Animal and Veterinary Sciences
2024; 12(1): 11-18
http://www.sciencepublishinggroup.com/j/avs
doi: 10.11648/j.avs.20241201.12
ISSN: 2328-5842 (Print); ISSN: 2328-5850 (Online)

Honey Physiochemical Properties and Factors Associated with Honey Quality in Ethiopia: A Review

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To cite this article:
Abebe Melese Tirfie. (2024). Honey Physiochemical Properties and Factors Associated with Honey Quality in Ethiopia: A Review. *Animal and Veterinary Sciences*, *12*(1), 11-18. https://doi.org/10.11648/j.avs.20241201.12

Received: December 13, 2023; **Accepted**: January 2, 2024; **Published**: January 18, 2024

Abstract: Honey is a naturally sweet material made by honey bees from plant nectar or secretions. The bees gather the nectar or secretions, change it by mixing it with other components, deposit, dehydrate, store, and then leave it in the honey comb to ripen and mature. Honey contains 80–85% carbohydrates, 15–17% water, 0.3% proteins, 0.2% ashes, small amounts of amino acids, vitamins, and other components in low concentrations. However, this component fluctuates depending on the impurities that affect the honey's quality. Thus, the current review aimed to provide information on physiochemical properties of honey and the factors that affect honey physiochemical properties. Obtaining premium honey and other bee products is the ultimate aim of beekeeping. However, factors like a lack of improved bee hive technology, chemical application, honey bee disease, predators, pests, honey harvesting and processing methods, honey adulteration, toxic plants, and intensifying farming practices are the main ones that negatively affect the quality and composition/physiochemical properties of honey. In addition to these difficulties, the physiochemical characteristics of honey deviate from those established by the Condex Alimentariuse Commissions, Ethiopian Apiculture Board, and European Union. The government and non-governmental organizations should therefore provide training on the challenges of honey production related to honey's physiochemical properties to all beekeepers and other stakeholders who participate in the beekeeping sector directly or indirectly in order to mitigate the problem of honey quality reduction.

Keywords: Adulteration, Agrochemical, Honey, Toxic Plants, Quality Parameter

1. Introduction

Ethiopia's economy is still based on agriculture, which is also the country's main driver of growth. It contributes to over 48% of the country's GDP growth, 85% of export revenue, and the primary source of income, livelihood, and way of life for 85% of Ethiopians who reside in rural areas [1]. Up to 20% of Ethiopia's Economy and 60–70% of the population's means of subsistence come from livestock, according to the Central Statistics Agency [2].

Honey is the natural sweet substance produced by honey bees from the nectar of plants or from secretions of living parts of plants or excretions of plant sucking insects on the living parts of plants, which the bees collect, transform by combining with specific substances of their own, deposit, dehydrate, store and leave in the honey comb to ripen and mature [3]. Beekeeping, which is one of the important livestock subsectors, contributes significantly to the improvement of the livelihoods of the nation's population [4].

In Ethiopia, beekeeping has a long history as a form of agriculture. It contributes significantly to the agricultural economy of the nation and represents 1.3% of agricultural GDP [5]. Apiculture is a business activity that does not affect the environment and is not a farm activity. It can help a society's economy flourish specifically as well as the economy of a country as a whole. The industry provides an environmentally friendly pastime that can aid in reducing poverty and preserving natural biodiversity in poor nations [6].

The number of bees in the nation is the highest in all of Africa. Almost 10 million bee colonies exist, of which 7.5 million are housed in hives and the remaining two million are found in forests [6]. As a result, the nation ranks third in the world for beeswax production and is one of the top producers of honey. Around 2.5% of the worlds and 21.7% of Africa's honey production comes from Ethiopia [6]. In Ethiopia,

beekeeping is regarded as a revenue-generating activity that complements the idea of small-scale agricultural development [7]. Also, it is environmentally benign, doesn't compete for limited land resources, and offers opportunities for off-farm jobs and revenue generation [8].

Honey has a content of 80-85% carbohydrates, 15-17% water, 0.3% proteins, 0.2% ashes, and minor quantities of amino-acids and vitamins as well as other components in low levels of concentration [9]. The physicochemical examination of honey holds significance in the global trade due to its increasing usage in a wide range of culinary products. The nutritional value and non-nutrient functions of honey (sweetness, humectancy, viscosity, flavour enhancement, colour, hygroscopicity, miscibility, and spreadability) are what motivate the widespread usage of honey as a food ingredient. [10].

