heat treatment and storage [92].

### Antimutagenic and Antitumor Activity

Mutagenic substances act directly or indirectly by promoting mutations of the genetic structure. During the roasting and frying of food heterocyclic amines are formed, e.g. Trp-p-1 (3-Amino-1,4-dimethyl-5H-pyridol [4,3-b] indole). The antimutagenic activity of honeys from seven different floral sources (acacia, buckwheat, fireweed, soybean, tupelo and Christmas berry) against Trp-p-1 was tested by the Ames assay and compared to a sugar analogue as well as to individually tested simple sugars [93]. All honeys exhibited a significant inhibition of Trp-p-1 mutagenicity. Glucose and fructose were found to have a similar antimutagenic activity as honey. Nigerose, another sugar, present in honey [18,19] has an immunoprotective activity [94]. The anti-metastatic effect of honey and its possible mode of anti-tumor action was studied by the application of honey in spontaneous mammary carcinoma in methylcholanthrene-induced fibrosarcoma of CBA mice and in anaplastic colon adenocarcinoma of Y59 rats [95]. A statistically significant anti-metastatic effect was achieved by oral application of honey. These findings indicate that honey activates the immune system and honey ingestion may be advantageous with respect to cancer and metastasis prevention. In addition, it is postulated that honey given orally before tumour cell inoculation may have an inhibitory effect on tumour spreading. In another study of the same group the effect of honey on tumour growth, metastasising activity and induction of apoptosis and necrosis in murine tumour models (mammary and colon carcinoma) was investigated [96]. A pronounced antimetastatic effect was observed when honey was applied before tumour-cell inoculation (per oral 2 g kg<sup>-1</sup> for mice or 1 g kg<sup>-1</sup> for rats, once a day for 10 consecutive days).

In another study the anti-tumour effect of honey against bladder cancer was examined *in vitro* and *in vivo* in mice [97]. According to these results honey is an effective agent for inhibiting the growth of different bladder cancer cell lines (T24, RT4, 253J and MBT-2) *in vitro*. It is also effective when administered intravesically or orally in the MBT-2 bladder cancer implantation mice models.

### Anti-inflammatory Effects

Anti-inflammatory effects of honey in humans were studied by Al Waili and Boni [98] after ingestion of 70 g honey. The

mean plasma concentration of thromboxane B(2) was reduced by 7%, 34%, and 35%, that of PGE(2) by 14%, 10%, and 19% at 1, 2, and 3 hours, respectively, after honey ingestion. The level of PGF(2 $\alpha$ ) was decreased by 31% at 2 hours and by 14% at 3 hours after honey ingestion. At day 15, plasma concentrations of thromboxane B(2), PGE(2) and PGF(2 $\alpha$ ) decreased by 48%, 63% and 50%, respectively. The ingestion of honey decreased inflammation in an experimental model of inflammatory bowel disease in rats [99]. Honey administration is as effective as prednisolone treatment in an inflammatory model of colitis. The postulated mechanism of action is by preventing the formation of free radicals released from the inflamed tissues. The reduction of inflammation could be due to the antibacterial effect of honey or to a direct antiinflammatory effect. The latter hypothesis was supported in animal studies, where antiinflammatory effects of honey were observed in wounds with no bacterial infection [100].

### Various Physiological Effects

The effect of honey on the antibody production against thymus-dependent antigen in sheep red blood cells and thymus-independent antigen (*Escherichia coli*) in mice was studied [101]. Oral honey intake stimulates antibody production during primary and secondary immune responses against thymus-dependent and thymus-independent antigens.

In animal experiments honey showed an immunosuppressive activity [102]. This might explain why it has been hypothesised, that ingestion of honey can relieve pollen hypersensitivity.

