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Physicochemical and Rheological Properties of Ethiopian Honey

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ABSTRACT

Ethiopia has about 10 million bee colonies, the largest bee population in Africa and the largest honey producer in Africa, and the tenth-largest honey producer all over the world. The total honey production of Ethiopia is estimated to be 53 000 tons. Honey is a viscous, aromatic, sweet food that is consumed and enjoyed by people around the world. For this reason, it requires certain standards and norms that guarantee its identity and quality so that consumers may safely consume honey, and the same shall have free circulation in the internal market and access to the external market. Honey quality is determined by its physicochemical and rheological constituents. Knowing honey characteristics is useful for processing, packaging, and storage of honey in appropriate conditions which are used to preserve their qualities and know their nutritional and medicinal value as well. The majority of Ethiopian honey possesses good characteristics in terms of physicochemical and rheological properties although there is a slight variation among parameters due to different factors. Training and creating awareness beekeepers and other stakeholders on honey quality may reduce the problem related to honey quality.

Keywords: Physicochemical; Rheological; Quality; Honey; Ethiopian

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Introduction

Honey is a highly prized food product across the world [1], which is composed mainly of two monosaccharide sugars, i.e. fructose and glucose [[2], and minor components, such as other carbohydrates (sucrose, etc.) and non-sugar components, i.e. Proteins, enzymes, amino and organic acids, lipids, vitamins, volatile chemicals, phenolic acids, flavonoids, and minerals [3,4].

With the rapid growth in honey production, Ethiopia is the largest honey-producing country in Africa and one of the top ten countries in the world [5]. The production shows an increment, for instance, in the year (2001-2015), Ethiopia‘s honey production increased from 28,000 tons to 54,000 tons [6]. However, the majority of honey is crude and poorly managed. Honey is of good quality as long as it is in the hive, but faulty handling from the time of its harvest until it reaches to market is responsible for its inferior quality [7]. Several factors have contributed to its low quality among which high moisture content is the major quality problem in the country. Harvesting unripened honey, unsuitable honey storage containers, and storage places are also attributed to high moisture content [8].

The composition and the flavor of honey depend on a huge number of variables, the most important of which is the type or types of plant that provided the source nectar, climatic condition during productions, processing and storage condition, beekeeping practices in removing and extracting honey [9]. Because of the multiple importance of honey from food to medicine, it is of great interest to carry out a complete analysis of honey and to formulate values ranges of various honey parameters and characteristics. Honey is generally evaluated by a physicochemical and rheological analysis of its constituents. Knowing honey characteristics allows the packaging and storage of honey in appropriate conditions to preserve its qualities. Physicochemical and rheological properties of honey also indicate whether honey is adulterated or pure depending on the value of the parameter as it decreased or increased when adulterant materials were added to it. Indeed, according to Ouchemoulkh et al.[10] physicochemical characteristics are widely used to differentiate botanical and geographical origins of honey and then complete pollen analysis.).Therefore, the determination of physicochemical parameters of honey is very significant to the honey industry, as these factors are intimately related to storage quality, granulation, texture, flavor, and the nutritional and medicinal values of honey [11,12]. Having the information about honey quality characteristics would allow the stakeholders to pack and store the honey in proper conditions to preserve its quality and taste. In addition, it provides information regarding the energetic and nutritional quality, as well as the possibility of falsifying honey [12]. Therefore, this present review aimed to summarize honey quality characteristics based on physic-chemical and rheological properties from Ethiopia.

Materials and Methods

The methodological approach was to firstly review existing literature to define and outline the honey physicochemical and rheological characteristics than to analyze local and European data on the quality parameters requirements of honey more generally, and specifically in Ethiopia. For data collection different scientific databases including Science Direct, Google Scholar, Springer, and Pub med were included, regardless of the time of publication. This review covers mainly publications that deal with honey physicochemical properties, rheological properties honey quality composition journal to achieve the final objective.

Physicochemical properties of Ethiopian honey

Physical properties of honey

Knowledge of the physical characteristics of honey is important for the different aspects of honey technology: harvest, storage, granulation, and liquefaction [13]. Various studies [9,14] identified the diversity of the physical characteristics of honey to be dependent on the nectar and pollen of the original plant, colour, flavour, moisture, and contents of proteins and sugars.

