EVALUATION OF HONEYBEE HIVE DENSITY ON THE AVOCADO (*Persea americana m*) FRUIT PRODUCTION AND HONEY QUANTITY AND QUALITY DURING AVOCADO FLOWERING IN DARA OTILCHO DISTRICT SIDAMA REGIONAL STATE, ETHIOPIA

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DIDECATION

This thesis document is dedicated to my family for their comprehensive moral, encouragements in my academic and their commitment.

BIOGRAPHICAL SKETCH

The author of this thesis was born in 1986 EC from his father Fikrie Mamo and mother Wudinesh Teka in Abichu Gea woreda,north Shewa Zone, Oromia Region, Ethiopia. He followed his primary school at Dirma elementary school and his secondary school at Mendida secondary school and also attended Muka Turi preparatory school. He joined Hawassa University in 2004 E C. He studied Animal and Range science and graduated in June 2006 EC. After his graduation, he worked at the Gewane Federal ETVT College. In September 2020 he joined Hawassa University to pursue his Master’s degree in Animal Production.

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LIST ABBREVATION

AAU…………………………......Addis Ababa University

ANOVA…………………………Analysis of Variance

CSA………………………………Central Statistical Agency

DM……………………………….Dry Matter

EAS…………………………….....East African Standards

EC………………………………..Electrical Conductivity

EU………………………………..European Union

WHO……………………………..World Health Organization

EIAR……………………………..Ethiopian Institute of Agricultural Research

FAO………………………….......Food and Agricultural Organization

HMF……………………..…….Hydroxymethylfurfural

IHC…………………………….....International Honey Commission

QSAE…………………………….Quality Standard Authority of Ethiopia

SAS…………………………….....Statistical Analysis Software

SPSS…………………………......Statistical Package for Social Science

TSS…………………………….....Total Soluble Solids

TA……………………………….Titratable Acidity

N………………………………...Number of House Houlds

USDA……………………………United States Department of Agriculture

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Abstract

This study was conducted in the Darra Otilcho district of Sidama region, Ethiopia to assess bee keeping activities, impact of honeybee hive density on the quantity and quality of avocado fruit and to determine the effect of hive density on honey quantity and quality produced. 116 bee keepers were selected using multistage sampling method for household survey from highland and midland agro ecologies. 12 Avocado orchards with an area of 1 ha for each orchard were selected purposively based on ownership of avocado tree for experimental work. For this study, Randomized Completely Block Design was applied with four treatments (0 hive (T1) (only for fruit), two hives (T2) and four hives (T3) and six hives (T4) each with three replications. The result of the study indicated that supplementing pollination by honeybee hives per orchard increased avocado fruit set than the control (no hive per orchard). The largest fruit weight (258gm), fruit length (13.2cm) and fruit yield per tree (246kg) were obtained from treatment four. In the current study, supplementing pollination by honeybee hives per orchard revealed better Total soluble solids, Dry Matter and lower Titratable acidity as compared to the control. Pollen determination of all treatment samples indicated that the mono flora of Persea americana honey consisted of 55.27%, 64.86% and 56.96% for treatment two, three and four, respectively. The highest average of the honey yield per hive was recorded from treatment two (17.66kg) and the lowest mean values were obtained from treatment four (12.8kg). The overall mean of honey sample of all treatments obtained indicated that physiochemical parameters except electrical conductivity (0.98) the rest of honey quality such as moisture content (19.75%), Ash (0.5 g/100 g), HMF (18.16 mg/kg), pH (4.48) ,free acidity (28.2 meq/kg), (glucose (31.52 g/100 g), Fructose (36.47 g/100 g) and sucrose (2.35 g/100 g)) were evaluated in this study to comply with national and internal standards. There is statistical variation ($p < 0.05$) observed between a honey sample of treatments and that of farmers for Ash, electrical conductivity, free acidity, HMF and Sucrose parameters. The current study indicated that the observed result of honeybee production in avocado orchards was valuable for farmers and strongly suggested that honeybee pollination had a significant role in avocado productivity.

Keywords: beekeepers, honeybee, honey quality, Darra district, Persea Americana

1. INTRODUCTION

1.1 Back ground of Study

Ethiopia is one of the largest honey producers in Africa. This is due to diverse floras which are a good source of nectar and pollen for honeybees, huge number of honeybee colonies, varied ecological and climatic conditions (Haftey *et al*., 2018). Ethiopia has the potential to produce 500,000 tons of honey per year, but currently production is limited to 53,782 tons (FAO, 2021). Out of the total honey production about 37.13% used as household consumption, about 58.46% for sale and the rest is for others (CSA, 2019). Honeybee production serves as source of employment and income generation for subsistence smallholder farmer's mainly the small land holders and landless, poverty alleviation, improving biodiversity and increasing crop productivity through pollination (Amulen *et al*., 2019; Ajabush, 2018).

Honey is a natural sweet substance, viscous and aromatic product, produced by honeybees from the nectar of blossoms, the secretion of living parts of plants, or the excretion of plant-sucking insects on the living parts of plants (Khan *et al*., 2018;Syahriati *et al*., 2021). Quantity and quality of honey are important to determine its suitability for processing and aspect for domestic and international markets, as it helps achieve competitive premium prices and promote human health. Ethiopian honey is a good quality bee product for the local and international market and differs in color, taste, and quality and quantity produced (Miklyaev *et al*., 2017).

The amount of honey yield per year varied based on hive type, agro-ecology and other factors like weather condition, the availability of flora, colony strength and management (Alemayehu *et al*., 2022). In most cases, success in honey yield depends on the availability of sufficient bee foraging resources in terms of both quality and quantity of nectar. r and pollen (Tura and Admasu, 2019). Physicochemical analysis is method of determining quality of honey. The quality of honey, composition and its specific character are determined by types of flowers utilized by bees, production methods, handling, processing and on the climatic conditions in which the plants grow (Mary *et al.*, 2019).

Honeybees (*Apis mellifera L*.) are the main pollinators; which is providing the highest service in crop pollination. They pollinate 90% of the globally most important crops (Requier, 2019). Honeybee has brought about a significant economic contribution to improve agricultural crop production quantity and quality, essential for biodiversity maintenance and improvement, human food, diversify income generation and mitigate poverty (Ricketts & Shackleton, 2020 ; Zekiros , 2019). The most important crops around different area are visited and pollinated by bees and rely on them for reproduction (Patel *et al*., 2021). Out of the 53 major agricultural crops cultivated in Ethiopia, 33 of them (62.2%) are dependent on biological pollinators, and from the total biological pollinator, honeybees contribute 80% of pollination service (Worku, 2018). Most crops produce a fruit or a seed only after successful pollination. Proper pollination can improve the quantity and quality of fruits and others crop produced. According to Rollin & Garibaldi (2018) honeybee densities in the crops were determined through counting colonies per hectare or visits per flower and it has effect on crop productivity (fruit set, seed set, fruit weight and/or yield). The percentage of flowers converted into fruit and the yield increases with colony density.

Honeybee colonies naturally sustain themselves and produce honey by foraging from natural and cultivated crop (Elfiyos and Abera, 2018). Avocado flower is one option that is available for beekeeping area (Teklu, 2016). Honeybees collect avocado nectar (Ohad *et al*., 2007). There are two types of avocado cultivars. In Type A' cultivars the female stage of the flowers are open in the morning and the male stage is open in the afternoon. In 'Type B' cultivars, the male stage is open in the morning and the female stage is open in the afternoon (Alcaraz *et al*., 2011). Frequency of bees in avocado flowers was affected by environmental temperature and characteristics of the avocado flower. The higher number of bees visits to avocado flower is related to the warmer weather (Víctor *et al.*, 2020).

Flowering system of avocado serves to reduce the chance of self-pollination while increasing the chance for cross-pollination. As wind pollination is not effective in avocado, pollinators are required to improve pollination. To ensure optimal pollination, avocado growers place bee hives in orchards to facilitate avocado pollination which helps to increase the Avocado fruit production. The number of hives to use per area for a given crop varies according to field and colony conditions. Higher densities of honeybee hives are necessary for good pollination of crops whose flowers are not very attractive (Toni *et al.*, 2020). According to Peña and Carabalí (2018) high honeybee density or 4 -6 bee hive per hectare resulted in higher honeybee density per tree and higher fruit set and yield in comparison with no hive per hectare and also Dixon (2006) reported that for avocado pollination, ten (10) hives per ha is recommend. The optimum of honeybee hive density in avocado orchards contributes to improving pollination and increase fruit production of avocado (Raphael *et al*., 2021).

1.2 Statement of the problem

Ethiopia has a huge natural resource base for honey production; however productivity in the country is remaining low. One of the prominent factors for this low honey production are shortage of honeybee forages, the traditional husbandry practices besides diseases and parasites (Kalayu *et al*., 2018). In Ethiopia quality of honey produced from multi flora and honey quantity of different type of hive was evaluated by researchers. Honey from market without identifying its source of flora was also evaluated. Dinku and Bereket (2019) reported that the average amount of honey harvested per hive per year from traditional hive, transitional and modern hive in the southern Ethiopia were 5.6±1.49kg, 11.9±3.15kg and 10.8±2.91kg, respectively. Furthermore, According to Tufo *et al*. (2017) the average honey yield obtained in kilograms per hive per year from traditional, transitional and frame hive in Dawro zone of southern Ethiopia (12.85), (32.99) and (40.095), respectively. Many studies by different researchers, for instance, Amhara and Tigray Regions (Mekuanint and Meareg, 2019), Guji Zone (Birhanu, 2016), Bale zone (Aynalem *et al*., 2020), East Gojam Zone (Aschalew *et al*., 2020) and Eastern Tigray (Yetimwork, 2015) were carried out on the evaluation of the quality of honey in different parts of Ethiopia. But, there is a limitation on evaluation of quality and quantity honey produced from mono flora plant and evaluation of pollen in honey to identify the sources of bee forages. Honeybee pollination is as essential for crop production as water and fertilizer but, its role is not well understood by farmers. Avocado flowers open twice, once in the female stage and once in the male stage at different times. One of the reasons of Avocados characterized as having low fruit set is lack of sufficient pollinating insects. Avocado requires honeybee pollination (USDA, 2015). If avocado flowers are not pollinated, no fruit will develop. Little information has been documented in regard to honeybee hive density on avocado orchards in the country.

In Sidama regional state there are certain studies conducted on honey production potential, beekeeping constraints, and seasonal availability of bee forages with its flowering season (Teklu, 2016 ; Tariku and Zerihun, 2019). Mekonen *et al*. (2019) reported that Avocado is one of the important flowering plants of honeybee. However, there is no well-organized information regarding to honey quantity and quality (physicochemical analysis) of honey produced from avocado flower dominant area in the study area and other parts of the country. In addition to these there is inadequate study in relation to honeybee hive density on fruit production from avocado in this region. Therefore the aim of this study was to evaluate the effect of honeybee hive density on fruit production and honey quantity and quality from study area.

