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Boletín de Ciencias Agropecuarias del ICAP

Publicación semestral, Vol. 10, No. 20 (2024) 01-09

ICAP
ISSN: 2448-5357

Una breve revisión de la composición y valor nutracéutico de la miel de *Apis mellifera*

A brief review of *Apis mellifera* honey composition and nutraceutical value

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Abstract:

Honey, a natural substance produced by bees from flower nectar or insect secretions, has been used for millennia for its medicinal and culinary properties. This review explores honey's composition, properties, and potential health benefits. Honey primarily comprises sugars, water, and various substances such as enzymes, amino acids, organic acids, vitamins, minerals, pigments, phenolic compounds, and volatile compounds. Its composition varies based on plant source, bee species, and environmental conditions. The carbohydrates in honey, mainly fructose and glucose, comprise around 80% of its content, with smaller oligosaccharides. Honey also contains enzymes (such as invertase and diastase), which play roles in sugar breakdown and are used as quality indicators. Honey also contains organic acids, minerals (like potassium and calcium), and vitamins such as C and B complex. Phenolic compounds and flavonoids contribute to honey's antioxidant, anti-inflammatory, and antimicrobial properties. More than five hundred aromatic compounds are responsible for their distinct aroma and flavor. The diverse composition of honey gives it a range of biological activities, including antioxidant, antibacterial, antifungal, antihypertensive, antitumor, anti-inflammatory, antidiabetic, and hepato-protective effects. Despite its nutritional value and health benefits, consumption of honey should be moderate due to its high sugar content. Further research is needed to fully understand honey's mechanisms and potential therapeutic applications in various health conditions

Keywords:

Bioactive compounds, antioxidant activity, proximal composition, biological activity

Resumen:

La miel, una sustancia natural producida por las abejas a partir del néctar de las flores o de las secreciones de insectos, se ha utilizado durante milenios por sus propiedades medicinales y culinarias. Esta revisión explora la composición, las propiedades y los posibles beneficios para la salud de la miel. La miel se compone principalmente de azúcares, agua y diversas sustancias como enzimas, aminoácidos, ácidos orgánicos, vitaminas, minerales, pigmentos, compuestos fenólicos y compuestos volátiles. Su composición varía según factores como la fuente vegetal, la especie de abeja y las condiciones ambientales. Los carbohidratos de la miel, principalmente fructosa y glucosa, constituyen alrededor del 80% de su contenido, con cantidades menores de oligosacáridos. La miel también contiene enzimas como la invertasa y la diastasa, que desempeñan un papel en la descomposición del azúcar y se utilizan como indicadores de calidad. Además, la miel contiene ácidos orgánicos, minerales como el potasio y el calcio, y vitaminas como la vitamina C y las vitaminas del complejo B. Los compuestos fenólicos, incluidos los flavonoides, contribuyen a las propiedades antioxidantes, antiinflamatorias y antimicrobianas de la miel. Más de 500 compuestos aromáticos son responsables de su distintivo aroma y sabor. La composición diversa de la miel le otorga una variedad de actividades biológicas, que incluyen efectos antioxidantes, antibacterianos, antifúngicos, antihipertensivos, antitumorales, antiinflamatorios, antidiabéticos y hepatoprotectores. A pesar de su valor nutricional y beneficios para la salud, el consumo de miel debe ser moderado debido a su alto contenido en azúcar. Se necesita más investigación para comprender completamente los mecanismos y las posibles aplicaciones terapéuticas de la miel en diversas condiciones de salud.

***Palabras clave**:*

Compuestos bioactivos, actividad antioxidante, composición proximal, actividad biológica

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Fecha de recepción: 26/04/2024, Fecha de aceptación: 08/05/2024, Fecha de publicación: 05/07/2024

DOI: https://doi.org/10.29057/icap.v10i20.12886

1. Introduction

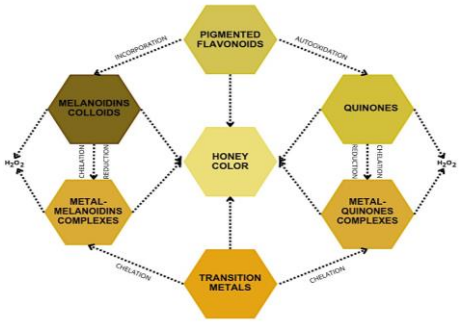
The use of honey dates to prehistoric times; the first reference appears in a Sumerian table dating from 2100 - 2000 BC, in which honey is used as a medicine and an ointment [1, 2]. Our ancestors consumed honey by collecting it from hives and smoked the hives to scare away the bees and extract the honey [3, 4].