Hygroscopicity

Hygroscopicity is the ability of a substance to absorb and hold moisture from the surrounding. The strongly hygroscopic nature of honey is vital both in processing and for final use. Different researches show that normal honey with a water content of less than 18.3 % or less will absorb moisture from the air if the relative humidity is above 60% [15]. However, the same hygroscopicity of honey can become problematic during processing or storage, causing difficulties in preservation and storage due to excessive water content. Honey, especially when rich in fructose, is very hygroscopic i.e. it absorbs moisture from the air when the container is not closed. This may lead to an increase in water content and possible fermentation. For this reason, honey must be always stored in containers with tight-fitting lids .

Fermentation

Fermentation of honey is caused by the action of sugar-tolerant yeasts upon the sugars dextrose and levulose, resulting in the formation of ethyl alcohol and carbon dioxide. The alcohol in the presence of oxygen then may be broken down into acetic acid and water. As a result, honey that has fermented may taste sour [16]. Fermentation of honey is sometimes a problem. The main factors causing fermentation are high moisture content (above 20 %), high temperature, and a high yeast count (>10/gram). Uneven granulation of honey within a container can lead to small pockets with high levels of water, and this may result in fermentation. Honey that has begun to ferment can be used for making into fermented products like beer, wine, or vinegar [17].

Thermal characteristics

Like all sugar compounds, honey will caramelize if heated sufficiently, becoming darker in color, and eventually burn. However, honey contains fructose, which caramelizes at lower temperatures than glucose [18]. The temperature at which caramelization begins varies, depending on the composition, but is typically between 70 and 110°C [19]. The knowledge of thermal properties is essential in assuring the quality, stability, and safety of various food products [20]. According to White [21], the heat-absorbing capacity (specific heat) of honey, varies from 0.56 to 0.73cal/g/0C with its composition and state of crystallization. The same author also reported that the thermal conductivity of honey varies from 118 to 143 x 10~ cal/cm2/sec/°C. Ahmed et al.(20) also reported values of thermal characterization for some honey are at the range of (-127.19) to (-30.50). The relatively low heat conductivity, combined with high viscosity leads to rapid overheating from point-heat sources and thus the need for careful stirring and heating only in water baths.

Osmotic pressure

The chemical composition of honey, mainly sugars, makes honey a high osmotic pressure food. Together with its acid pH, the organic acid content, the hydrogen peroxide produced by glucose oxidase action, and other non-peroxide factors, the high honey osmotic pressure avoids microbial growth, increasing the stability and shelf life of the product [22].

Crystallization

Honey crystallization or granulation is a natural and spontaneous complex physical process. Glucose, which is less soluble than fructose, separates from water and precipitates out of the supersaturated solution, becoming glucose monohydrate crystals by water losses [23]. This process can be undesirable by beekeepers, since some consumers think that if honey is crystallized, then it has been somehow adulterated [24,25]. Crystallization only affects the honey color and texture, preserving the flavor and quality characteristics of the liquid honey. In principle, crystallized honey is not a spoiled product, but if a non-homogeneous crystallization occurs, the sugar concentration of the upper part decreases, increasing the moisture content of the liquid phase [26,27,28]. There is a general consumer perception that, if honey crystallizes or is granulated, it means that it has gone bad or has been adulterated with sugar or foreign substance which facilitate the crystallization process in honey.

Surface tension

Surface tension is another physical property of honey of great importance and largely applied in cosmetics. Honey has low surface tension. This property of honey makes it an excellent humectant in cosmetic products. The surface tension varies with the origin of the honey and is probably due to colloidal substances. Together with high viscosity, it is responsible for the foaming characteristics of honey [29].

Colour

Next to general quality determinations, colour is the single most important factor determining the import and wholesale prices of honey [29]. Colour in liquid honey varies from clear and colourless to dark amber or black. The honey colour is frequently given in millimeters on a Pfund scale or according to the U.S. Department of Agriculture classifications [12, 26]. The Pfund scale has water white, extra white, white, extra light amber, light amber, amber, and dark amber colour levels [29]. The colour of honey is characteristic of its floral source. Exposure to heat and the length of time that the honey stayed in the storage may also affect honey's colour. Honey appears lighter in colour after it has granulated. This depends upon the composition of the honey and its initial colour. Generally, the darkening of honey is temperature sensitive and occurs more rapidly when honey is stored at high temperatures. Light honey, like the Harenna forest honey [30] and also *Tebeb/Mentesie* (Bacium) honey, generally fetch the highest prices. Nevertheless, in Germany, Austria, and Switzerland, dark honey is especially appreciated. Dark coloured honey is reported to contain more phenolic acid derivatives but less flavor. The colour content of Ethiopian honey is reported as shown in Table 1. Based upon research that most honey samples have dark color indicating reach in mineral content.