1.3 Objective of the study

1.3.1 General objective

- ✓ To evaluate the effect of honeybee hive density on avocado fruit production and honey quantity and quality produced during avocado flowering in the study area.

1.3.2. Specific objectives

- ✓ To assess bee-keeping activities in the study area.
- ✓ To determine impact of honeybee hive density on quantity and quality of avocado fruit in the study area.
- ✓ To determine the effect of hive density on honey quantity and quality produced in the study area.

1.4 Research Questions

1. What are the current bee keeping activities in the study area?

2. What is the time of floral calendar of avocado in the study area?

3. What are the floral resources for honeybees in the study area?

4. Does honeybee pollination affect quality and quantity of avocado fruits?

5. What is the botanical origin of honeys from the study sites?

6. How does the quality of honey in the study area compared with farmer and Quality and Standards Authority of Ethiopia?

1.5. Limitation of the study

The field experiments were done in one season to assess the role of bee pollination on avocado fruit yield and quality and evaluate honey quality and quality. More than one season experimental studies may be required to assess the stability of pollination service for avocado and others fruits. However, the experiments are indispensible and show as an indicator to the importance of honeybee pollination and quality of fruit and honey.

2 LITERATURE REVIEW

2.1 Beekeeping systems in Ethiopia

Ethiopia is one of the best areas in the world for beekeeping activities (EIAR, 2017). Ethiopian honey production accounts for approximately 2.5% of world production and 21.7% of African honey production (Sebeho, 2015). Being blessed with plenty of water resources and ranges of honeybee floras are created productive ground for the development of beekeeping in Ethiopia. In areas where wild colonies of bees living in hollow trees and caves are found, honey hunting is still a common practiced in Ethiopia. The critical classification of honeybee production system is based on employed technologies and probable productivity of each system. Presently, in the country Traditional, Transitional (Top bar hive) and Modern (frame hive) beekeeping methods are exercised (Segni, 2017).

Traditional beekeeping is the major and oldest type of beekeeping practiced in Ethiopia. Traditional beekeeping is practiced with hives constructed from natural materials from the surrounding areas such as wood, mud/ clay (Sahle *et al.* 2018). The honey yield and quality of traditional hive systems is lower than transitional or modern systems despite similar availability of flora resources mostly attributed to the management system (Legesse, 2015). Transitional type of beekeeping is intermediating between traditional and modern beekeeping methods. It is one of the improved methods of beekeeping practices. Modern beekeeping is mostly practiced in the southwestern and in the central highland areas of Ethiopia (Poudel *et al*., 2018). Honey from frame hives is suitable for production of table honey for local and export market (Sahle *et al.* 2018). In different parts of Ethiopia, authors reported different result of honey yield from different types of honey.

Table 1: Annual honey yield in different part of Ethiopia.

Authers name and year	Honey yield from different hive in kg per hive/year			Study area
	Traditional	Transitional	Modern	
Mohammed *et al.* (2016)	5.28	12.19	29.98	Jimma Zone, Southwestern Ethiopia
Juher (2020)	8.242	10.741	\ 17.686	Denbiya Dsitrict, Amhara Region
Segni (2017)	4.77	10.08	18.95	West Shewa zone, Oromia Region
Abebe (2017)	5.67	12.7	16.9	South Wollo zone
Teklu and Dinku , (2016)	-	19.87	22.05	Gedeo zone, SNNPR, Ethiopia

2.2 Importance of beekeeping

Beekeeping activity has important contribution to national economy of the country as well as for the subsistence smallholder farmers (Ajabush, 2018). Honeybees are the most economically valuable pollinator. Currently, bees pollinate approximately 30% of our world's food supply and 90% of all wild plants (floral biodiversity is responsible for the medicine and also the ecological factors) (Shaden *et al*., 2021). The domesticated bees produce honey and allied products. Honey is nutritional and has several medicinal properties, thus it provides a good market for all the apiary products (Lee *et al*., 2015).

2.2.1 Bees as crop pollinators

Honeybee pollination is one of the basic conditions for environmental protection and biodiversity. Crop pollination by insects (predominantly by bee species) is an essential ecosystem service that increases both the yield and quality of crop production and regeneration of plant species worldwide (Melin *et al*., 2014). Tariku and Zerihun (2019) have also reported that honeybees are critically important for the function of ecosystem and the maintenance of agricultural production through their pollinating activities. Pollination is one of the most important factors that affect seed production in agricultural crops. Pollination has two important consequences. It maintains biodiversity of flowering plants, and it maintains ecosystem function.

In agriculture, lack of adequate pollination can lead to deformed fruit and reduced crop yield. Stein *et al*. (2017) reported that in West Africa pollination effectiveness of Cotton and sesame flowers determined in terms of fruit set and fruit quality**.** Honeybee pollination improves the yield of red onion (*Allium cepa*), niger (*Guizotia abyssinica*, apple (*Malus sylvestris)* and faba bean (*Vicia faba*) in Ethiopia (Tura and Admassu, 2019).

2.2.2 Honey production

Ethiopia is one of few countries in the world with a long tradition of beekeeping that gave an opportunity of supplying honey and honey products to the international market. The country is estimated to have ten million honeybee colonies, which is largest in Africa and it is expected to become a major commodity for acquiring foreign currency to improve the Ethiopian economy. Honey is produced in almost all parts of the country. However, the dominant honey-producing regions in Ethiopia are Oromia, Amhara, and SNNPR (Southern Nations, Nationalities, Peoples Regional Government) that accounts for 54.3%, 19.5%, and 16.6% of the total production (CSA, 2020) while Tigray and Benshangul-Gumuz accounts for 8% and 7% of the total honey production, respectively. According to Yetimwork (2015) beekeeping is an important source of income for smallholder farmers in order to sustain their livelihood, main reason for involvement of the farmers in beekeeping was income generation. It does not only serve as a source of additional income, but also quite a number of people entirely depend on beekeeping and honey selling for their livelihoods.

Honey production is highly dependent on plant flowering, because the nectar and the pollen of the flowers provide energy and protein, respectively, which are required to brood rearing and colony development (Bozek, 2021). Honey is an excellent energy source because it contains simple sugars that are ready for assimilation immediately on reaching the intestine. In Ethiopia most of honey goes for preparation of local beverage *Tejj* while small amount being used for other purposes (Teklu and Dinku, 2016).

2.3. Honey and its Quality

Honey is defined as “the sweet substance naturally produced by honeybees from the nectar of flowers, which the bees collect, transform and store in honey comb (Mohamed *et al.*, 2020). Honey can be also defined as a very saturated aqueous solution containing numerous carbohydrates such as fructose, glucose, maltose, sucrose and other oligosaccharides and polysaccharides (Sakač *et al*., 2019). Honey is prepared when honeybees forage over a wide area to collect nectar, water, and pollen as they visit flower to flower rich in pollen and nectar. It is categorized according to its origin (blossom honey, honeydew honey, monofloral honey, multifloral honey), the way it has been harvested and processed (comb honey, strained honey, chunk honey, extracted honey, pressed honey, crystallized or granulated honey, creamed honey), and its intended use (table honey, industrial or bakers' honey) (Alvarez *et al*., 2014).

Honey quality covers a wide range of specifications, which includes organoleptic properties (color, aroma, taste and texture), chemical composition (water, sugars, protein, minerals, enzymes and vitamins content, free acidity, water insoluble solids, diastase activity, electrical conductivity and hydroxymethylfurfural), level of contaminants (pesticides and antibiotic residues, heavy metals and additives), microbiological characteristics, analytical method through labeling (Khalil *et al*., 2012).

2.3.1. Avocado Honey

The floral origin of honey determines characteristics of honey like quality, types, flavor, and color. In the countries where Avocado is grown, it is potentially a rich source for honey. Avocado honey is desirable for consumers due to unique taste and high quality (physiochemical properties of acceptable in national and international standards). In terms of the sugar fraction, the fructose and glucose contents of avocado honey are in ranges of 36.9-39.1 g/100g and 28.90-31.79g/100g, respectively (Serra *et al*., 2019). Avocado honey is characterized by its dark color; high minerals content and high pH value (García-Tenesaca *et al*., 2018).

2.3.2 Composition of Honey

The composition of honey is related to its botanical and geographical origin and it can vary significantly depending on the storage condition and storage period (Bobis *et al*., 2020). Honey has consisted of 80-85% carbohydrates, 15-17% water, 0.1%-0.4% protein and few amounts of vitamins, amino acids and proteins are also an integrant of honey (Khalil *et al*., 2012). Proline is the main amino acid found in honey, constituting approximately 59% of the entire amino acid content (Puścion *et al*., 2020). According to Abera *et al*. (2017) honey mainly consists of 80% sugars (35% glucose, 40% fructose, and 5% sucrose) and 20% water. Organic acids, enzymes, amino acids, minerals, vitamins, pollen grains, and phenolic compounds are the other minor ingredients found in honey (de Sousa *et al*., 2016). Beykaya (2021) explain the most important enzymes in honey are glucose oxidase, diastase, and invertase. In addition, honey contains a few quantities of amino acids, the most important of which is proline. Geographical origin, botanical source of nectar, environmental and climatic condition as well as its harvesting, processing and storage methods are influenced the composition of honey (Veena *et al*., 2020).

2.3.3 Factor influences honey quality

According to Yetimwork (2015) and Abebe (2017) major factors that influences honey quality includes honey maturity, the production methods, inappropriate materials used for honey handling, microbial growth, Types of bee hive, Careless storage conditions of honey, high levels of Hydroxymethylfurfural (HMF), climatic conditions, processing and storage conditions as well as floral sources which provide nectar and pollen.

2.3.4 Physicochemical parameter of honey

The physicochemical properties of honey influence its storage quality, texture, and granulation flavor, nutritional and medicinal quality (Rohini *et al*., 2023). Nectar types that the honeybee used, bee species, geographical ecology (climatic and soil) and post-harvest honey handling practices are factors that influence physicochemical properties of honey (Ofijan, 2018). Physicochemical parameters of honey include the following contents.

2.3.4.1 Moisture

Moisture is analyzed to determine the safety of the product, giving a quality criterion that determines the ability of the honey to remain stable and free of fermentation. The low moisture content protects honey from microbiological activity and thus it can be preserved for longer period (El Sohaimy *et al*., 2015). The highest moisture content was observed in transitional hive followed by traditional hive while the lowest moisture content was observed for modern hive (Aynalem, 2020)

Moisture content of the honey exceeds the standard (>21%) the fermentation yeast in the honey change the sugar in the honey to alcohol. This results in changing the honey taste into sour taste. The moisture content of honey increased when the honey is stored where the relative humidity is greater than 60% because honey by its nature absorb the moisture from the air. And when the honey harvested at its immaturity stage its water content will be high (Bayissa, 2014).