Due to the consumption of honey as part of the human diet, beekeeping is developed, an activity dedicated to breeding and caring for bees to obtain products such as honey, royal jelly, propolis, wax, and pollen [5]. In Mexico, beekeeping is an ancient activity of the livestock subsector. It has acquired great socioeconomic importance since it represents a significant source of jobs, generating up to 100 100,000 jobs and income in rural areas and foreign exchange for the country [6]. In Mexico, more than fifty-seven tons of honey are produced yearly; Yucatán is the leading producer, with approximately eight thousand tons yearly [7].

2. Honey

Honey is a sweet natural substance that bees produce [8]. Currently, two types of honey are produced worldwide: traditional honey from *Apis mellifera* and honey from stingless bees [9]. Bees produce honey from the nectar of flowers from the secretions of the living parts of plants or from the excretions of sucking insects, present in the living parts of plants (honeydew honey) that bees collect and transform by combining them with their specific substances, deposit, dehydrate, store and leave in hives to mature [10, 11].

Figure 1. Compounds and reactions that influence the colors of honey.



Modified from Perna et. al (2013) [65].

The color of honey can range from colorless to dark brown. Its consistency can be fluid or viscous in terms of flavor and aroma; these vary according to the plant of origin [12-14]. Honey is considered a functional food since various studies demonstrate the health benefits of honey [8, 9, 15].

3. Honey composition

Honey is a very complex biological product, so its chemical composition varies due to several factors such as the nature of the soil, climate, geographical area, harvested species, breed of the bee and the physiological state of the colony [8, 16, 17]. Honey is mainly composed of approximately 80% sugars (mainly glucose and fructose) and other constituents [18, 19] such as 17% water and 3% of various substances such as enzymes, amino acids, organic acids, vitamins, minerals, pigments, phenolic compounds, volatile compounds and solid particles derived from the honey harvest [20]. Phenolic compounds have been shown to have many flavonoids and phenolic acids, which exhibit a wide range of biological effects demonstrated in previous studies [21, 22].

4. Carbohydrates

Honey is a naturally sweet food because it mainly comprises carbohydrates which ranges 60 to 95% of the dry weight [20, 23]. Carbohydrates comprise Monosaccharides (70%), disaccharides (9%), trisaccharides, and other oligosaccharides (1.5%) can be identified, and the floral type is a critical factor in modulating this proportion [24].

Monosaccharides are usually present in an average percentage of 38% for fructose and 31% for glucose, although there may be exceptions [25]. As honey ages, monosaccharides decrease, and oligosaccharides increase. Over time, fructose degrades to become hydroxymethylfurfural or can form oligosaccharides [26]. The available disaccharides are maltose (7%), sucrose (1-3%), trehalose (<2.5%), isomaltose (0.5-1.5%), turanose (0.5-1.5 %), nigerosa (0.2-1%), melibose (<0.5%), palatinose (<0.3%), kojibiose, gentibiosa, maltulose and laminaribiosa, among others [9, 27]. Trisaccharides and other oligosaccharides were mainly found: melecytose (<5%), erlose (<3.5%),

raffinose (<1%), 1-cestose, theanderose, maltotriose, panose, isopanose, 6-glucosylsucrose, 3- isomaltosylglucose, isomaltotriose, isomaltotetralose, isomaltopentose and arabinogalactomannan [19, 28, 29].To ensure the authenticity of the honey, it must have a fructose and glucose content equal to or greater than 60%, and the sucrose content should not be more significant than 5% [19, 30].