In a study humans received a diet supplemented with a daily honey consumption of 1.2 g/kg body weight [87]. The effects observed in blood serum were an increase of monocytes (50%), iron (20%), copper (33%), a slight increase of lymphocyte and eosinophil percentages, zinc, magnesium, hemoglobin and packed cell volume and a reduction of: ferritin (11%), immunoglobulin E (34%), aspartate transaminase (22%), alanine transaminase (18%), lactic acid dehydrogenase (41%), creatine kinase (33%) and fasting sugar (5%).

## NUTRITION AND HEALTH EFFECTS

### Oral Health

There is much debate whether honey is harmful to teeth. Some reports show a cariogenic effect of honey [103–106] or a much less cariogenic effect than sucrose [107]. Due to its antibacterial activity honey ingestion inhibits the growth of bacteria, causing caries [108,109] and might induce a carioprotective effect [110,111]. It was shown that Manuka honey, a very potent antimicrobial honey, has a positive effect against dental plaque development and gingivitis [112] and can be used instead of refined sugar in the manufacture of candy [109].

According to electron microscope studies the ingestion of honey causes no erosion of tooth enamel as observed after

drinking fruit juice [113]. Ten minutes after consumption of fruit juice tooth erosion was observed, while 30 minutes after honey ingestion the erosion was only very weak. This effect can be explained only partially by the calcium, phosphorous and fluoride levels of honey and other colloidal honey components might also play a role.

Summarising the different findings, it can be concluded that honey is probably not as cariogenic as other sugars and in some cases it can be carioprotective. But to be on the safe side, it is advised to clean the teeth after consumption of honey.

### Gastroenterology

According to the Muslim holy book “The Holy Hadith”, dating back to the 8th century AD prophet Mohamed recommended honey against diarrhoea [114]. Also, the Roman physician Celsus (ca. 25 AD) used honey as a cure for diarrhoea [115]. The application of honey for prevention and treatments of gastrointestinal disorders such as peptic ulcers, gastritis, gastroenteritis has been reported in various books and publications from Eastern Europe [6,7,116–120] and from Arab countries [121]. Honey is a potent inhibitor of the causing agent of peptic ulcers and gastritis, *Helicobacter pylori* [122–124]. In rats honey acted against gastric ulcers experimentally induced by indomethacin and alcohol [125–128]. Honey is not involved in prostaglandin production, but it has a stimulatory effect on the sensory nerves in the stomach that respond to capsaicin [125,129]. A second mechanism of action has been proposed, postulating that this effect is due to the antioxidant properties of honey. Honey intake in rats prevented indomethacin-induced gastric lesions in rats by reducing the ulcer index, microvascular permeability, and myeloperoxidase activity of the stomach [130]. In addition, honey was found to maintain the level of non-protein sulphhydryl compounds (e.g. glutathione) in gastric tissue subjected to factors inducing ulceration [125,129,131,132]. Ingestion of dandelion honey reduced gastric juice acidity by 56% [133]. The gastric emptying of saccharides after ingestion of honey was slower than that after ingestion of a mixture of glucose and fructose [134].

Other important effects of honey on human digestion have been linked to oligosaccharides. These honey constituents have prebiotic effects, similar to that of fructo-oligosaccharides [135,136]. The oligosaccharide panose was the most active oligosaccharide. The oligosaccharides cause an increase of bifidobacteria and lactobacilli and exert the prebiotic effect in a synergistic mode of action [137]. According to an invitro study on five bifidobacteria strains honey has a growth promoting effect similar to that of fructose and glucose oligosaccharides [138]. Unifloral honeys of sour-wood, alfalfa and sage origin stimulated the growth of five human intestinal bifidobacteria [139]. In another study honey increased both in vivo (small and large intestines of rats) and in vitro the building of *Lactobacillus acidophilus* and *Lactobacillus plantarum*, while sucrose had no effect [140]. In clinical studies with infants and children honey shortens the duration of bacterial diarrhoea and



did not prolong the duration of non-bacterial diarrhoea [141]. In certain cases, consumption of relatively large amounts of honey (50 to 100 g) can lead to a mild laxative effect in individuals with insufficient absorption of honey fructose [142,143]. Fructose alone is less readily absorbed in the intestinal tract than fructose together with glucose [144]. The mild laxative properties of honey are used for the treatment of constipation in Eastern Europe [6].