2.3.4 .2 PH

The pH determined refers to the hydrogen ions present in a solution of honey and can influence the formation of other components such as the production of hydroxymethylfurfural (HMF). The pH of honey on its botanical source, the pH of nectar, soil or plant association, and the concentration of different acids and minerals such as calcium, sodium, potassium and other ash constituents. PH is an important factor that governs and can reduce the growth of microorganisms. The natural acidity of honey inhibits growth of many pathogenic bacteria whose minimum tolerated pH is in the range of 4.0–4.5 (Patricia *et al.*, 2010).

2.3.4. 3 Free Acidity

Free acidity is a good quality parameter that influences honey texture, stability, taste and shelf life (Yayinie *et al*., 2021). Free acidity affects the quality of honey and an essential parameter determining its deterioration. High moisture content and temperature are the cause of fermentation of honey. Fermentation of honey is formed due to the action of sugar tolerant yeasts upon the sugars dextrose and laevulose, resulting in the formation of ethyl alcohol and carbon dioxide. During fermentation, glucose and fructose are converted into carbon dioxide and alcohol. Alcohol is also hydrolyzed in the presence of oxygen and converted to acetic acid, which contributes to the amount of free acidity in honey (Dekamo *et al.,* 2021). 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. The acid content of honey is relatively low, which is used to indicate the honey taste. Most of acids of honey are added by the honeybee and the main acid is gluconic acid, a product of oxidation by glucose oxidase. The variation values of free acidity of different honey types may be attributed to contents of organic and inorganic acids, availability floral types, harvesting procedure, geographical condition, harvesting season of honey and storage condition of honey (Getachew, 2020).

2.3.4. 4 Ash

Ash content expresses the richness of honey in mineral content. The minerals calcium, magnesium, iron, copper,cadmium and zinc in the form of sulfate and chloride are found in small amounts. Minerals influence the color of honey and are present in higher concentrations in dark honey than light-colored honey. The variation in the ash content of honeys depend botanical origin, material collected by the honeybees and soil composition (Mekuanint and Meareg, 2019). Honey which has high ash content they have also high electrical conductivity. Ash content is excellent quality criteria that can be used for geographical as well as botanical origin determinations (El Sohaimy *et al*., 2015).

2.3.4. 5 Hydroxymethylfurfural (HMF) Aldehyde

Hydroxymethylfurfural (HMF) is an intermediate product of the Maillard reaction, and is formed by the direct dehydration of sugars under acidic conditions, mainly by the decomposition of fructose during heat treatment applied to food. HMF is used as an indicator of heat and storage changes in honey. HMF is easily formed at low temperatures in the presence of low-pH or acidic conditions, while high temperature and long storage duration increase its concentration to a large extent. HMF formation is correlated with chemical characteristics such as pH, free acid content, total acidity, lactone content and mineral content, which in turn are related to the floral source of collected honey samples (Shapla *et al*., 2018).

2.3.4.6 Colour

The colour of honey varies with the botanical origin (nectar source), age and storage conditions (Dekamo *et al*., 2021). Honey colour is important for purposes of marketing and quality indicator for consumers. Darker honeys are mostly for industrial use, while lighter honeys are marketed for direct consumption (Senan *et al*., 2017). In many countries with a larger honey market, consumer preferences are determined by the colour of honey as an indicator for a preferred flavor (Da Silva *et al.*, 2016).

Table 2. Standards of honey color

USDA color standard	**Pfund scale (mm)**
Water white	0 to 8
Extra White	>8 to 17
White	>17 to 34
Extra light amber	> 34 to 50
Light amber	> 50 to 85
Amber	>85 to 114
Dark amber	>over 114

2.3.4 .7 Sugars

According to Da Silva *et al*. (2016) honey is mostly a concentrated aqueous solution composed of a mixture of reducing sugars, but it also contains some amounts of near 30 other complex sugars. Due to its high sugar content, on average 80–83%, honey is very good energy source (304 kcal/100 g). Botanical/geographical origin of honeys is influenced sugar composition. Thus, the concentrations of fructose (F) and glucose (G), in addition to the ratio between them have been proposed as indicators to distinguish honeydew honey from nectar honeys. The amount of sucrose is a very important parameter in evaluating the honey maturity. Sucrose available in natural or pure honey is little because of the activity of invertase enzyme present in honey. These enzymes are responsible for the breakdown of sucrose. Thus, the content of sucrose in pure honey is low. High levels may indicate a variety of adulterations, such as adding cheap sweeteners like cane sugar or refined beet sugar; early harvest, indicating that the sucrose was not completely transformed into glucose and fructose; or prolonged artificial feeding of honeybees with sucrose syrups, resulting in high commercial profits (Puscas *et al*., 2013). Overheating of the honey sample might denature invertase, stopping the enzyme activity that breaks down the sucrose into glucose and fructose. Thus, sucrose level remains high in the heated honey (Dekamo *et al*., 2021)

2.3.4.8 Electrical Conductivity

The electrical conductivity of honey is limited by the Codex Standard for Honey which states that the conductivity should be no more than 0.8 mS/cm (Codex Alimentarius Committee on Sugars, 2001). The conductivity varies depending on the geographical and botanical conditions. Electrical conductivity is a good criterion of determining the botanical origin of honey to distinguish whether honey is from honeydew or floral nature (Belay *et al*., 2013). Electric conductivity is the indication of ionizable acids and inorganic substances present in it and it is a good criterion for determining the botanical origin of honey, the higher their content the higher the resulting conductivity. The electrical conductivity of honey is closely related to the concentration of mineral salts, organic acids and protein (Aynalem, 2020).

Table 3: The National and International honey quality standards

Characteristics tested	World Standards	FAO/WHO Standards	National Standards
Moisture content, % by mass	18 – 23.	21 – 23	21 max
Total ash, % by mass	0.25 – 1 0.	0.6 – 1	0.60 max
Total reducing sugar	60 – 70	65 min	65 min.
Sucrose content, % by mass	3 – 10	5 – 10	5 max
Acidity, milli equiv. acid/kg	5 – 54	40/kg	40/kg

Source (QSAE, 2005)

2.4 Avocado production

The avocado is a tropical evergreen, upright tree, variable in shape, from tall to widely spreading forms with multiple branches. Fruit bearing starts 3-6 years after transplanting and may continue for 50 years, but the average life span is 35 years. Avocado varieties are classified in three groups, known as the West Indian, Guatemalan and Mexican "races". West Indian avocados originated in the tropical lowland areas of southern Mexico and Central America whereas the Guatemalan and Mexican avocados originated in mid-altitude highlands in Guatemala and Mexico (Schaffer *et al*., 2013). The avocado flower has both functional male and female reproductive organs. The male floral organ, which produces pollen, is comprised of the anthers and stamens. The female floral organ is comprised stigma (which receives the pollen) style and ovary. If weather conditions are relatively stable then in 'Type A' cultivars the female stage of the flowers is open in the morning and the male stage is open in the afternoon. In 'Type B' cultivars, the male stage is open in the morning and the female stage is open in the afternoon. This flowering system is called 'dichogamy' (Dymond *et al*., 2021).

Avocado was first introduced in Ethiopia around 1938 by private orchardists in Hirna (Eastern Highlands of Ethiopia) and Wando genet (Southern highlands of Ethiopia) and it has been distributed to different agro ecological zone (Zekaries, 2010) ; Abduselam, 2016). In Ethiopia avocado trees The main avocado producing areas include the Sidama and Woliata areas in the south, the Jima and Mizan areas in the southwest and the Hararge area in the eastern region of the country (Birhanu and Dawit, 2013). Avocado trees in Ethiopia are mainly grown as integral component of Coffe (*Coffe Arabic*) and Enset (*Enset Ventricosum*) production systems (Zekaries, 2010). The major avocado varieties grown in Ethiopia include Hass (Guatemalan), Pinkerton (mexican and indian cross), Fuerte (Mexican and Guatemalan cross), Bacon, Napal and and Ettinger (Abduselam, 2016).

In Ethiopia about 245,336 tons of avocado was produced (FAO, 2021). Due to comfortable climatic condition and soil characteristics most of Avocado production is practice in southern Ethiopia (Abduselam, 2016). Avocado cultivation in Ethiopia is characterized by insufficient number of trees per Ha, disease problem, lack of adaptable high yielding and better quality avocado varieties and production practice is poorly supported by scientific agronomic practice. The fruit yield per hectare was different based on Varieties of avocado, the maximum Fruit yield obtained from Fuerte (14,372 kg/ha) and the minimum fruit yield was obtained from Pinkerton avocado variety (12,262 kg/ha) (Aschalew *et al*., 2021).

According to Biazin *et al*. (2018) in southern high land of Ethiopia avocado production systems have effect on fruit productivity, the mean annual fruit yield per avocado tree was higher when avocado trees were grown in the coffee or enset-based agroforestry systems as compared to the trees grown individually around homes. Avocado uses as a fresh fruit and in the oil industry, avocado is also useful in the cosmetic, soap and shampoo industry (Maregesi *et al*., 2014). Avocado farming has improved the livelihoods of farmers through increase generating income, employment opportunities, improving food security, poverty reduction and nutritional security (Shamil, 2023)..

2.4.1 Avocado fruit quality and its characteristics

Quality parameters of fruits likes oil content, dry matter, TSS, pH, composition in the fruit and physical characteristics is necessary for the evaluation of a maturity index for avocados growth in Ethiopia that could give help for local and international marketing efforts, with highest confidence (Tsegay, 2017). Acidity is related to both sweetness and sourness of fruit. Titratable acidity is the method used to measure acidity. From the main fruits avocado fruits have great advantage with a potential for domestic and export market and industrial processing in Ethiopia (Kenbone, 2017). Fruits produced from cross- pollination seem to have more chances of reaching the maturity stage than fruit resulting from self-pollination (Alcaraz & Hormaza, 2021). Avocado fruits have a number of characteristics that help indicate harvest maturity. Skin texture, appearance and color are an indicator of harvest maturity in most avocado cultivars and it's graded according to size and weight. Fruit characteristics of avocado determined through fruit weight, fruit length, fruit diameter and others (Poudel *et al*., 2018).

2.4.2 Role of the honeybee in the pollination of crops

In tropical crops, 70 % of the 1330 cultivated species are favored by these pollinators, while in European crops, 84 % of the 264 cultivated species depend on the animal pollination process, and it is known that the yields of some fruit, seed and nut crops decrease by more than 90 % without these pollinators. Promotion of pollination services significantly benefits agricultural productivity, food security, and the achievement of sustainable development goals (Thomas *et al*., 2020).