Table 1. Summary of Colour for Ethiopian honey

Origin of honey	Percentage of colour detected out of total sample				Reference
	Light Amber	Extra light Amber	Amber	White	
Harrena Forest	62.5%	37.5%			[30]
Tigray Region	55.26%	26.32%	10.53%	7.89%	[31]
East Wollega Zones of Oromia	25%	25%	50%		[32]

Water activity

Water is quantitatively the second most important component of honey. Water activity value < 0.60 is microbiologically stable. It is the better quality criteria for honey than the water content. Water content and water activity of various honey are reported to be at the range of: 10.6- 29.0 g/100g and 0.483-0.70 respectively [33]. Belay et al. [34] reported the water activity ranges from 0.60 to 0.48 in the honey sample analyzed from Ethiopia. Foods with higher levels of monosaccharide units have a higher level of aw kinetics. The higher proportion of fructose and glucose in honey makes water molecules unavailable for the growth of microorganisms, as the monosaccharide units bind water. Honey industries considered moisture alone as a key feature for the spoilage, stability, and storage behavior of honey. Moisture content alone cannot reasonably govern the growth and multiplication of microorganisms. Water activity plays a better role in the quality of honey [35]. The aw value ranges from 0 to 1. If the value of aw is above 0.61/0.62 limits the growth of microorganisms, including Osmo tolerant yeast [35]. Belay et al. [34] study indicated that Ethiopian monofloral honey has a lower tendency of spoilage by microorganisms, and is free from the risk of fermentation.

Chemical properties of honey

pH

Mostly honey is acidic and has a low pH value. The low pH of honey inhibits the presence and growth of microorganisms. Honey pH has great importance during the storage of honey, as they influence the texture, stability, and shelf life of honey [36]. According to Bardy et al. [37], most honey is acidic with a pH ranging from 3.2 to 4.5 which is inhibitory to most neutrophilic bacteria. IHC [38] recommended an average of 3.9. Most acids are added by the bees [39]. In Ethiopia, the pH of most honey is studied by many authors as shown in (Table 2). Based upon the research pH of Ethiopian honey it appears that almost all honey samples were found to be acidic. Although the Variations observed in the honey samples may be attributed to the presence of different acids found in different floral types [40], the low pH of honey has the advantage to prevent the presence and growth of microorganisms. In addition, the pH of honey mainly indicates the buffering action of the inorganic cation constituents of the acids present. pH values have great importance during the extraction and storage of honey as it influences the texture, stability, and shelf life of honey [41,42] .On the other hand, the pH determination could also be correlated with other authenticity parameters to verify adulterations. The pH is indeed a useful index of possible microbial contamination and adulteration [32]. Therefore, the low pH of Ethiopian honey confirms that it well inhibits the presence and growth of microorganisms. The storage factor and temperature also contribute to the low pH value in honey.

Free acidity

Free acidity may be explained by taking into account the presence of organic acids, which are proportional to the corresponding lactones, or internal esters, and some inorganic ions such as phosphates or sulfates [43]. These properties of honey can influence honey stability and its storage conditions and also they give some information on honey origin [44]. The high acidity of honey is an indication of the fermentation of sugars present in the honey into organic acid [10]. The free acidity of the Ethiopian honey sample is shown in Table 2. Regarding the reported data the majority of free acidity in the different parts of Ethiopia shows good characteristics. However, the presence of different organic acids, geographical origin, and harvest season can affect the honey's acidity [4,45, 46] and storage condition and adulteration with water. Although the acidity of honey is desirable, when the acidity increases very much, the honey becomes sour. The acceptable limits for Free acidity values (≤40meq/kg) are set by QSAE and CAC, whereas the limit for honey acidity according to the EU [47] honey standard is ≤ 50 meq/kg. Free acidity below the acceptable limit indicates the freshness of the honey samples and the absence of unwanted fermentation in the analyzed honey samples. Free acidity also shows the presence of adulteration in the honey samples if it's above the requirement set. The Codex [45] on Sugars permits a maximum value of 50.00meq/kg-1 for free acidity. Higher values may be indicative of the fermentation of sugars into organic acids.