These days, the quality of bee products, especially honey, has decreased worldwide, especially in developing nations, as a result of unlawful practices and other processes. The physiochemical characteristics of honey and other bee products are being significantly impacted by this illegal behaviour. Several reports from various parts of the nation have at every step corroborated this. The purpose of this review paper is to address the following goal.

1. To review factors influencing honey physiochemical properties.
2. To review honey physiochemical properties.

2. Honey Production Potential in Ethiopia

Ethiopia has potential for beekeeping because the country's climate encourages the growth of a variety of plants and agricultural products that provide honeybees with a good supply of nectar and pollen. It is favorable for the beekeeping industry thanks to its abundant and diversified plant resources and favorable climatic conditions [11]. The nation has the capacity to produce more than 500,000 tons of honey annually, and its current yearly production of both honey and beeswax is insufficient compared to this capacity [12, 13].

Ethiopia has a large number of beehive colonies and a variety of sources for honey, yet the country produces significantly less honey than it could. This might be because the country's various agro-ecologies have not yet been described, and the apiculture industry has not gotten much attention in terms of research and development [14]. Ethiopian annual honey production was estimated about 500,000 metric tons which is shared with about 23.5% and 2.35% of African and world's honey production, respectively [15]. The beekeepers in particular and the country in general are not benefiting from the sub sector [16]. Research revealed that the number of beehive colonies in the nation has been decreasing, which has caused the production of honey and beeswax as well as export revenues to decrease [5]. This is ascribed to drought, population pressure from an ever-growing population and the resulting changes in vegetation, as well as the excessive use of pesticides. In addition, relative to the potential of the nation, the items produced in this subsector are nevertheless subpar, poorly run, and unappealing in appearance. Due to this, natural honey imported from Egypt, France, the United Kingdom, Italy, the United Arab Emirates, China, and Corea has taken its position on the local market [17]. The type of hives used the methods of removing and storage of honey play a vital role in the quality of honey [18, 19].

3. Physiochemical Properties of Honey

The chemical composition of honey refers to the chemical constituents that are responsible for the biological activities of bee's honey such as the proteins, phenols, flavonoids, and vitamins [20]. There are four physical states of honey: liquid, viscous, partially crystallized, and entirely crystallized [21]. The composition and quality of honey are greatly influenced by geographical and environmental factors [22]. The quality and properties of honey are related to honey maturity, the production methods, climatic conditions, processing and storage conditions as well as nectar sources of the honey [23]. However, quality and composition of honey are negatively affected by factors such as overfeeding sucrose and sucrose variants, harvesting prior to maturity, and inappropriate storage conditions [23]. The type of hive used and the methods of collection and storage of honey play a vital role in determining the quality of honey [24].

The physicochemical composition, flavour and colour of honey vary due to climate, soil, flora, bee species and production methods. The precise composition variation depending on the plant species on which bee forages are the main constituents. The physicochemical properties of honey are important for determines the quality of the honey [25]. The physicochemical properties of honey are the quality parameters which include the pH, acidity, moisture, electrical conductivity, ash content, total dissolved solids (TDS), hydroxymethylfurfural (HMF), sugar content (total glucose, fructose, and sucrose), and enzyme activity (diastase and invertase [26].

Table 1. *Physicochemical properties of honey at national and international standards.*

no	Variable	Unit	CAC	EU	QSAE
1	Moisture content (%)	g/100g	<21	<21	Grade A 17.5-19 Grade B 19.1-20 Grade C 20.1-21
2	Reducing sugars (%)	g/100g	≥ 65	≥ 65	Minimum 65
3	Sucrose (%)	g/100g	≤ 5	≤ 5	Maximum 10
4	Water-insoluble solids (%)	g/100g	≤ 0.1	≤ 0.1	Maximum 0.1
5	Ash (%)	g/100g	≤ 0.6	≤ 0.6	Maximum 0.6
6	Free acid (%)	meqkg-1	≤ 50	≤ 40	Maximum 40

no	Variable	Unit	CAC	EU	QSAE
7	pH	-	-	-	3.91
8	Hydroxymethylfurfural content (%)	mg/kg	≤ 60 mg/kg	≤ 40 mg/kg	-