Honeybee has a great potential in raising the productivity of cross-pollinated as well as other crops those need insects for their pollination and they are essential for efficient agricultural production, which increase yield of many agricultural and horticultural crops without changing environmental balance (Veer and Jitender, 2017). Workers of honeybees visit multi-flowering plant species at a time to collect nectar and pollen at a time they serve as cross pollinator. Honeybees provide pollination services that are crucial for sexual reproduction and improving the quality and quantity of many agricultural crops (Zekiros, 2019). This indicated that honeybees are the most efficient insect pollinators in cultivated crops. Tura and Admassu (2019) also reported the effect of pollination on yield and quality of niger, onion, apple, and faba bean seeds in Ethiopia indicated that honeybee pollination plays a great role in the Ethiopian crop production. Managing honeybees for crop pollination have a great role for the improvement of agricultural crop yield in terms of quality and quantity.

2.4.3 Role of honeybee in pollination of avocado

Avocados are characterized as having low fruit set meaning that most of the flowers never set fruit. In many species, this can result from inadequate pollination. According to Perez-Balam *et al*. (2012) in avocado orchards, it is common practice to introduce honeybee colonies (Apis mellifera) to promote pollination. Adequate pollination leads to enhanced quality of the produce such as fruits. Tools to better manage pollination in avocado are required given the increasing production of avocados globally, the need for more sustainable production systems that make better use of inputs such as insect pollination (Garibaldi *et al*., 2019). Insect pollinators are thought to facilitate avocado pollination and thus increase production, and there is evidence of opportunities to improve yield through improved pollination service (Dymond *et al*., 2021). Honeybees (*A. mellifera*) were noted to be the most abundant and frequent insect flower pollinators of avocado (Mulwa, 2019).

Pollinators are thought to facilitate avocado pollination and thus increase production, and there is evidence of opportunities to improve yield through improved pollination service. Managed honeybees pollination services improve avocado fruit production (Toni *et al*., 2018). Bees appear to be very important for moving pollen from the male stage flowers to the female stage flowers, completing the pollination process in cross pollination. High pollination efficiency for fruit set, increased the production and improved the weight of the fruit of avocado**.** Insufficient pollination has been suggested as one of the possible limiting factors in commercial avocado production .One of the key aspects of avocado production use of managed honeybee colonies for provision of pollination service, which assures fruit set and increase productivity. Successful pollination of avocado occurs only when flowers in the female stage receive pollen from flowers in the male stage (Monzón *et al*., 2020).

2.4.4 Managing bees for pollination

The use of honeybees to pollinate various agricultural and horticultural commodities has been demonstrated to be an efficient means of improving fruit and seed set in responsive species. Bee pollination is important for increases fruit yield and quality and has a role in faster fruit ripening. Achieving the best results from the use of honeybees for this purpose requires careful management on the part of both the service provider (beekeeper) and the producer of the commodities to be pollinated (orchardist/farmer). Hive strength, hive placement and hive density are the key factors to be considered when managing honeybees for pollination The recommended colony density depends on the attractiveness of the crop, the composition, abundance and attractiveness of the other competing floral resources in the landscape, the population density and composition of non-managed bees, the location and strength of honeybee colonies and other environmental variables like the climate (Orianne and Lucas, 2019). The suitable temperature range for bees to forage is 15–25 ◦C, and bees will stop foraging when the temperature is below 14 ◦C or above 30 ◦C (Pal *et al*., 2019).

3 MATERIALS AND METHODS

3.1 Description of the study area

The study was conducted in Dara Otilcho District of Sidama National Regional State, in southern Ethiopia (Fig. 1). The District is located 77 km away from the regional city Hawassa. The altitude of the District is 1000-2400 meters above sea level. It extends between 6°50’4’’ N latitude and 38°23’36’’ E longitude (Dara Otilcho District Agriculture Office, 2021). The study area receives an annual rainfall of 900 mm to 1200 mm and an annual temperature ranges from 20 °C to 25 °C. The study area has a wet season from April to October and dry season is between November to March. The District borders with Aleta wondo District to the North, Dara District to the South, Oromiya region to the East and Aletachuko District to the West direction. The total land area of the District is about 9501.38 hectares. From this about 394.9ha, 2012.3ha, 472.7ha and 87.4 ha covered by grazing land, crop land, forest land and others respectively (Dara Otilcho District Agriculture Office, 2021).

The District has a suitable climatic condition for agricultural products mainly Avocado, *Enset*, Coffee and others like Corn, *teff* and other crops and cattle breed is the Arsi Bale cattle. The District is classified into Dega and Woina-dega agro-climatic zones. Soil types are mainly clay and silt is dominant. Some natural forests are available in the district; however, no conserved areas are found (Dara Otilcho District Public Relation Office, 2021). The farming system practiced in District is agro forestry and the grazing lands are covered by different vegetation types. According to the Dara Otilcho District livestock and fishery resource development office report, the total livestock population of the District consists of more than 32770 local and 7923 crossbred cattle, 16893 sheep, 14717 goats, 7963 local 12170 exotic poultry and 1853 horse, 489 donkeys, and 133 mules. The total livestock population of the District is 94,911. The total human population of the Dara Otilcho District is 109,747. From these 53,776 (49%) are male and 55971 (51%) female (Dara Otilcho District Public Relation Office., 2021).

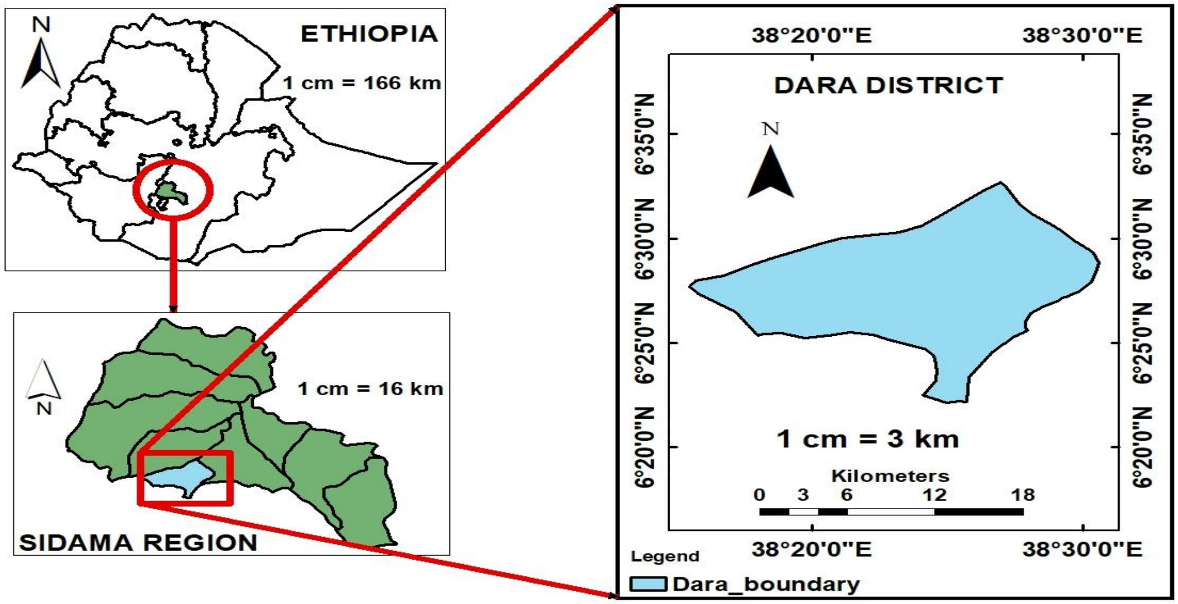

Figure 1: Map of the study area.

3.2 Sample Size and Method of Sampling for survey part

This study had two components: the first part was a survey, which was conducted to assess the beekeeping practices and avocado flowering season in the study area. The second part was an experiment, which was aimed at determining avocado fruit production and the quantity and quality of honey based on honeybee hive density.

For survey part, multi stage sampling method was used to collect data. First, Darra district was selected purposively from Sidama regional state based on potential honey producers and availability of Avocado trees as well as the District is GIZ project area. Then after, based on the information obtained from Darra Otilcho district office of Agriculture, agro-ecology was stratified to midland and high land. From a total of 18 kebeles in the district 4(four) (two from each high land and midland agro ecology) were selected randomly. Then the 58 representative beekeepers from each agro-ecology were purposely selected using simple random sampling technique and a total of 116 beekeepers were selected for this study. The information related to beekeeping and avocado flowering time issues was gathered from the selected beekeepers using a structured questionnaire.

The sample size was determined by applying Yamane formula

$n = N/ (1 + Ne2)$

Where: n = sample size, N = population, and e = sampling error (precision level)

$n = N/ (1 + Ne2)$

Hence $n= 162/1+ 162(0.05^2) = 116$.

3.3 Experiment design and treatment

A preliminary study was conducted to collect information on beekeeping practices, availability and flowering period avocado tree in the study area. Based on this observation, the experiment was designed in the orchards of avocado tree dominated area in the Dara Oliticho district of Sidama region during the flowering period of avocado plant and when other plants available around the site stop flowering. For this study, the experiment was Randomized Completely Block Design applied with four treatments each with three replications. The treatment was based on density of honeybee hive. Accordingly, 0 hive (T1) (only for fruit), two hives (T2) and four hives (T3) and six hives (T4) was carried out.

3.4 Experimental procedure

The study was undertaken to evaluate effect of honeybee hive density on avocado fruit production and honey quantity and quality in Dara Oliticho district. First site of avocado tree abundantly found which their age (12-15) and height (10-12) was closely related selected. A total of 12 avocado orchards with an area one (1) ha for each orchard were selected purposively based on possession of avocado tree. The selected Orchards were free from honeybee colonies before introduced honeybee colonies for treatments and were grouped into four groups based on treatment. A total of 36 honeybee colonies were used with Transitional (Kenya top bar) hive based on treatment.

To see the effect of honeybee hive density on honey and fruit of avocado similar management practice was undertaken to each treatment. Four avocado trees (one tree from each East, West, and North and South direction) were selected. On selected avocado tree three branches were tagged randomly, then after three clusters of flower per tagged branches of avocado trees were selected from each treatment to evaluate fruit set, yield and quality of Avocado fruit. From each treatment, 12 fruits samples were collected from all parts of avocado tree (top, medium and bottom) for evaluation of individual fruit weight and length avocado fruit. At the end of flowering honey was harvested and sample of honey was collected from each site for honey quality analysis.

3.5 Data collected

During the study period data related to households, honey quantity and quality and fruit production were collected. Both primary and secondary data were gathered for this study. The primary data including questionnaire, key informants and field observation were used. On the other hand, secondary data was collected from secondary sources including the office of agriculture, published and unpublished materials.