Table 1. Proximal composition of the honey

Compound	Value
Fructose	38.20%
Glucose	32.00%
Saccharose	1.38%
Maltose	6.80%
Other sugars	3.10%
Humidity	17.20%
pH	3.91
Free Acidity	22.03 meq/Kg
Lactone	7.11 meq/Kg
Acidity Total	29.12 meq/Kg
Mineral content	0.17%
Total Nitrogen	0.04%
Index of Diastase	20.8

Modified from Ball, 2007 [31].

5. Water

Water is the second component of honey, and its content is related to botanical, climatic, and edaphic factors, as well as the degree of maturity (time of extraction). The usual values range from 17-18% [20], but they can also be found between 14-25%. Honey tends to absorb water when the environmental relative humidity is equal to or greater than 60%. However, a high-water content can cause fermentation and favor the development of chemical browning, which is why maximum values of 20% are established [32, 33].

6. Nitrogenous compounds

The nitrogen content in honey ranges between 0.03 and 0.13%. The main constituents are free amino acids and enzymes, the primary source being pollen [9]. Proteins come from insects and plants with 0.2%. Insects provide enzymes, such as invertase, diastase (amylase), and glucose oxidase, as well as plants, such as alkaline phosphatase and catalase [34]

Invertase participates in the degradation of sucrose into glucose; however, in the final stage of honey ripening, a small amount of sucrose remains present [31]. Diastase is characterized by breaking the chemical bonds of maltose, it is used as an indicator of honey quality, where the quality of honey is positively proportional to the amount of diastase [35, 36].

Glucose oxidase comes from the pharyngeal glands of the bee, and its quantity is varied. The hydrogen peroxide produced after the action of glucose oxidase on glucose contributes to the antibacterial action of honey. These enzymes' presence in honey differentiates it from other sweeteners [31]. The content of free amino acids is 0.01%; one of those identified is proline, which can have a presence of 30-80% [9] 0.3-25 mg/kg of choline, 0.06- 5 mg/kg of acetylcholine and in smaller quantities are asparagine, phenylalanine, aspartic acid, glycine and serine [35].

7. Organic acids

Approximately twenty organic acids have been found, representing 0.6%, highlighting acetic, citric, lactic, malic, oxalic, succinic, formic, and butyric acids, with gluconic acid being the majority [9]. All acids contribute to the pH of honey, which is 3.3-4.6 for floral honey and 5.5 for honeydew honey. Acids, together with carbohydrates and hydrogen peroxide, contribute to the microbiological stability of honey, as well as have a considerable impact on the conservation, stability, and sensoriality (flavor and aroma) and physicochemical properties (acidity and pH) of honey [20]. A high acid value indicates alteration due to fermentation, so the maximum value is 50mEq of acids/kg of honey [37].

8. Minerals

The amount of minerals in honey ranges from 0.05 to 1.5%; this percentage is influenced by botanical origin, climate, and extraction techniques. Potassium is the majority element, followed by calcium, magnesium, and sodium [20]. Zinc, iron, manganese, copper, chromium, selenium, aluminum, iodine, chlorine, and fluorine are found in smaller quantities [19].

Table 2. Mineral average content of *Apis mellifera* honey

Mineral	Average (ppm)	Range (ppm)
Potassium	205	100–588
Sulfur	58	036–108
Chlorine	52	23–75
Calcium	49	23–68
Match	35	23–50
Magnesium	19	11–56
Sodium	18	06–35
Iron	2.4	1.2–4.8
Copper	0.3	0.14–0.70
Manganese	0.3	0.17–0.44

Modified from Ball, 2007 [31].

9. Vitamins

Vitamins are a group of organic compounds that participate in metabolism, growth, and development and regulate cellular functions. They are required in small amounts to form coenzymes and cofactors [38]. The predominant vitamin in honey is vitamin C (0.5-2.5mg/100g) [39]. Some studies indicate that vitamin C in honey has antioxidant effects because it can reduce oxidation caused by oxygen ion superoxide. Honey also contains B complex vitamins such as thiamine (<0.01mg/100g), pyridoxine (<0.03mg/100g), riboflavin (<0.02 mg/100g), niacin (<0.2 mg/100g), pantothenic acid (<0.1 mg/100g) and folic acid (<0.01 mg/100g) 021) [38, 40].