CAC = Codex Alimentarius Commission; EU = European Union; meq = milliequivalent; QSEA = Quality and Standards Authority of Ethiopia. Source = CAC (2001); QSAE (2009); EU Council (2002)

3.1. Moisture Content

The moisture content of honey is related to its degree of fermentation. Moisture is an important constituent of honey, and it affects various properties honey like density, specific gravity, refractive index, viscosity and optical properties [27]. Moisture content is one of the important parameter to be considered in the quality of honey. Honey is an excellent hygroscopic product and has tendency to absorb atmospheric moisture and thus readily increase its moisture levels. Harvesting period, weather, amount of humidity inside the hive, nectar conditions, method of analysis in the laboratory used and treatment during storage and extraction can influence moisture content of honey. Low moisture content is important to protect honey from the attack of microorganisms, and it increases shelf life. On the other hand, if the moisture content of honey is high, it is more likely that the honey will ferment upon storage due to high levels of microorganism [28]. In Ethiopia, The maximum and the minimum acceptable limit for moisture content of Ethiopian honey is 23%, 17.5% respectively [29]. While the maximum acceptable moisture content of honey by the International Honey Commission is 20% [10].

In Ethiopia, research conduct in amhara regional state in and around gonder zuria woreda the overall mean moisture content of honey was 14.41±0.13% [30], In Bale Natural Forest, South-eastern Ethiopia 18.80±0.36% [31], homesha district of western Ethiopia 16.4 ± 1.07% [32], study conduct in amhara and tigray regions the honey moisture content reported was as Burie 19.09 ± 0.43%, Geregera 17.52 ± 0.43%, Liben 19.83 ± 0.43%, Axum 16.34 ± 0.26%, Debre Tembien 17.34 ± 0.22%, Raya Azebo 18.44 ± 0.54% [33], 18.5% a research report conducted in Gomma Woreda of South Western Ethiopia [34].

3.2. Sugar Content

In honey, both sugar and water content is estimated to be 95 - 99%. Fructose, glucose, maltose, raffinose and sucrose are the main sugers in honey. The main reducing sugars of honey are glucose and fructose which account 65-75% of the total sugars [35]. Glucose determines the speed of honey crystallization while fructose determines the level of hygroscopic features of honey [36]. Reducing sugar in honey attributes to predetermine stages of honey ripeness nectar sources in different geographical locations [20], and also it attributes to determine the sugar composition of honey [35].

In Ethiopia, studies were conducted in amhara and tigray regions the honey reducing sugars content was reported as Axum 66.37 ± 0.24%, D/Tembien 66.03 ± 0.56%, R/Azebo 64.30 ± 0.78%, Burie 64.93 ± 0.38%, Geregera 65.89 ± 0.20%, Liben 62.10 ± 0.48% ([33]. In Bale Natural Forest, South-eastern Ethiopia the overall reducing sugar was reported as 66.41±0.57% [31]. Homesha district of western Ethiopia, 65 ± 3.02% [32], In Bale Natural Forest, South-eastern Ethiopia honey reducing sugar reported as 66.41±0.57% [31], at Gomma Woreda, South Western Ethiopia reported as 67.9% [34].

3.3. Honey Ph

The pH level affects the keeping of honey quality as it influences its texture, stability and shelf-life [37]. If there is a low pH (high acidic), it can inhibit the presence and growth of micro-organisms, and it can extend shelf-life. It also makes good taste for consumption. This type of honey would be more compatible with many food products for consumption in domestic and national markets [34]. Due to the presence of gluconic acid, formic acid, oxalic acid and lactic acid honey is acidic in nature [38]. However, excessive acidity of honey is not recommended as it leads to sour, off-taste and running texture [39].

A research conducted in Gomma Woreda of South Western Ethiopia, the ph of honey was reported as 3.20[34], in amhara region, gonder zuria woreda, the overall mean of honey was reported as 4.22±0.02 [30]. Studies were conducted in amhara and tigray regions the honey ph content in different place was reported as Axum 3.85 ± 0.01, D/Tembien 4.00 ± 0.08, R/Azebo 3.79 ± 0.04, Burie 4.20 ± 0.01, Geregera 3.91 ± 0.01, Liben 3.89 ± 0.05 [33]. In Bale Natural Forest, South-eastern Ethiopia the values of honey ph was reported as 3.75±0.06 [31] and honey pH of 4.02 ± 0.26 at homesha district of western Ethiopia [32].