3.5.1 Household survey

For survey part data on socio-economic characteristics of households, topographic characteristics of the fields, flowering period of avocado, source of honeybee, supplementation of feed, swarming activities, Perception farmers pollination, type of hive they used, honey yield, honey harvesting period and frequency of harvesting honey in the study area were collected.

3.5.2 Avocado fruit set

Data on fruit set per cluster was obtained from each treatment. In order to determine the percentage of fruit set, the number of flowers (flowering) and the number of finally formed fruits was recorded on three inflorescences (cluster of flower) label per randomly selected branch of the tree after the end of flowering. To determine the Percentage of fruit set, the following equation was used:

Percentage of fruit set = Number of fruits formed / Number of flowers * 100.

3.5,3 Fruit Length and weight

Fruit length and weight were measured by using digital caliper and weighting scale respectively after sample fruit from each treatment was harvested (Samnegård *et al*., 2019)**.**

3.5.4 Avocado fruit yield

Fruit produced from the study area was harvested to determine fruit yield per tree (Abdel-Karim *et al*., 2015).

3.5.5 Avocado fruit Quality

In order to determine avocado fruit quality fruit sample at a mature stage was collected from each treatment and prepared for evaluated Dry matter, soluble solids, pH and titratable acidity in Food science Laboratory at Hawassa University College Agriculture.

3.5.5.1 Dry Matter

The dry matter (DM) of avocado fruit was determined according to Kenbon (2017). The petridishes used for the moisture determination were dried at 130 degree Celsius for 1hr using drying oven. The dishes were removed and kept in a desiccator for about 30 minutes. The mass of empty dishes were measured as M1. This was regulated until constant weight was obtained. About 10g of the sample was weighed using analytical balance in to the dish and recorded as M2. The sample was mixed thoroughly and dried at 60 degree Celsius until it reached a constant weight. And it was taken and kept in a desiccator to cool. After cooling the weight was taken as M3 and then kept in oven for another 15 minutes. Then it was removed and allowed to cool in a desiccator and again the weight was taken. This process was repeated until constant weight was obtained.

Then, the dry matter content was calculated using the following formulae:-

$$\text{Dry Matter (\%)} = \frac{\mathrm{M3-M1}}{M2-M1} * 100$$

Where, M1 = weight of the dish, M2 = weight of the dish and the sample before drying, M3 = weight of the dish and the sample after drying.

3.5.5.2 Soluble Solids

Avocado fruit juice was extracted using juice extractor and soluble solids from extracted samples will be determined by using a digital or a hand refractomter (Tigist and Tolawak, 2016).

3.5.5.3 PH

PH was measured using digital pH meter after homogenizing 10 ml of the fruit juices in 90 ml of distilled water (Tigist and Tolawak, 2016).

3.5.5.4 Titratable acidity

The Titratable acidity of avocado fruit was determined according to Kenbon (2017). Ten (10) ml samples of filtrates prepared for the TSS test was pipetted to a 50-ml beaker and titrated against 0.1 N NaOH with phenolphthalein as the pH indicator until pink color was obtained. TA was calculated as number of milliliters of 0.1 N NaOH multiplied by an appropriate conversion factor. The conversion factor of 0.075 was chosen based on tartaric acid, a predominant acid in avocado. TA, expressed as % tartaric acid can be calculated as follows. Titratable acidity was expressed as g lactic acid/100g of juice and calculated using the formula:

$$TA = TA\ (\%) = \frac{\text{ml NaOH x N(NaOH) x acid meq.factor}}{ml\ juice\ titrated} \quad *100$$

Where, TA = Titratable acidity;ml NaOH = amount (in ml) of NaOH .

3.5.6 Honey yield

Honey produced from the study area was harvested from all treatment to determine honey yield. After harvesting of honey, the amount was measured immediately by using a sensitive balance weigh.

3.5.7 Pollen of honey sample analysis

Pollen types were determined through grouping and counting pollen grains in the prepared sediment of each honey sample using a microscope. According to Tura and Admasu (2019) the pollen types present in the honey samples were identified, counted, and classified, according to their percentages, as dominant pollen (more than 45% of the total pollen grains counted), secondary pollen (from 16 to 45%), important minor pollen (from 3 to 15%), and minor pollen (less than 3%). Pollen types were determined through using a microscope. Counts were expressed as percentages after counting a minimum 500 pollen grains on two slides from sample. The examination of the pollen slides were carried out with an optical microscope at 400 in order to make sound identification of the pollen types.

3.5.8 Honey quality

Physicochemical properties (moisture content, ash, PH and acidity, electrical conductivity, color, Glucose, Fructose, sucrose content and HMF) of honey produced in the study area was analyzed according to the Harmonized Methods of the International Honey Commission (2009) to compare with farmer and Quality and Standards Authority of Ethiopia (QSAE). Honey sample was collected in June or at the end of the avocado flowering period. A quarter of a kilogram (0.25kg) of honey samples from each treatment and three honey sample from the farmer who had transitional hive was collected in honey container, prepared for honey quality analysis and labeled with numbers, type treatment and date of collection. Physicochemical parameters of honey analysis were done in laboratory at Holeta Bee Research center. The quality of honey was analyzed through the following procedures.

3.5.8.1 Moisture Content

The moisture content of honey sample was estimated by determining the refractive index of the sample with the use of refract meter. The sample directly covered on the surface of the prism evenly; after two minutes the reading of refractive index was recorded. Each sample was measured twice and average of two readings was recorded and corresponding value for moisture content was recorded (Bogdanov, 2009).

3.5.8.2 Ash Content

Ash content was determined after the sample burnt in an electric muffle furnace (Birhanu Tesema, 2015) . Percent ash g/100 g honey was calculated by using

$$\text{Ash (\%)} = \frac{M1-M2}{MO} * 100$$

Where M0 =weight of honey, M1 =weight of dish + ash and, M2 =weight of dish

3.5.8.3 PH and Free Acidity

Solution of honey sample and distilled water was prepared based on scientific procedure for subsequent step. The solution was titrated with 0.1M sodium hydroxide (NaOH) solution to pH 8.30 consequently pH was evaluated with the help of pH meter after calibration (Bogdanov, 2009).

Acidity was determined as follow:

$$\text{Acidity} = 10V$$

Where V = the volume of 0.1N NaOH used and 10 is the amount of sample.

3.5.8.4 Determination of Glucose, Fructose a and Sucrose

Common sugars like glucose, fructose and sucrose were evaluated according to Admassu *et al*.(2022). The standard was prepared and 5gm of honey was taken and mixed in 40 ml distilled water. A 25 ml of methanol was placed into 100 ml of volumetric flask and then filtered using filter paper and poured into vials. Peaks were determined based on the holding times of the glucose, fructose, and sucrose.

3.5.8.5 Determination of Electrical conductivity

Electrical conductivity was determined according to Harmonized Methods of The International Honey Commission (Bogdanov, 2009). Honey solutions prepared by dissolving each honey in pure water (20% (w/v)) and conductivity values of honey solutions were measured by using EC meters (Electrical conductivity meter). The measured values were converted to 25C values, the electrical conductivity of honey samples were expressed in 25C, mS / cm2.

3.5.8.6 Determination Color

The color of honey samples was measured according to the P fund classifier. Briefly, homogeneous honey samples free of air bubbles were transferred into a cuvette with a 10-mm light path until the cuvette was approximately half full. The cuvette was inserted into a color photometer P fund honey color grader (No. 0061, made of USA) and the color grades were expressed in millimeter (mm) P fund grades compared to an analytical grade glycerol standard following the procedure of Codex Alimentarius Commission Standards. Measurements were performed for each sample using approved color standards of the United States Department of Agriculture

3.5.8.7 Hydroxymethylfurfural (HMF)

Hydroxyi-methylfurfural (HMF) was determined according to International Honey Commission (Bogdanov, 2009). The determination of the hydroxyi-methylfurfural (HMF) content is based on the determination of UV absorbance of HMF at 284 nm. In order to avoid the interference of other components at this wavelength, the difference between the absorbance of a clear aqueous honey solution and the same solution after addition of bisulphite was determined. The HMF content is calculated after subtraction of the background absorbance at 336 nm. Spectrophotometer operating in a wavelength range including 284 and 336 nm was used.

Accurately weigh 5 g of honey in small beaker and transfer with total of 25 ml distilled water to 50 ml volumetric flask. 0.50 Carrez solution I, mix, was added to 0.50 ml Carrez solution II (mix, and diluted to volume with distilled water and drop of alcohol was added to suppress foam. It was filtered through filter paper and the first 10 ml filtrate was discarded. 5ml filtrate was pipette into each of two 18 X 150 mm test tubes. 5.0 ml distilled water was added to one tube (sample) and 5.0 ml NaHS03 solution to other. It was mixed well by using Vortex and mixer determined. When absorbance is greater than 0.6, sample solution was diluted with water and reference solution with 0.1% NaHS03 solution to correct absorbance for dilution.

The absorbance of the sample solution against the reference solution at 284 and 336 nm in 10 mm quartz cells within one hour was determined. When the absorbance at 284 nm exceeds a value of about 0.6, the sample solution diluted with water and the reference solution with sodium bisulphite solution in order to obtain a sample absorbance low enough for accuracy. When dilution is necessary,

$$\text{The dilution, } D = \frac{\text{final volume of sample solution}}{10}$$

Calculation will be

$$\text{HMF in mg/kg} = (A284 - A336) \times 149.7 \times 5 \times D/W$$

Where: - A284 = absorbance at 284 nm A336 = absorbance at 336 nm

3.5.9 Honeybee colony Swarming and Absconding

During the study period data on colony swarming and absconding were collected from each treatment in the study area.

3.5.10 Partial budget analysis

To determine cost benefit analysis honey and fruit yield of avocado was evaluated in the study area. The cost and benefit sides was computed separately and the cost side divided the benefit side to compute the benefit cost ratio. Prices of the hives and management were considered to analysis cost. Prices of avocado fruit honey and other product was considered to analysis benefit.

NR = TR-TVC……………………………………………………………………….Equation 1

Where: NR = Net return, TR = Total return, TVC = Total variable cost

The change in net return was computed as:

$\Delta NR = \Delta TR - \Delta TVC$……………………………………………………………….Equation 2

Where: ΔNR = Change in net return, ΔTR = Change in total return,

ΔTVC = Change in total Variable cost.

The marginal rate of revenue quantifies the increase in net return associated with each additional

Unit of expenditure. This is expressed by percentage as:

MRR (%) = $\Delta NR/\Delta TVC$ X100………………………………………………….Equation 3 ΔTVC Where: MRR (%) = Marginal rate of revenue in percentage, ΔNR= Change in net return, ΔTVC = Change in total variable cost.