10. Lipids

Fatty acids, such as palmitic, oleic, lauric, stearic, and linoleic, are in small quantities in honey. They come from micro wax particles that, being so small, cannot be eliminated [41].

11. Aromatic compounds

More than five hundred compounds responsible for the aroma and flavor of honey have been identified [42, 43], such as esters of aliphatic acids (methyl formate, methyl and ethyl acetate, ethyl laurate) and aromatic acids (benzoate), methyl and ethyl, methyl and ethyl phenylacetate), aldehydes (formaldehyde, acetaldehyde, 2-phenylacetaldehyde), ketones (methyl ketone and ethyl ketone), and alcohols (methanol, ethanol, 2-phenyl ethanol). Aromatic compounds average concentration is 0.020 -2 mg/kg [20, 44, 45].

12. Phenolic compounds

The presence of polyphenols in honey is believed to come from plant nectar. In contrast, the quality and quantity of polyphenols depend on the geographical region, floral source, climatic conditions, and type of bee [9, 46, 47].

Phenolic compounds can be classified into simple phenolic compounds (they only have one phenol in their structure) and polyphenolic compounds (they contain several rings in their structure) [48]. Flavonoids have also been identified in honey, polyphenolic compounds with two phenolic rings joined by a propane bridge; their content is variable (20-2000 µg/100g). They come from nectar, pollen, and propolis. They are found naturally in many parts of plants [38], 4-hydroxybenzoic acid, p—coumaric acid, pinocembrin, quercetin, galangin, chrysin, kaempferol, and pinobanksin have been identified [46, 49]. They are responsible for the color and other products from non-browning enzymatic reactions. They are characterized by having antiseptic activity and anti-inflammatory and antioxidant properties [38].

Honey from different regions of the world contains similar types of phenolic acids, including gallic acid, syringic acid, benzoic acid, cinnamic acid, [8], caffeic, ellagic, ferulic, and p- coumaric acids; and antioxidants, such as tocopherols, ascorbic acid, superoxide dismutase (SOD), catalase (CAT), and reduced glutathione (GSH) [50]. The main therapeutic activities of honey are attributed to its polyphenol content because they are the most abundant phytochemicals [9].

13. Biological activity of honey

Honey has multiple biological benefits, among which we can highlight its antioxidant capacity through the capture of free radicals through the action of phenolic compounds [51-53]. Various studies show that honey has an antibacterial capacity [54, 55]; Ruiz-Ruiz et al., 2017 [2, 56], antifungal [57, 58] antihypertensive, antioxidant, [8] antitumor, anti-inflammatory, [52, 59] antidiabetic, anticancer using cell lines [15, 60, 61]. These functions are attributed to physicochemical factors such as high osmotic pressure caused by sugar concentration, low pH, hydrogen peroxide, and water activity [54]. Zhu 2020 [62], demonstrated antidiabetic activity by inhibiting α-amylase and α-glucosidase using phenols and flavonoids.

Gharzouli et al. 2002 [63] demonstrated gastroprotective activity by providing honey to rats with stomach ulcer damage, obtaining favorable results. A later study [64] demonstrated honey's hepatoprotective capacity.

Table 3. Vitamin C average content of *Apis mellifera* honey from different plant crops.

Honey	Vitamin C content
Chesnut	3.92 ± 0.17^{a}
Eucalyptus	3.83 ± 0.19^{a}
Multifloral	5.38 ± 0.51^{b}
Citrus	2.68 ± 0.14^{c}
Sulla	3.57 ± 0.21^{ac}
Average	3.89±0.29

Modified from Perna et. al (2013) [65].