Electrical conductivity

The electrical conductivity of honey is defined as that of a 20%w/v solution in water at 20 oC, where 20% refers to honey dry matter [38]. Electrical conductivity is the indication of ionizable acids and compounds in an aqueous solution and it is a good criterion to know the botanical origin of honey, the higher their content the higher the resulting conductivity. Several studies in Ethiopia reported the electrical conductivity of honey samples from different parts of the country as shown in table 2. A similar result has been reported for the honey produced from different floral sources in Malaysia with a mean 0.74 and 0.4 to 0.79 mscm-1 [48]. The maximum limit for electrical conductivity given by the Codex Alimentarius (0.8 mscm-1) (45). The variation of electrical conductivity of Ethiopian honey among the result of finding occurred because electrical conductivity is closely related to the concentration of minerals, acidity of honey, organic acids, and proteins, and it is a parameter that shows great variability depending on the floral source of honey [49]. Furthermore, high values of electrical conductivity might be due to storage time, temperature, water content, and concentration of ions and minerals [50]. As electrical conductivity concentration is closely related to ash or mineral content of the honey high value of electrical conductivity is also indicative of environmental pollution across the industry with heavy metals, pesticides, herbicides, insecticides, and sometimes additional substances containing high minerals to honey.

Ash content

Mineral content is an important indicator of possible environmental pollution and an indicator of the soil types of the area [63]. Honey normally has low ash content and it depends on the materials collected by the bees foraging on the flora [36,64]. Ash content was considered to be an indicator of the cleanliness of honey samples [65]. The ash content of honey from Ethiopia is reported by different authors as shown in table 2. At the national level, the mineral content of honey ranges from 0.01 to 1.16% with mean a value of 0.23% [66]. Similar values were reported by Kayode & Oyeyemi [12] in Nigeria honey that ranged from 0.004 to 0.440. The maximum limit set for ash content of the honey by EU, CA, and QSAE is (0.6%). Although the majority of the ash content value of Ethiopian honey fit the requirements set by Ethiopian standard, EU, and codex standard, the values of ash content above standard also reported which is because of many reasons. The mineral content variation is related to the geographical areas, seasons, and botanical origin of the honey [54]. The harvesting practice especially from the traditional hive, using dung for the smoke, improper storage materials and area, extraction methods used by the beekeepers, and personal and equipment hygiene cause to increase the ash content. The amount of mineral content is among various factors in determining honey color, the higher mineral amount of honey is usually observed in dark color honey types. Ash content is related to the color and flavor of honey, with a higher mineral content leading to a darker and stronger flavor [67,68] which are attractive features for its consumption. There is usually a positive correlation between the color, mineral content, and electrical conductivity of honey [68]. Many authors reported the variation in ash content comes from the natural property of soil and protein, there is much thought that indicates variation comes from improper handing from farm to fork in addition to environmental biodiversity. The ash content and electrical conductivity are important parameters to know the mineral content found in honey.

Hydroxyl-methyl-furfural (HMF)

Hydroxyl-methyl-furfural is a break-down product of fructose formed slowly during storage and very quickly when honey is heated. The amount of HMF present in honey is therefore used as a guide to storage length and the amount of heating that has taken place [26]. Virtually HMF absent in newly produced honey. Thus, its presence is considered the main indicator of honey deterioration. The HMF content of Ethiopian Honey is shown the table 2. According to QSAE [62] and IHC [38], the maximum limit of HMF content in honey is 40 and 60 mg/kg, respectively. The amount of hydroxymethylfurfural in honey is one of the important indicators of honey's quality indicating whether the honey is aged or over-heated [69] as well as long storage and adulteration .HMF is present only in trace amounts and its concentration increases with storage and prolonged heating of honey [70]. The low HMF