3.6 Statistical Analysis

The collected data was entered into Microsoft excel and descriptive statistics using SPSS version 16.0 was mainly applied mean, frequency and percentage to make analysis of household survey. One way analysis of variance (ANOVA) using the general linear model procedure of SAS software version 9 was used to test statistical significance difference between treatments for fruit yield and quality and honey quantity and quality. A test was made at 95% level of significance. The statistical model used to analysis data was collected for honey quality given below.

$$Yij = \mu + di + bj + \epsilon ij$$

Where, yij = Response variables (Honey yield, honey quality, fruit yield and quality parameters) μ = overall mean, di = the effect honeybee hive density, the effect of replication (block) and eij = random error

The result was organized by tables and graph.

4. RESULT AND DISCUSSION

4.1 Socio-economics characteristics of Households

From the total of sampled respondents interviewed, about 93.1% and 6.9 % of male and female headed households participated in beekeeping activities in the study area (Table 4). This finding implies that the male beekeepers dominated the beekeeping activity. This result is similar to the report of Juher (2020) and Tamiru (2017) in the east Denbiya district,Amhara region, Ethiopia and Gololcha district, Bale Zone, Oromia Regional State, Ethiopia. Both reported that most of the apiculture activities were dominated by man headed households. This may be due to traditional belief that bee-keeping activities are done by men. The majority of beekeeping activities like honeybee hive construction, catching a swarm of honeybees, hanging of hive on a tree, honey harvesting and other activities are done by male headed households.

The overall age mean of respondents was 38 years and ranged from 21 to 78 years and the majority age of beekeepers was between 30-45years old. This indicated that the productive age of people participated in beekeeping effectively, which is economically important for poverty reduction. This study result is similar to the study report of Abera *et al*. (2016) in Damot Gale Woreda, Wolaita Zone, and Southern Ethiopia reported that the majority of the respondents were found in the age 30-39 years old. The minimum and maximum family sizes of the respondents were 2 and 24, respectively, with the mean family size 7.06 persons per household. The result of the study revealed that the beekeepers in the study area have different family sizes engaged in beekeeping activity. The majority (88.8%) of respondents were married, whereas the percentage of single divorced and widowed were 6%, 2.6% and 2.6%, respectively (Table 4).

Regarding the educational status of these beekeepers, about 77.6% households were educated or got a chance to attend basic education, primary school and secondary school. The majority of the beekeepers in the study area have basic education followed by a primary education. This finding is in line with the report of Beyene (2019) who stated that the majority (80%) of beekeepers were educated. According to the result of this study about 22.4%of beekeepers were uneducated. This illiterate household limits beekeeping practices to further improve beekeeping technology. Among interviewed beekeepers the majority (83.62%) of respondents were protestant religion followers whereas about 11.2% and 5.8% were Orthodox and Muslim religion followers respectively (Table 4).

Table 4. Socio-economics Characteristics of Households

Demographic variables	Categories	Agro-ecology High Land N(58)	%	Midland N(58)	%	Overall N(1160	%
Sex	Male	55	94.8	53	91.6	108	93.1
	Female	3	5.2	5	8.4	8	6.9
Age	15-30	4	6.9	3	5.2	7	6
	31-45	31	48.3	32	55.17	63	54.3
	46-60	18	27.58	19	32.75	37	31.9
	Above 60	5	8.62	4	6.88	9	7.8
Marital status	Married	52	86.2	51	87.98	103	88.8
	Single	3	5.2	4	6.92	7	6
	Widowed	2	3.4	1	1.7	3	2.6
	Divorced	1	1.7	2	3.4	3	2.6
Educational status	Illiterate	14	24.1	12	20.68	26	22.4
	Basic education	15	25.86	20	34.5	35	30.35
	Grade 1-4	16	27.58	14	24.1	30	25.8
	Grade 5-8	9	15.5	7	12.06	16	13.7
	Grade 9-12	4	6.9	5	8.6	9	7.75
Religion	Orthodox	6	10.34	7	12.06	13	11.2
	Protestant	49	84.46	48	82.75	97	83.6
	Muslim	3	5.2	3	5.19	6	5.2

Sources survey result, 2021/22

4.2 Beekeeping system in the study area

According to the survey result, beekeeping was practiced as a sideline activity with other agricultural activities. There is no significant difference between agro ecology in terms of bee-keeping systems. Traditional (forest and backyard), intermediate (transitional) and frame beehives are three types of honey production systems practiced in the study area. Based on the present finding, most of the respondents (78.6%) in the study area practiced traditional beekeeping systems whereas 18.8 and 2.6% practiced transitional and modern bee keeping system, respectively (Table 5). Beekeepers practiced traditional beekeeping in the study area made hive from locally available materials like mud and bamboo. Both locally constructed transitional hive and Kenyan Top Bar hive were included in the transitional beekeeping practices. Due to the high cost of the modern and transitional hives and the lack of harvesting and processing beekeeping equipment, the majority of the beekeepers in the study area use traditional hives. The result of the current study agrees with the finding of Seyoum & Anja (2018) and Abera *et al*. (2016) who reported that the majority of respondents practiced traditional beekeeping systems. Similarly, Tariku and Zerihun (2019) also reported that the majority of beekeepers in wondo genet depends on traditional honey production system which is similar to present investigation.

Table 5. Beekeeping production system.

Activities	Categories	Agro ecology High Land N(58)	%	Midland N(58)	%	Overall N(116)	%	X^2	P value
Bee keeping production system	Traditional	46	79.3	43	74.1	89	76.8	1.04	0.59
	Transitional	9	15.51	11	18.9	20	17.2		
	Modern	3	5.2	4	6.8	7	6		

X2=Chi-Square value, N= Number of households

4.3 Honeybee Colony Management

4.3.1 Sources of honeybee colonies

Regarding the sources of honeybee colonies, about 91.4 % of the beekeepers started beekeeping by catching bee swarms, followed by a gift from parents (4.3%), buying honeybee colony(2.6%) and from forest (1.7%) (Table 6). There is no significant difference (p>0.05) observed between the two agro ecology in terms of sources of the honeybee colonies. This study revealed that most of the beekeepers established their beekeeping through swarm catching. This is due to the fact that farmers have experienced of huge indigenous knowledge of catching swarms during active reproductive and swarming seasons. This finding is in agreement with the study of Tamiru (2017) in Bale Zone, Oromia Regional State and Alemayehu *et al*. (2021) in Arba Minch Zuria District, Southern Ethiopia, reported that about 94% and 90.9% of beekeepers started beekeeping through catching swarms, respectively. But the result of the present study disagrees with the report of Meseret and Abera (2018). The majority (63%) of the Beekeepers stated that the primary source of honeybee colony was from their parents in the West Gojjam Zone, Amhara Region.

4.3.2 Placement of bee hive

From the beekeepers interviewed, about 84.5% of beekeepers in the study areas placed their honeybee colonies in the backyard while about 8.6% of the beekeepers placed their honeybee colonies placed under the eaves of the house and 6.9% hung on trees near the homestead (Table 6). Statistically, there is no difference ($p>0.05$) observed between two agro-ecologies. The result of the study indicated that the majority of beekeepers in the study areas placed their honeybee colonies in the backyard. Hive placement in backyards are easier for daily inspection of honeybee and controlling from thief, predators and ants.

This finding is similar to the research finding of Alemayehu *et al*. (2021) in Arba Minch Zuria District, Southern Ethiopia and Dinku and Bereket (2019) in Hawasa ,Southern Ethiopia indicated that majority of beekeepers placed their honeybee colonies hive in the back yard. However, the present study is not in agreement with report of Soresa *et al*. (2021) and Tulu *et al*. (2020) indicated that the 54.2% and 64% of bee keeper placed their honeybee colony hive in the forest respectively.

Figure 2. Hive placement

4.3.3 Supplementary Feeding practices of honeybees

The result of the study indicated that about 81.9% of beekeepers in the study area provided supplementary feed to honeybee colonies during shortage of the bee forage (Table 6). The supplementary feeds include peas flour (Shiro), Enset starch (bula), sugar and honey. 18.1% of beekeepers do not provide supplementary feed for their honeybees. Most the beekeepers provide supplementary feed for their honeybees. The result of this study agrees with the finding reported by Seid (2020) in Gonder, Amhara region and Gebrehaweria *et al*. (2018) in Afar region. Similarly, Dawud *et al*. (2020) in West Hararghe Zone, Oromia Regional State, Ethiopia reported that the majority of beekeepers supplement their honeybee colony. However, this study result differ from Tamiru (2017) in Bale zone, Oromia region indicated that about 24.5% of beekeepers provided feed for their honeybee colony.

Table 6. Honeybee hive placement, source of honeybee colony and Supplementary feed of honeybees

Activates		Agro ecology Midland (%)	Highland (%)	Over all (%)	X^2	P value
Hive placement	Back yard	81.06	87.93	84.5		
	Under eave of house	10.34	6.89	8.6	0.44	0.8
	hang on trees near home	8.6	5.17	6.9		
Source of honeybee colony	Catching bee swarms	89.65	93.1	91.4		
	Gift from parents	6.89	1.7	4.3	4.17	0.24
	Buying colony	3.44	1.7	2.6		
	Forest	0	3.44	1.7		
Provide Suppleme ntary feed	Yes	86.2	77.6	81.9	1.4	0.28
	No	13.8	22.4	18.1		

4.4 Honey yield from different Hive types

The result of the present study revealed that traditional, transitional and modern hive showed a difference in honey yield per year. The overall mean amounts of honey yield per year from traditional, transitional and modern hives were 6.18±1.51kg, 13.75±1.69kg and 21.86±2.59kg respectively (Table 7). The mean value of honey yield was different among the three types of hives. This indicated that types of honeybee hives influenced honey yield. The result of this finding was similar to the report of Alemayehu *et al*. (2022) who reported that the mean values of honey yield harvested per year were 5.14kg, 15kg and 22.54kg for traditional, transitional and modern hives respectively in Horo Guduru Wollega Zone. Similarly, Alemayehu *et al*. (2021) in the Arba minci area reported honey yield harvested per year from three agro ecologies were 5.81 ± 5.09kg, 20.05 ± 4.31 kg from the traditional and modern hives, which related to present study. Tufo *et al*. (2017) showed that the mean values of honey yield harvested per year were 12.85kg, 32.99kg, and 40.095kg for traditional, transitional and modern hives respectively, which is higher than the current finding. However, Dawud *et al*. (2020) reported averages of honey yield 8±2.83 and 13.9±4.04 kg from transitional and modern hives, respectively which is less than the current study. The difference of honey yield harvested might be due to variation honeybee flora abundance, hive types, climatic condition, agro ecology and management undertaken for honeybee colony.