3.4. Hydroxymethylfurfural (HMF)

Hydroxymethylfurfural (MF) is considered as one quality parameter in evaluating honey freshness and honey deterioration and it is a good indicator of honey quality [40]. HMF is a six-carbon heterocyclic organic compound containing both aldehyde and alcohol (hydroxymethyl) functional groups. HMF is a cyclic aldehyde produced by sugar degradation through the Maillard reaction (a non-enzymatic browning reaction) during food processing or long storage of honey [41-43]. HMF concentration is widely recognized as a parameter affecting honey freshness because it is typically absent (or is present in only very small amounts in fresh honeys), while its concentration tends to rise during processing and/or because of aging. Honey stored at low temperatures and/or under fresh condition HMF concentrations, while aged and/or honey stored at comparatively higher or medium temperature has high HMF concentrations. In addition to storage conditions, the use of metallic containers and honey floral sources are critical factors affecting HMF levels. Higher HMF concentration is indicative of poor storage conditions and/or excess heating of honey [44].

In Ethiopia, studies were conducted in oromia regions at bale Harenna forest the HMF contents of honey was reported as 0.71 ± 0.03mg/kg and 0.68 ± 0.04mg/kg from traditional hive and modern/fram hive respectively [45]. In amhara regional state in and around gonder zuria woreda the overall mean HMF contents of honey was 23.27±0.56mg/kg [30] and 1.8 ± 0.24mg/kg at homesha district of western Ethiopia [32].

3.5. Ash

Ash (minerals) content of honey can be influenced by different factors such as floral origin, type and physiology of each plant, differences in soil types, atmospheric conditions, the substances gathered by the bees during foraging [46]. Mineral content in honey can also play a vital role in determining the colour, nutritional value, aroma, flavour, medicinal value and in keeping qualities of honey. Mixing of floral honey and honeydew honey can result in higher values of mineral content [47].

In Ethiopia, studies were conducted in amhara and tigray regions the ash contents of honey was reported as Axum 0.18± 0.01%, D/Tembien 0.08 ± 0.00%, R/Azebo 0.10± 0.00%, Burie 0.45 ± 0.03%, Geregera 0.13 ± 0.01%, Liben 0.28 ± 0.02% [33]. In oromia region homesha district of western Ethiopia 0.17 ± 0.07% [32], bale 0.21±0.007% [31], 0.34±0.05% in Godere Woreda Gambella [48].

4. Factor Affecting Physiochemical Properties of Honey in Ethiopia

In addition to its organoleptic qualities (flavor, consistency, and color), honey's chemical composition, particularly its moisture and HMF content, the diastase index, pH, acidity, as well as the amount and proportion of carbohydrates, is used in the international honey trade as a quality indicator (sugars). A sample of honey's quality can be determined by the concentration of these indications in the sample [49].

4.1. Beehive Technology/Beekeeping Equipment's

According to [50] beekeeping is the maintenance of honey bee colonies, commonly in hives, by humans. There are many types of bee hives commonly used by bee keepers throughout the world for honey production. They are all categorized as modern and traditional bee hives [50, 51]. Low-technology hives can be kept near home and honey harvest from these hive contaminated with break wax, smoke, cloth and grasses of hives warped/covered. Modern hives the combs can be lifted from the hive and then replaced and this allows the beekeeper to examine the condition of the colony without harming it. Honeycombs can also be removed from the hive for harvesting without disturbing combs containing brood. The colony is therefore not harmed and the bees can continue gathering honey to replace that which has been harvested which ensures good quality honey can be harvested, free of contaminating pollen or brood [52]. The main benefits of using improved beekeeping equipment are to get high yield and quality of honey [53].

According to Tulu [54], Because of modern equipment is expensive and hard to come by, beekeepers don't use it very often. Because of this, Ethiopian beekeepers primarily rely on using conventional bee hives and related equipment, which produces low yield and quality honey at the national level and poses a supply and quality problem to Ethiopian honey exports. [55].