Supplementation of honey in concentrations of 2, 4, 6 and 8 g/100 g protein fed to rats, improved protein and lipid digestibility [145].

### Cardiovascular Health

The effects of ingestion of 75 g of natural honey compared to the same amount of artificial honey (fructose plus glucose) or glucose on plasma glucose, plasma insulin, cholesterol, triglycerides (TG), blood lipids, C-reactive proteins and homocysteine, most of them being risk factors for cardiovascular diseases, were studied in humans [47]. Elevation of insulin and C-reactive protein was significantly higher after glucose intake than after honey consumption. Glucose reduced cholesterol and low-density lipoprotein-cholesterol (LDL-C). Artificial honey slightly decreased cholesterol and LDL-C and elevated TG. Honey reduced cholesterol, LDL-C, and TG and slightly elevated high-density lipoprotein-cholesterol (HDL-C). In patients with hypertriglyceridemia, artificial honey increased TG, while honey decreased TG. In patients with hyperlipidemia, artificial honey increased LDL-C, while honey decreased LDL-C. In diabetic patients, honey compared with dextrose caused a significantly lower rise of plasma glucose [47].

Honey can contain nitric oxide (NO) metabolites which are known indicators for cardiovascular disease risk. Increased levels of nitric oxides in honey might have a protecting function in cardiovascular diseases. Total nitrite concentration in different biological fluids from humans, including saliva, plasma, and urine was measured after ingestion of 80 g of honey [146,147]. Salivary, plasma and urinary NO metabolite concentrations showed a tendency to increase. Different honey types contained various concentrations of NO metabolites, darker or fresh honeys containing more NO metabolites than light or stored honey. After heating, NO metabolites decreased in all honey types.

Compared to fructose-fed rats, honey-fed rats had a higher plasma  $\alpha$ -tocopherol level, and a higher  $\alpha$ -tocopherol/triacylglycerol ratio, as well as lower plasma nitrate levels and lower susceptibility of the heart to lipid peroxidation [56].

### Infants

The application of honey in infant nutrition used to be a common recommendation during the last centuries and there are some interesting observations. Infants on a diet with honey had better blood formation and a higher weight gain than when a diet without honey was applied [148]. Honey was better

tolerated by babies than sucrose [149] and compared to a water based placebo significantly reduced the crying phases of infants [150]. Infants had a higher weight increase when fed by honey than by sucrose, and showed less throw up than the sucrose controls [151]. When infants were fed on honey rather than on sucrose an increase of haemoglobin content, a better skin colour and no digestion problems were encountered [152,153]. Infants on honey diet had a better weight increase and were less susceptible to diseases than infants fed normally or when given blood building agents [148].

The positive effects of honey in infant diet are attributed to effects on the digestion process. One possible cause is the well established effect of oligosaccharides on *B. bifidus* [154], see also section Gastroenterology. When fed on a mixture of honey and milk infants showed a regularly steady weight gain and had an acidophilic micro-organism flora rich in *B. bifidus* [155]. Another experiment with honey and milk showed that infants were suffering less frequently from diarrhoea, and their blood contained more haemoglobin compared to those on a diet based on sucrose sweetened milk [152]. Honey fed infants had an improved calcium uptake, and lighter and thinner faeces [156].