Table 2 . Summary of physico- chemical properties of Ethiopian honey

Place	RS (%)	S (%)	MC	FA (meq kg -1)	pH	EC (µs cm^{-1})	Ash(%)	Water I (%)	HMF) (mg/ kg-1)	Diastase (Gothe units)	Reference
Supermarkets for Addis Ababa and Adama					4.11-4.33	0.10-0.29	0.17-0.46				[51]
Tepi area				17-29	3.96-4.26	0.0966-0.337					[32]
Adigrat and surrounding areas	50.31 – 79.56	2.24 – 12.21	17.56 – 22.57	3.99-45.17	3.40 - 4.65	0.13 - 0.56	0.09 - 0.54		8.32-45.26		[31]
Bale Natural Forest, Southeastern Ethiopia	51.28 – 69.2	3.01 – 7.62	14.60 – 22.8	13 – 46	3.3 – 4.85	0.22 – 1.34	0.14 – 0.30		27.10-40.80		[52]
Siltie Wereda, Siltie Zone, SNNP	66.44 - 71.64	2.160 - 6.01	14.61 - 19.54	12.41 - 33.67	4.13 - 5.02		0.12 - 1.67	0.006 - 1.53			[53]
Homesha district of western Ethiopia	62.0 - 71.0	4.4 - 12	15.01 - 18.16	18.01 - 36.54	3.52 - 4.46		0.014-0.31	0.01 to 0.46	0.5 - 3.2		[54]
Gesha, Masha &Sheko of Southwestern Ethiopia beekeeper	54.4 to 79.99	1.32 % to 10.98	20.4 % to 24.8 %	15.05 - 56.7			0.02- 0.55		2.2 - 36.15		[55]
West Shewa Zone, Oromia Region	61.38–72.87	6.84–15.94	16.61–18.64	7.42–13.8	3.77–4.22	0.384–0.646	0.030–0.095				[56]
Sekota district, northern Ethiopia	63.4-71.7	1.0 - 5.2	13.9-17.7	10-38.98	3.55-4.75		0.01-0.52		0-2.5		[57]
Debre-Nazret Kebelle of Tigray Region, Ethiopia			17 to 23	17.33 - 32.7	2.99 - 4.45	0.21 - 0.51	0.09 - 0.30	0.06 - 0.38	14.66 - 15.21	4.22 - 9.76	[58]
Tigray region, northern Ethiopia	67.7-80	1.27-4.24	17-21	18-43			0.02-0.44				[40]
Gomma Woreda of South Western Ethiopia	61.15 - 77.41	0.75-6.96	15.66 - 23.4	0.30 - 57.30	3.45 - 4.18		0.05-0.60		0.05 - 17.70		[59]
Silti district, southern Ethiopia.	66.44-71.64	2.160-6.01	14.61-19.54	12.41-33.67	4.13-5.02		0.12-1.67				[60]
Selected districts of Arsi Zone			17.9-21		3.39-4.2		0.04-0.41	0.32-0.41			[61]
Ethiopian Monofloral Honey		1.1-2.8	14.4-20.54	20-55	3.4-4.6	0.14-0.58	0.20-0.39				[34]
Ethiopian standard			21 max	40			0.6 max	0.1 max	40 max	3	[62]
EU standard	65	5	21	40			1		40		[47]
FAO/WHO	65	5-10	21-23	40			0.6-1		80 max		[38]
World			18-23	5-54	3.2-4.5			0.26-0.84	40-80	3-10	[[38]

***** RS(reducing sugar);S(Sucrose);MC(Moisture content),FA(free Acidity),EC(Electrical Conductivity),WI(Water insoluble water),HMF(Hydroxy methyl furfural aldehyde) content of honey produced indicates its freshness and the good honey handling practice of the area. IHC [38] reported that HMF is generally not present in fresh honey and its content increases during conditioning and storage, depending on the pH and storage temperature. Naturally occurring levels of HMF are about 10 mg/kg [26]. Amounts exceeding the maximum limit are considered the main indicator of honey deterioration [71,72] either through heating or long periods of storage. [73] indicated that the higher values of HMF also point towards the possibility of honey adulteration by invert syrup, In the same way as an indication of heated honey and content more than 150 mg kg-1 is taken to indicate adulteration with inverted sugar [45]. Therefore, HMF level is not only indicative of honey freshness but also storage duration and conditions and it is also a major honey quality factor that indicates honey freshness and adulteration associated with overheating.