4.2. Chemical Application

The physiochemical properties of honey are diminished if it is contaminated with toxic chemicals, such as heavy metals and pesticide residues [56]. Honey can be contaminated with pesticides from agricultural practices and beekeeping. Plant protection products are persistent in the environment. These compounds can be transferred by nectar from the environment into honey, and it represents an indirect source of pollution. Veterinary drugs such as acaricides used by beekeepers to control Varroa destructor mite infestation of bee colonies represent the direct source of pesticide contamination of honey [57]. Residues of pesticides such as organochlorine (OCs) and organophosphorus (OPs), carbamates and pyrethroids have been detected in honey [57]. Chloramphenicol, nitrofurans and nitroimidazoles are common antibiotics in beekeeping the limit has been established at 0.5 ng/g of honey to reduce risk of contamination [58].

Antibiotics are another group of contaminants that can influence the quality of honey. This group of compounds is used by beekeepers to prevent or treat bee diseases. The practice is prohibited by the European Union, and the presence of antibiotic residues in honey is also prohibited [59]. The presence of antibiotics in honey is a global problem, as they can produce residues and pose risks to human health. They can also cause allergic reactions, antibiotic resistance in humans [60]. The use of antibiotics in beekeeping is not allowed [59].

Honey bees are exposed to pollutants when they consume pollen, nectar, and plant residues in water. The bees are exposed to pesticides, herbicides, and fungicides when they are sprayed on crops because they come into contact with pollen, nectar, and the air, water, or soil [62]. When bees are on the flowers at the time of application of the insecticide and the bees die instantly. Some other types of pesticides allow the bees to return home and then they die. There are certain pesticides that do not have any effect on the adult honey bees but cause damage to young and immature bees [62].

In Ethiopia, in certain regions of the nation, the use of agrochemicals is a serious issue that leads to bee deaths, population declines, decreased honey output, and polluted (low-quality) honey. This suggests that low quality/physiochemical qualities of honey as well as a scarcity of honey supplies would limit Ethiopia's honey export. [63]. In our country Ethiopia, chemical poisoning by pesticide and herbicides application is one of the major constraints in beekeeping for the result of to get low honey yield and quality [12, 14, 64].

4.3. Honey Bee Disease, Pests and Predators

Honey bees were afflicted with illness and attacked by parasites and vermin, just like all other living things, risking

their health and lives [65]. In a short amount of time, disease, pests, and predators devastate honey bee hives. Ethiopia, one of the subtropical nations, has ecological and climatic circumstances that are favorable to bees and that are also favorable to many types of honey bee pest and predators that interact with the lives of honey bees, according to tucker [66]. Diseases, pests, and predators harm honey bee colonies, which has a detrimental effect on the quantity and quality of honey produced [67-69]. Ants, wax moths, mice, birds, honey badgers, wasps, bee lice (Braula coeca), beetles, lizards, toads/frogs, praying mantis, and spiders were among the most common honey bee pests in Ethiopia [70-72]. The major bee microbes are of bacterial, fungal, or viral origin. Diseased honeybees are expected to produce honey with different biochemical and physicochemical characteristics because of their responses to disease events and consequences, in addition to the presence of the microbes themselves [73]. The major honey bee disease in Ethiopia, Chalk Brood Diseases, Nosematosis, and Amoeba was reported in South and South parts of the country [71, 74].

4.4. Honey Harvesting and Processing Methods

Different management, harvesting and processing techniques can influence the final quality of honey. Processing Honey should be processed as soon as possible after removal from the hive. Careful protection against contamination by ants and flying insects is needed at all stages of processing. It is important to remember that, Honey is a food and it must therefore be handled hygienically, and all equipment must be perfectly clean and that honey is hygroscopic and will absorb moisture, therefore all honey processing equipment must be perfectly dry [75].

According to Shenkute [68], who conducted their study in Kaffa, Sheka and Bench-Maji zones of Ethiopia, where traditional honey production system and forest beekeeping is dominantly practiced in particular, the respondent beekeepers have indigenous knowledge on when the honey ripens and is ready for harvest and during harvesting beekeepers use teff straw and animal dung for smoking which contaminants honey physiochemical quality. A study conducted bale zone oromia region, smoking materials had a negative effect on honey quality [76]. The quality of honey was mainly compromised by harvesting immature honey, bad extraction methods and contamination by extraneous materials. When honey is harvested prematurely, fermentation occurs frequently, and this negatively affects the quality of honey, due to higher water content [77].