Table 7. Honey yield from different types of hive

Agro-ecology	Honey yield per hive per year (Kg)		
	Traditional	Transitional	Modern
High land	5.81	12.36	19.25
Midland	6.56	15.15	22.98
Over all	6.18±1.51	13.75±2.59	21.31±2.58

4.5 Frequency and season of honey harvesting

The result of the study indicated that, about 87.9% of beekeepers harvested their honey twice and 9.5% harvested three times per year in the study area (Figure 3). This implies that the majority of the beekeepers harvested honey twice. The result of this finding is similar with the report of Tamiru (2017) who stated that honey was harvested twice in the Bale zone Oromia Region. However, the present study is not similar to the report of Gebrehaweria *et al*. (2018) in Afar Region, who indicated that all beekeepers harvested honey more than once and some Beekeepers harvested honey five times based on the availability of honeybee floral resources. In the study area, due to lack of knowledge about proper harvesting time and lack of bee forages, some beekeepers (2.6%) also harvested the honey once a year

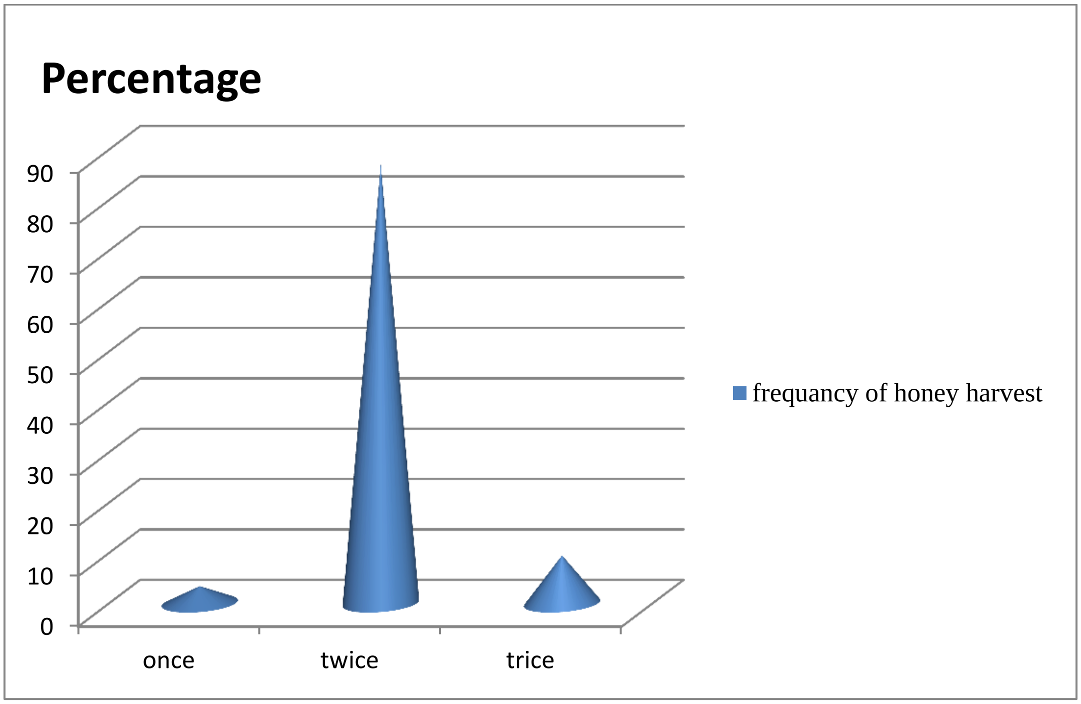

Figure 3. Frequency of honey harvest

The majority of beekeepers (87.9%) honey harvesting season in the study area was from October to December and April to June, followed by some beekeepers (9.5%) harvesting honey from October to December only (Table 8). Beekeepers harvested honey in different season based on the availability of honeybee floral resources.

Table 8. Season of honey harvest

Harvesting season	Agro ecology		
	Midland (%)	Highland (%)	Overall (%)
October to December only	8.6	10.3	87.9
October to December and April to June	89.6	86.2	9.5
September to October, November to December and April to June.	3.4	0.8	2.6

4.6 Honeybee flora in the study area.

Most important flowering plants in the study area described by respondents and key informants are presented in Table 9. According to field observation the honeybee plants in the study area were classified as trees, shrubs, herbs, and cultivated crops. Establishing apiary site requires adequate knowledge of beekeepers on the types and flowering times of bee floras (Tariku and Zerihun, 2019). Identifying a floral calendar is a timetable that indicates the approximate date and duration of the flowering periods of the important honeybee forages (Tura and Admassu, 2018).

Table 9. List of common Honeybee flora identified

No	Common Name flora	Scientific name of flora	Type of the plant (Tree, shrub herb, cultivated crop)	Flowering time (months)	Source (pollen or Nectar)
1	Gerawa	Vernonia Spp	Tree	December	P&N
2	Masincho	Croton macrostachyus	Tree	May	P&N
3	Adeyabeba	Bidens spp	Herbs	October	P&N
4	Avocado	Persea Americana Mill	Tree	September-decemeber April-June	Pollen and nector
5	Mango	Mangifera indica	Tree	Septembe-december	Pollen
6	Birbira	Milletia feruginea	Tree	January-april	P&N
7	Keyi Barzaf	Eucalyptus camaldlensis	Tree	March-june	P&N
8	Buna	Coffe arrabic	Shrubs	January-Febrary	Nectar
9	Wadicho	Cordita Africana	Tree	June-july	P&N
10	Rejicho	Vernonia figiera olive	Tree	May	P&N

11	Badala	Zea mays	Crops	June-august	Pollen
12	Girar	Acacia albida	Tree	May	P&N
13	Bakela	Vicia faba	Crops	September-November	P&N
14	Mashila	Sorghum bicolor	Crops	September-November	Pollen
15	Gomen	Brassica carinata	Crops	June- November	P&N
16	Sesbania	Sesbania sesban	Tree	Nov-January	P&N
17	Gesho	Rhamnussp	Shrubs	March- April	P&N
18	Atar	Pisum sativum	Crops	September-November	P&N
19	Honicho	Juniperus procera	Tree	May	P&N
20	Kulkual	Euphorbia abyssinica	Shrubs	September- November	P&N
21	Chat	Catha edulis	Tree	July-October	P&N
22	Weira	Olea Africana	Tree	September- December	P&N
23	Hadda	Guizotiascabra sub sp	Herbs	Year round	P&N
24	Warka	Piscus Species	Tree	March	P&N
25	Dinech	Cicerarietinum	Crops	September-November	P&N
26	Muzi	Musa paradisca	Tree	September- October	P&N
27	Gulo	Ricinuscommuni	Tree	September- October	P&N
28	Mech	Guizotia scabra	Tree	September-October	Pollen
29	Papay	Carica papaya	Tree	September to November	P&N
30	Zeyitona	Psidiumsp	Tree	March	P&N

4.6.1 Bee flora species Abundance

According to the survey result, the dominant bee flora of species in the study area were *Bidens spp, Eucalyptus camaldlensis, Coffe arrabic, Croton macrostachyus, Persea Americana, Cordita Africana, Mangifera indica ,Vernonia Spp and Zea mays*. Most of the bee flora in the study area was flowering once per year at different times; the other was flowering twice. Flowering frequency of avocado flora was two times per year. The flow season of honey production was based on honeybee flora availability.

4.7 Perception of Beekeepers on pollination

All respondents knew honey bee. According figure 4 the result of the survey indicated that in the study area about 36.5% of beekeepers know the role of insects in avocado pollination. However, about 63.5% of respondents did not know about pollination services. This revealed that some fruit production farmers need training and awareness creation on pollination services to increase productivity of fruit. In the study area different insect pollinators identified by respondents were honeybee, wasps, stingless bee and fly. This study does not agree with finding of Tarakini *et al*. (2020) who stated that the majority respondents (67%) understand about pollination. However, the current result of the study is relates to finding of Misganaw *et al*. (2017) and Zekiros (2019) reported that the majority of farmers had no knowledge about pollination and importance of insect pollinator in Ethiopia. Understanding how pollination affects avocado fruit production is necessary for development of agriculture.

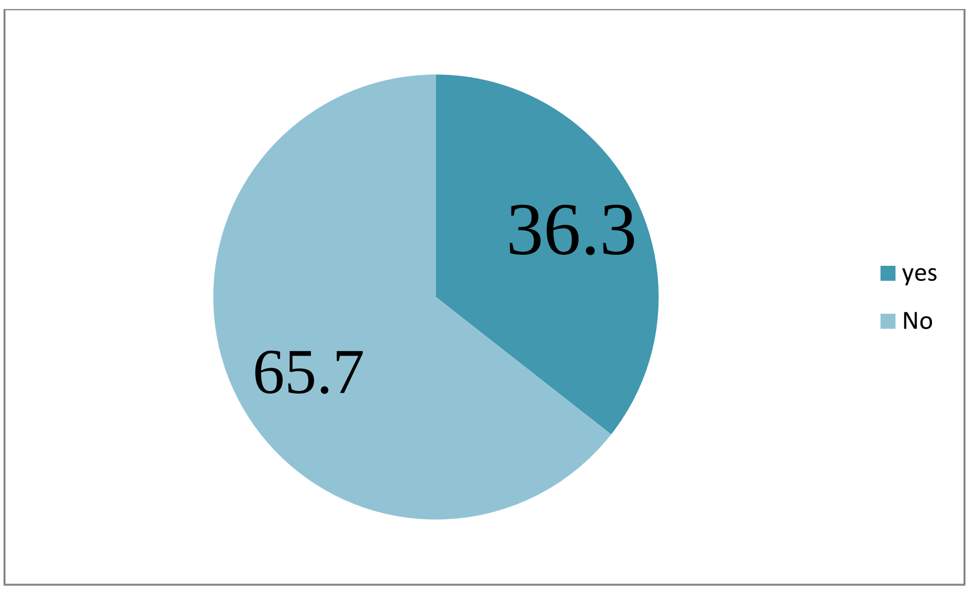

Figure 4. Perception of Beekeepers on pollination

4.8 Effect of hive density on Avocado fruit production

4.8.1 Effect of hive density on Fruit set of Avocado

The result of current finding showed that the highest fruit set percentage was recorded from treatment 4 (26.78%) and lowest fruit set percentage was obtained from treatment1 (5.92%) (Table 10). Statistically highly significant difference ($p<0.05$) were observed among the treatment's regarding to fruit set. This might be due to increased fruit set percentage was based on the density of honeybee hive. As density of honeybee hive increased per orchards the number of honeybee visited per tree was increased which used for increasing fruit set percentage of avocado fruit. This result suggested that pollination limited fruit set percentage of avocado. Successful fruit set in avocado is based on an overlapping of flowering stages, sufficient insect activities and temperature above $10c^{o}$ (AbdelKarem *et al*., 2016).