Moisture content

The moisture content of honey is the quality criterion that determines the capability of honey to remain stable and to resist spoilage by yeast fermentation and mold formation: the higher the moisture content the higher the probability of spoilage during storage Honey moisture content depends on the environmental conditions such as temperature relative humidity of the area and the manipulation of honey during the harvest period by beekeepers, [74] and season of production and maturity of honey [75]. The moisture content of honey is practically the most important quality parameter because the rate of fermentation and its shelf life span is greatly determined by the amount of moisture contents [46]. Honey only with less than 18% water can be stored with little or no risk of fermentation. However, honey with over 19% water will ferment [76]. As shown in table 2 the moisture content of Ethiopian honey is reported in a different previous study. The maximum limit of moisture content of Ethiopian honey so far analyzed is 32% and the maximum acceptable limit for moisture content of Ethiopian honey is 23% [66] while the maximum acceptable moisture content of honey reported by the International Honey Commission is 20% [38].

Moisture content is one honey quality parameter that affects the overall quality of honey. If beekeepers don’t know appropriate harvesting time and season, if they don’t use appropriate storage materials during handling, processing, and storage because honey is hygroscopic property the moisture content became high. This parameter is a major problem in Ethiopia's honey because the majority of honey in Ethiopia is harvested from the traditional beehive with traditional harvesting and processing technique with a lack of adequate knowledge of beekeepers on honey property. The problem does not only arise from beekeepers, collectors and retailers also lack knowledge on how to handle the honey and how to protect the quality collected from beekeepers. Even though this is not the only factor the moisture content of Ethiopian honey becomes high as compared to world standards. The moisture content is also high because of the adulteration of honey, especially water. The low moisture content of the reported honey samples is important and affects keeping quality, indicating good storage ability of the honey, since high moisture content could lead to fermentation during storage.

Sugar profile of honey

Sugars are the main constituents of honey comprising about 95% of honey weight [70]. Reducing and non-reducing sugars together, account for 85-95% of the carbohydrate in honey; composition depends mainly on the honey’s botanical origin, geographical origin, and is affected by climate, processing, and storage [13,67]. The sugars present in honey are responsible for properties such as energy value, viscosity, hygroscopicity, and granulation [77]. Honey is a mixture of principally two reducing sugars namely glucose and fructose, giving it similar properties to invert syrup. Other sugars present in significant amounts are disaccharide sucrose (cane sugar), maximum sucrose content of 5% is required by the proposed Codex [45]. Sucrose is defined as non-reducing, which is hydrolyzed either by mineral acids or by enzyme invertase.

Reducing sugar

The reducing commonly found in honey are fructose and glucose. The reducing sugar content of Ethiopian honey is shown in Table 2. Adgaba (66) reported reducing sugar in Ethiopian honey which accounted for about 70% on an average. Silici [78] and White et al. [76] also reported their observation close to this result, in which the average for reducing sugar was 67.60 % and 69.47% in Turkey and U. S. honey, respectively. Consequently, there was variation in the percentage of reducing sugar of Ethiopian honey as compared to the standard for Ethiopia, Codex, and EU, there is may of because the content of these sugars is related to the ripeness of honey, and adulteration of honey can alter the composition of sugars [79]. However, as mentioned earlier, it is important to consider that these parameters also can vary according to botanical origin as reported by Maurizio [80] that the sugar spectrum of honey depends upon the sugar present in the nectar and enzymes present in the bee and the nectar. Honey ripeness and storage conditions modify honey sugars' .During storage, the content of monosaccharides decreases, and the content of oligosaccharides increases [76,81) because of enzymatic activity and acid reversion [71]. Honey quality criteria regulations; establish minimum limits for the sum fructose and glucose as well as maximum limits because the content of these sugars is related to honey overheating, storage, ripeness, and can reveal possible adulteration. Total reducing sugar contents in all honey samples are within quality requirement limits (≥65%) (QSEA; CAC; EU).