4.5. Honey Adulteration

Honey being a natural substance of relatively high commercial value and limited supply; it is more prone to adulteration and fraudulent practices such as selling it under a false name or origin. It is big issues also problem in our country Ethiopia as it greatly affecting the quality and marketing honey. The floral and honeydew sources that honeybees use, as well as the local and meteorological conditions, all affect the content and characteristics of honey [78]. Any amount of substance(s) added to food alters the proportions of particular ingredients or causes an irregularity in the food's composition. In order to identify and categorize the types and amounts of probable adulterants in honey, factors such as HMF, ash, free acidity, diastase activity, sucrose, and electrical conductivity are crucial [79]. Adulteration of the honey take place results reduction in nutrition and medicinal value [80]. Honey colour is one of its most changing features when the honey adultrate and the adulterated honey are brighter in color while the pure honey is more reddish [81]. While the study conducted by Gemeda and Negera [82], in oromia region, the colour of the honey changed depends on the adulterant materials. Their finding states that adulteration of honey with sugar by boiling honey and water by using heat means have light white in colour, adulterating honey with equal amount honey with sugar melting of sugar have red colour and it becomes solid, adulterating white honey with sugar by directly adding have extra white colour, adulterating honey with molasses using heat have black colour looks like honey coffee honey colour.

According to Jaafar [83], an increase the moisture content of honey is indicative of adulteration. In Ethiopia different adulterant materials identified and reported are sugar, water, molasses, ripened banana, coca cola, invert sugar, sugar syrup, wheat flour syrup or flower, potato, sweet potato, maize syrup or flower, pollen, empty combs, melted candy and hot water [9, 82, 84]. Supplementary feeding with sucrose and inverted sucrose syrup has been shown to affect the water and HMF content, diastase activity, free acidity and pH value of honeys [85].

4.6. Toxic Plants

According to Zewde [86], honey bees are poisoned by certain plant species. A local plant known as Ababbo Diima (emerging red hue flower) is reputed to kill worker bees throughout their blossoming stages. It has been claimed that bees are harmful to toxic plants such Cassia siamea, Croton macrostachyus, Aloe brahana, Zizyphus mucronata, Phytolacca dodecandra, and Susbania species, and that the honey made from their nectar is dangerous to humans [87, 88].

5. Conclusions and Recommendations

Beekeeping is an important agricultural activity in Ethiopia. Owing to its varied ecological and climatic conditions, the country is home to some of the most diverse flora and fauna in Africa. This diversity makes it highly suitable for sustaining a large number of bee colonies. Even if Ethiopia has huge number of honeybee colonies production of honey is far below its potential and the country not benefited more from the sector due to different factors.

Factors associated with Physiochemical properties of honey are the one which determines the country benefited from the sector. Honey has a content of 80-85% carbohydrates, 15-17% water, 0.3% proteins, 0.2% ashes, and minor quantities of amino-acids and vitamins as well as

other components in low levels of concentration. The physicochemical properties of honey are the quality parameters which include the pH, acidity, moisture, electrical conductivity, ash content, total dissolved solids (TDS), hydroxymethylfurfural (HMF), sugar content (total, glucose, fructose, and sucrose) and enzyme activity. However, quality and composition of honey are negatively affected by factors such as lack of improved bee hive technology, chemical application, honey bee disease, predators, pests, honey harvesting and processing methods, honey adulteration, toxic plants and intensifying farming practice are the major one.

To mitigate factors those affect honey physiochemical properties the following recommendations are forwarded:

Training beekeepers and other stakeholders on beekeeping production challenges associated with honey physiochemical properties like that of the followings:

Training beekeepers on how to harvest, handle, process and storage of honey to keep the standard of honey physiochemical properties.

Training both beekeepers and non-beekeeper crop cultivation farmers on how to use agro chemicals, what types of chemicals used and aware about how to harmfulness of agro chemicals on honey physiochemical properties to mitigate agro chemical problems.

The government, non-government organization and other stockholders should be provide improved beekeeping equipment's or reduce the cost and increase the supply and access to beekeepers in order to solve challenges regarding to lack of improved beekeeping equipment's.

Create awareness to beekeepers and other environment communities about toxic plants which harm honey bee itself and their bee products.

Government, non-governmental organizations and other stockholders should be aware and advice the honey producers, retailers and wholesalers about honey adulteration affects the consumers health and reduce the foreign currency exchange of the country.

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Conflict of Interests

The author(s) declares no conflict of interest.

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