13.1 Antioxidant activity

Antioxidants are agents for countering the deterioration caused by oxidants such as O_2, OH-, radicals, superoxides, and lipid pyroxyl. Chronic and degenerative diseases, such as cancer, synthesis of mutagens, aging, and atherosclerosis, are persistent and susceptible to oxidative stress, so the cells exhibit a defense system against oxidative damage [66]. This defense system consists of radical-free agents, agent protectors, and oxidative agents such as catalase, peroxidase, ascorbic acid, tocopherol, and polyphenols. These antioxidant agents stimulate biomolecules such as carbohydrates, proteins, lipids, and nucleic acids, which the cells HE alters by this stimulation, ultimately triggering an antioxidant response [66].

Honey exhibits strong antioxidant activity. Phenolic acids are responsible for the antioxidant activity of honey. However, sugars, proteins, amino acids, carotenes, organic acids, Maillard reaction products, reactive oxygen species (ROS) production, and other minor components could contribute to the antioxidant action [60, 67]. It was established that honey increased the amount and activity of antioxidant agents such as beta carotene, vitamin C, glutathione reductase, and uric acid in healthy human subjects [66, 68].

13.2 Antidiabetic activity

Type 2 diabetes consists of progressive hyperglycemia, insulin resistance, and β-insufficiency of the cells, which can result in the toxicity of glucose, cytokines inflammatory, and stress oxidative, and is responsible for 90-95% of all cases of diabetes [69]. In this syndrome, there are many abnormalities of lipoprotein metabolism, and carbohydrates are involved with a level of elevated glucose. The complications of this disorder can include hyperosmolar ketoacidosis, diabetes, and a hyperglycemic state, which can lead to death [70].

In studies carried out in vivo, it has been shown that honey has antidiabetic components, antioxidants, and a hypoglycemic effect, which was observed to reduce glucose levels in type 2 diabetes mellitus. This antidiabetic or hypoglycemic agent of honey is attributed to fructose since it helps regulate the

response system to insulin, resulting in a controlled blood glucose level [71]. The hydrolysis of carbohydrates forms monosaccharides such as glucose, fructose, and galactose before their absorption. Some studies have suggested that fructose is taken up by the two receptors GLUT5 and/or GLUT2 through proteins [72].

The hypoglycemic fructose in life can also regulate glucose levels; in this, fructose stimulates the phosphorylation enzymes, such as glucosidase, which triggers the phosphorylation of the glucose hepatic and inhibits enzymes, inhibiting glycogenolysis [73]. Therefore, fructose regulates glycogen and glucose metabolism, demonstrating its vital regulatory role in controlling hyperglycemia.

A study observed that the effect of honey may be due to the modulation of the insulin signaling pathway [74] since this is a crucial component. It is known to modulate the functions of several substrates that regulate the progression of the cell cycle, cell survival, and cell growth. The effect of the extracts of honey on the via of signaling of the insulin activated by Akta has been investigated, and it was observed that elevated levels of NF characterized the development of insulin resistance- κ Serine B, MAPK, and substrate1 phosphorylation [66, 74]

14. Conclusion

Honey is an essentially energetic food (304 kcal /100g). Its sweetening power is 1.2 to 1.3 times greater than sucrose's; the same number of grams provides greater sweetness. Its glycemic index is variable according to the type of honey and the glucose/fructose content. Its protein content is shallow, predominantly proline, a non-essential amino acid. The mineral and vitamin content are low. Therefore, even in large quantities, honey only covers a small proportion of the essential nutrients. However, unlike other sweeteners, honey contains phytochemicals that give it additional value; most are enzymatic (catalase, peroxidase, diastase, invertase, and glucose oxidase) and chemical (phenolic acids and flavonoids) antioxidants.

From a nutritional point of view, it is crucial to inform people about the consumption of large amounts of honey and its possible health risks due to its high carbohydrate content. However, the ancient use of honey and recent discoveries of biological compounds in honey support research into its effect on oxidative stress, wound healing, aging, inflammation, cancer, diabetes, bacterial growth, and atherosclerosis. Despite growing evidence of honey's healthy roles, precautions are still required for its consumption.

Acknowledgment

To project 321293, financed by CONAHCyT, entitled: “Strengthening of fair production-consumption circuits of native beehive products” (“Fortalecimiento de los circuitos justos de producción-consumo de los productos de la colmena de las abejas nativas”)

Conflict of interests

The authors have no conflict of interest.

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