Non-reducing sugar (sucrose content)

Sucrose is non-reducing sugar found in honey. The amount of sucrose in honey differs according to the degree of maturity and nectar compound of the honey. Unripened honey that was very early harvested contains too much sucrose [76] the sucrose has not been converted to fructose and glucose [82]. Sucrose content does not reach zero after several years of storage, however, even though honey may still contain active invertase [76]. The determination of sucrose and fructose: glucose ratio is valuable for assessing adulteration by sucrose and to predicting honey crystallization tendency [35]. As shown in Table 2, the sucrose content of Ethiopian honey is reported by many authors. Adgaba [66] also reported the mean value of sucrose content national average 3.6%. There is an indication that values of sucrose content varied across data reviewed and some values show the above the requirement set by Ethiopian standard, codex, and EU. The slight excess value of sucrose content of honey may be due to adulteration of the honey by addition of commercial sugar to honey, harvesting of unripe honey. According to International Regulatory Standards, it should not exceed 5% (g/100g). The sucrose content above 5% (g/100g) indicates that honey is adulterated with sugar or sucrose.

Enzyme activity

The enzyme content of fresh honey is one of the characteristics which make this foodstuff different from other sweeteners, but processing, heating, and prolonged storage can all lower the amount of enzyme activity. The activity of an enzyme in honey also depends on the age of the bees, stage of the colony, nectar flow, environmental conditions, and beekeeping practices [83]. In Europe, diastase activity is still considered to be the main parameter for evaluating the freshness of honey and it can be used to indicate the processing and storage conditions of honey. White & Subers [84] demonstrated that invertase is destroyed more quickly than diastase if honey is heated, so invertase activity could be a better indicator of honey quality than diastase activity. Takenaka and Echigo [85] observed that both diastase and invertase showed a decrease during storage which was greater in honey with high water content. Krauze [86] studied changes in diastase and invertase in honeydew honey and concluded that diastase is about twice as stable as invertase.

Laude et al.[87] found that invertase activity seemed to be influenced by beekeeping practices and the treatment of honey. There is a finding reported about the diastase of Ethiopian honey. Equar et al.[58] reported the diastase activity varied from 4.22 to 9.76 Goth scale with a mean value of 7 in honey analyzed from Debre Nazaret kebele of Tigray region while in a study by Andargie & Ashine [88] diastase number of autumn harvested Dangilla district honey was ranged from 0.78 to 38.41 Goth scale. According to Codex and European Union, diastase content of good quality and acceptable honey is 8 Schade scale [38]. The minimum diastase activity value of 3, similarly to the Ethiopian honey quality standard for honey with natural low enzyme content. The diastase activity of honey has the relevance of indicating overheating, as it is heat-sensitive [26]. However, recent complaints are coming from Ethiopian honey exporters that the majority of their collections have diastase far below the standards even for fresh and unprocessed honey. This is because Ethiopian beekeepers use heat to separate honey and wax, during these heat-sensitive enzymes, the aroma and flavour of honey were denatured from it.

Water-insoluble solid/matter

For most consumers, good-quality honey is expected to be visually free of defects, clean and clear. Honey which has a very high pollen content appears cloudy, and the presence of many other contaminations such as particles of wax, dead bees, splinters of wood, and dust certainly does make it look unappetizing and unappealing for anyone to buy and consume, and hence it appears as if it's of very low value. The water-insoluble solids content is directly dependent upon honey handling and high concentrations are a sign of improper handling during harvest. This indicates that honey's water-insoluble matter is used as a criterion of honey cleanliness. As shown in table 2 the water-insoluble of honey from Ethiopian is reported by many authors. The maximum acceptable level of water-insoluble matter in honey is 0.1% according to Ethiopian standard [62] and it is 0.1% for extracted honey and 0.5% for pressed honey as reported by Codex [45]. According to IHC [38], even 0.1% of water-insoluble matter in honey is a very high value. The high water-insoluble is also a sign of adulteration with solid-like banana and other adulterant materials which contain solid and fiber-like products is found in it. In general, the insoluble matter measures the impurities of the honey and impurities come from improper handling of honey at the time of harvesting extracting, storing, processing, transportation, and utilization, this improper includes adulteration of honey with cheap substance.

Proline

Proline originates mainly from the salivary secretions of honeybees (Apis mellifera L.) during the conversion of nectar into honey. In honey, proline represents a total of 50 to 85%amino acids [89]. Proline has been used as a criterion for the evaluation of the maturation of honey, and in some cases, adulteration with sugar. A minimum value of 180 mg kg-1 of proline is accepted as the limit value for pure honey [90]. Even though this quality parameter is a good indication for adulteration and ripeness of honey during harvesting, there is no reported proline content of Ethiopian as well as there is the standard requirement for this parameter.