However, there is a health concern for infants regarding the presence of *Clostridium (Cl.) botulinum* in honey. Since the presence of this bacterium in natural foods is ubiquitous and honey is a non sterilized packaged food from natural origin the risk of a low contamination level cannot be excluded. Spores of this bacterium can survive in honey, but they cannot build toxin. Thus, in the stomach of infants younger than one year the bacteria spores from honey can survive and theoretically build the toxin, while children older than 12 months can ingest honey without any risk. In some cases, infant botulism has been attributed to ingestion of honey [157–160]. In Germany one case of infant botulism per year is reported [160]. As a result of the reported infant botulism cases some honey packers (e.g. the British Honey Importers and Packers Association) place a warning on the honey label that “honey should not be given to infants under 12 months of age”. Recently, a scientific committee of the EU examined the hazard of *Cl. botulinum* in honey [161]. It has concluded that microbiological examinations of honey are necessary for controlling the spore concentration in honey, as the incidence of *Cl. botulinum* is relatively low and sporadic and as such tests will not prevent infant botulism. In the EU countries the health authorities have not issued a regulation for placing a warning label on honey jars.

### Athletic Performance

The physiological action of gel and powdered forms of honey as a carbohydrate source for athlete performance was studied recently under controlled conditions by Kreider and coworkers [162–165]. Honey increased significantly the heart frequency and the blood glucose level during the performance [162]. It did not promote physical or psychological signs of hypoglycaemia in fasted athletes [163], or during resistance

training [164]. In another trial the effect of low and high GI carbohydrate gels and honey were tested on a 64 km cycling performance [162,165]. Both high (glucose) and low GI (honey) gels increased cycling performance and the effect of honey was slightly better than the one of glucose. According to the above studies honey is well tolerated and can be an effective carbohydrate source for athletic performance.

### Different Health Enhancing Effects

A positive effect of honey on hepatitis A patients was found after ingestion of clover and rape honey, causing a decrease of the alanine aminotransferase activity (by 9 to 13 times) and a decrease of bilirubin production by 2.1 to 2.6 times [133]. Honey has a supportive effect on patients who have undergone a cancer radiation therapy by reducing the incidence of radiation mucositis. Patients with head and neck cancer treated with radiation therapy were given honey. There was a significant reduction in the symptomatic grade 3/4 mucositis among honey-treated patients compared to the controls; i.e. 20% versus 75%. The compliance of the honey-treated group of patients was better than the controls. 55% of the patients treated with honey showed no change or a positive gain in body weight compared to the controls, the majority of which lost weight [166]. Honey was administered to chemotherapy patients with neutropenia and was found to reduce the need for colony-stimulating factors [167]. Febrile neutropenia is a serious side effect of chemotherapy.

### Allergy

Honey allergy seems relatively uncommon; allergies reported can involve reactions varying from cough to anaphylaxis [145]. In this study it was reported that patients allergic to pollen are rarely allergic to honey, although there is one reported case of combined honey pollen allergy [168]. The incidence of honey allergy, reported in a group of 173 food allergy patients was 2.3% [cited in 169]. In this study the honey allergy is explained by the presence of components of bee origin.

### CONCLUSION

Due to variation of botanical origin honey differs in appearance, sensory perception and composition. It contains mainly carbohydrates. The glycemic index of honey varies from 32 to 87, depending on botanical origin and on fructose content. The main nutrition- and health relevant components are the carbohydrates, which make it an excellent energy source especially for children and sportsmen. Besides its main components, the carbohydrates fructose and glucose, honey contains also a great number of other constituents in small and trace amounts, producing numerous nutritional and biological effects: antimicrobial, antioxidant, antiviral, antiparasitic, antiinflammatory, antimutagenic, anticancer and immunosuppressive activities.

Different nutritional studies have confirmed various effects after honey ingestion, e.g. enhanced gastroenterological and cardiovascular health. Besides, honey showed physiological effects on blood health indicators as well as effects on hepatitis A and radiation mucositis patients. However, it should be pointed out that most of the studies in humans were based on relatively high honey intakes of 50 to 80 g. Honey compositions, and also its different biological effects, depend to a great extent on the botanical origin of honey. This fact was often not considered in the reviewed studies.

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