Rheological properties

Rheology is the branch of physics in which we study how materials deform or flow in response to applied forces or stresses [91]. This property is of great practical importance to beekeepers and honey processors as the knowledge of honey rheology is necessary for the area of process engineering that involves different stages including handling, storage, processing, quality control, and transportation. The flow behavior properties as indicated by rheological profiling provides an indirect measure of product consistency and quality, which is the guiding factor for the design of mechanics of honey processing Honey rheology is one of the most important characteristics of honey because it affects the quality and is useful for the processing equipment design [92]. The rheological properties of honey have also been reported to depend on several other parameters such as temperature, shear rate, time, sugar composition, water activity, water content, and crystal size [93].

Viscosity

The viscosity of a material is its resistance to flow. Viscosity is an important technical parameter during honey processing, because it reduces honey flow during extraction, pumping, settling, filtration, mixing, and bottling, which influences the quality of the product [94]. Honey of high quality is usually viscous. James et al.[95] stated that the viscosity of honey is a function of the composition of its sugars, water, and colloid content. It is also influenced by temperature, moisture content, as well as the presence of crystals and colloids in the product. In normal circumstances, higher moisture levels result in a reduction in viscosity. Other factors influencing the viscosity of honey are the composition of individual sugars and the amount and type of colloids present in honey. Freshly extracted honey is a viscous liquid. Raising the temperature of honey lowers its viscosity a phenomenon widely exploited during industrial honey processing [15].

Honey is sugar syrup and the viscosity characteristics can be governed by the molecular chain length of sugars present in the honey. For the same mass fraction, disaccharides contribute to a higher viscosity than monosaccharides in a solution system [96]. Belay et al. [34] study the flowing behavior of Ethiopian monofloral honey and reported that moisture content and water activity affected the viscosity of honey. The authors mentioned the viscosity of honey substantially decreases with increasing moisture and water activity. This could be due to the tendency of the solid components attached to water molecules, which decreases the liquid phase of the honey. The viscosity of honey increased with reduced aw at a different shear rate [30].

Even though the moisture content of the honey has a strong effect on the flowing capacity of the honey, the viscosity of honey also depends on its floral origin, which was directly related to its composition [97]. Generally, honey is considered to exhibit Newtonian behavior [98] but some researchers also reported about non-Newtonian behavior of honey, which is due to the presence of protein colloids [20,99]. Ethiopian monofloral honey exhibited Newtonian fluid behavior as linearity shear stress versus shear rate obtained according to the findings of Belay et al.[34]. Bogdanov[100] reported that the viscosity increase due to temperature occurs very slowly at first. However, while honey is very viscous, it has rather low surface tension.

Density

The density of honey is an important physical property that influences stratification in honey. Honey density, expressed as specific gravity, is greater than the density of water and depends on the water content of the honey [65]. Because of the variation in density, it is sometimes possible to observe distinct stratification of honey in large storage tanks. The high water content (less dense) honey settles above the denser, drier honey. Such inconvenient separation can be avoided by more thorough mixing. Therefore, when honey with different specific gravity is pulled into a storage tank, distinct stratifications may form based on their density variations. The degree of mixing and the final moisture content of honey in storage tanks depend on the individual specific gravity of different types of honey.

Conclusion and Recommendation

Ethiopia has about a million households that are engaged in beekeeping and produce different types of honey that vary in terms of color, consistency, and purity. The quality of honey is mainly determined by its chemical, physical and rheological characteristics. Quality control of honey is important to determine its suitability for processing and to meet the demand of the market. The present review indicated that most honey quality parameters analyzed from different locations of Ethiopia fulfilled national and international honey quality standards; although there is variation among the parameters which is may due to different factors and may be adulteration problems. Careless handling of honey can reduce its quality. Thus combined efforts are needed from the government, non-governmental organizations, research centers, scientific communities, and the regulatory authorities through the development and implementation of better handling methods of honey, training beekeepers on the quality, Therefore, the following recommendations forwarded:

• Strict national legislation passed on apiculture sector to avoid unnecessary use of different substances which affect the honey quality

•Training beekeepers and other stakeholders on how to handle the quality of honey, about good manufacturing practices and monitoring are useful to protect honey quality.

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