Supplementation of pollination by honeybee to other pollinator in avocado orchards had great advantages for avocado fruit set percentage, indicating higher fertilization success in supplementation honeybee pollination than no hive per orchards. The result of this finding is similar to the study of Peña & Carabalí (2018) who reported that increasing honeybee hive per orchards increased the fruit set percentage of avocado and Alcaraz & Hormaza (2021) who stated that introducing six hives in avocado orchards increased fruit set percentage of avocado fruit. Similarly, current result is comparable to Abdel-Karim *et al*. (2015), Mulwa (2019) and Islam and Kfrawey (2018) who indicated that fruit set percentage of avocado was 13-27.6%, 6.9-21.0 and 6.93-15.42% respectively.

Figure 5. Flowering of avocado and fruit set

There was strong correlation observed between density of hive and fruit set percentage(r=0.96). The correlation between number of hive and fruit set percentage indicated that when number of hive per Avocado orchards was increasing, fruit set percentage of avocado also increased.

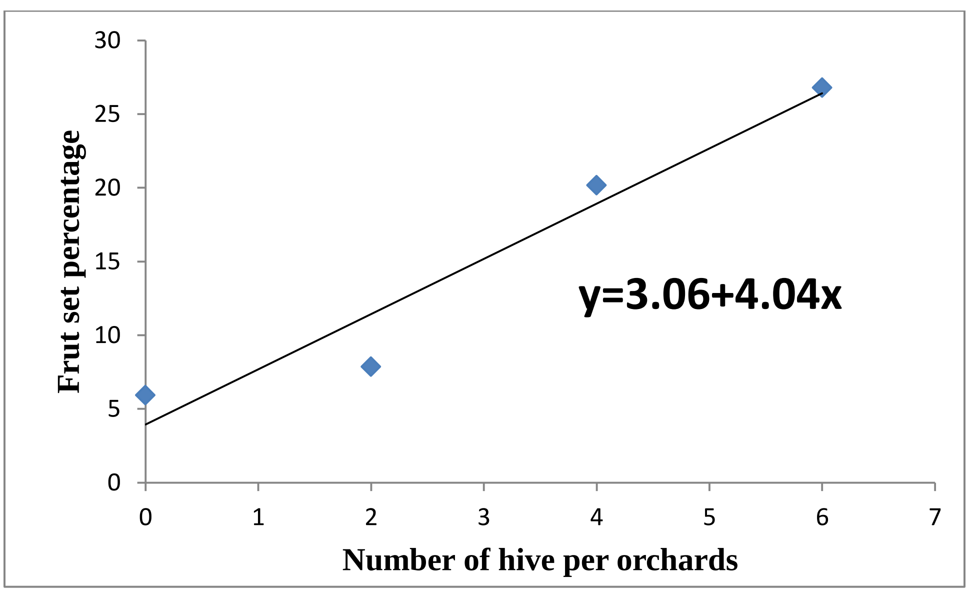

Figure 6. Regression between number of hive and fruit set percentage of avocado.

4.8.2 Effect of bee hives density on length and weight of avocado fruit

The obtained result of present investigation is presented in Table 10. From all sites of the study, treatment four scored highest fruit length (13.2cm) and shortest value of fruit length (7.1cm) was recorded from control or no hive in the orchards with over all mean 9.8cm. Honeybee-pollinated fruit had a higher significant value of fruit length as compared to fruit obtained from open-pollinated. This finding indicated that supplementary honeybee-pollination increased the fruit length of avocado. The result of present investigation regarding to avocado fruit length is agreement with the study of Anees *et al*.(2022) on Strawberry fruit, who indicated that length of fruit value was varied based on types of pollinator and Panatda *et al*. (2018) who indicated that length of avocado fruit was longest based on honeybee pollination than other pollinator. Similarly, Avinash (2023) reported the value fruit length of mango is higher for fruit pollinated by honeybee (10.3cm) than fruit produced from open pollination (9.01cm) and pollinator exclusion (5.67cm).

In the study area weight of individual avocado fruit was measured for all treatments. The result of this study demonstrated that the lowest individual fruit weight of avocado was recorded for treatment one (185gm), whereas the highest result was obtained from treatment four (258gm) (Table 10). Significant differences were observed among treatments regarding to avocado fruit weight. By introducing two, four and sex hives per orchards, individual fruit weight of avocado increased by 14.6, 32.4 and 39.45%, respectively, compared to an orchards without hive. This might be due to introduced honeybee hive at a different number in orchards, which improved pollination service. This investigation showed that introducing honeybee hives per orchards increased the individual weight of avocado. The present study agrees with the finding of Peña & Carabalí (2018) who reported that introduction of honeybee hive in avocado orchard had increased fruit weight of avocado. Additionally the result of present finding is in agreement with study of Mulwa (2019) who stated that pollination by honeybee had increased fruit weight of avocado and Rose *et al*. (2021) who reported that honeybee supplementation pollination on avocado orchards significantly increased fruit weight of avocado than hand and open pollination.

4.8.3 Effect of honeybee hives density on yield of avocado fruit

The result of present study revealed that the highest fruit yield per tree was obtained from treatment four (246.78kg) and lowest fruit yield was recorded from treatment one (137.15kg)

(Table 10). Statistically, there is highly significant difference ($p<0.05$) observed among the treatment's regarding to fruit yield per tree. By introducing two, four and sex hives per orchards, fruit yield increased by 28.81, 45.02 and 79.56%, respectively, compared to the control. This might be due to the different density of honeybee hive introduced per orchards. When honeybee hive density introduced into orchards was increased up to 6 hives, fruit yield per tree was increased.

Similar to this study Peña & Carabalí (2018) who reported that when avocado orchards were supplemented with honeybee colony pollination, resulted in fruit yield increased by 68% than no honeybee hive per orchards. Mulwa (2019)), Stern *et al*. (2021) and Islam and Kfrawey (2018) showed that avocado yield is influenced by pollination which is similar to present finding. Zekiros (2019) indicated that the fruit yield produced from honeybee pollination is higher than the fruit obtained from open pollination and, which is related to present study. Therefore, it's clearly indicated that honeybee pollination has great role in avocado fruit production. Honeybee is one of potential of pollinators in avocado orchards (Christopher, 2020). Bee pollination is more effective than wind and self-pollination, resulting in a high number of fruit produced (Klatt et al., 2013)

Table 10. Fruit set, weight and yield of avocado fruit

Parameter	Types of treatments				P value
	Treatment 1	Treatment 2	Treatment 3	Treatment 4	
Fruit set (%)	5.92^{d}	7.86^{c}	20.16^{b}	26.78^{a}	0.001
Fruit weight(gm)	185^{c}	212^{b}	245^{a}	258^{a}	0.001
Fruit length(cm)	7.1^{c}	8.2^{c}	10.5^{b}	13.2^{a}	0.001
Fruit yield (kg)	137.15^{d}	176.67^{c}	198.9^{b}	246.78^{a}	0.001

Percentage or Mean with different letters were significantly different at level of $p<0.05$

4.9. Effect of bee hive density on fruit quality of avocado

The result of avocado fruit quality is presented in Table 11. In the current study, introducing 4 and 6 hives per avocado orchards revealed that better TSS, DM and lower TA values as compared to control in terms of fruit quality. This result revealed that honeybee pollination was increased fruit quality of avocado. The current result of study confirm finding of Mulwa (2019) who reported that honeybee most abundant pollinator, which enhancing quality of avocado fruit through improving quality parameters. Panatda *et al*., (2018) also indicated that the quality of avocado fruit was significantly higher in the honeybee pollination than in the domestic pollinator. Effective pollination is an essential requirement for yield and quality of avocado fruit production (Rose et al., 2021)

A sample prepared B oven C PH meter

Figure 7. Image taken during laboratory analyzed of fruit.

4.9.1. Dry matter

The current result of dry matter content of all treatment is presented in Table 11. Significant variation was observed among treatments. Treatment four (30.8%) showed the highest dry matter followed by treatment three (28%), two (24.1%) and one (19.1%) respectively. These indicated that when honeybee hive density per orchards increased, dry matter content of avocado fruit increased. Highest dry matter showed that fruit had lowest moisture contents and other nutrients like oil was highest. The increase dry matter is closely related the maturation of avocado fruit (Alaika and Tilahun, 2020). Dry matter content of fruit is the simplest and relatively accurate maturity evaluation for avocado fruit maturity stage and it increases during fruit development due to increase of oil (Tsegay, 2017). Supplementary bee pollination increases growth rate of fruit (Zhang *et al*., 2022). Similar to the present study, Cavigliasso *et al*. (2020) showed that the mean value of dry matter in pollination with *A. mellifera* was significantly higher than that of fruit obtained by open pollinated. This study also agrees with the work has been done by Samnegård *et al*. (2019) who reported that apple fruit from supplement pollination had high dry matter content as compared to natural pollination. The overall mean of dry matter (25.5%) of present study falls in the ranges of 19.6-36.45% and 22.19-35.08% dry matter content of avocado, which is reported by Bayram *et al*. (2016) and Kenbon (2017) respectively.

4.9.2. Total Soluble Solid

The total soluble solid content of avocado fruit juices was evaluated and found that 2, 2.5, 2.8 and 3.5 for treatment 1, 2, 3 and 4, respectively (Table 11). Fruit obtained from treatment four had the highest TSS than the rest of treatment. Lowest TSS of fruit juices was recorded from treatment one. Statistically, there was significant difference observed among treatments concerning TSS. This might be due to the effect of honeybee pollination (Bereket, 2022). According to Adedokun *et al.* (2022) total soluble solid (TSS) is a measure of soluble sugars in fruit juices and important parameter of fruit quality. The level TSS in fruits depends on varieties, soil types, pollinator, climatic condition and growing location.

Avocado orchards supplemented by honeybee at different hive density showed that superior TSS value than the control (no hive per orchards). This result clearly indicated that honeybee had great role in fruit quality of avocado through improving pollination service. The result of this study is in agreement with the study of Anees *et al*. (2022) in Straw berry fruit and Rajan & Reddy (2019) in mango fruit, who stated that the TSS value of fruit is influenced by pollination. Avinash (2023) reported the value of TSS is higher for fruit pollinated by honeybee than fruit produced from open pollination and pollinator exclusion. Similarly, Cavigliasso *et al*. (2020) showed that Blueberry fruits from honeybee pollination have higher TSS value than open pollinated. The TSS values recorded in this finding was nearest to previous study on avocado fruit in Jimma zone by Tigis and Tolawak (2016).

4.9.3. PH

All evaluated avocado sample fruit juices were acidic and had pH value 6.01, 6.04, 6.65 and 6.68 for treatment 1, 2, 3 and 4, respectively (Table 11). Significant differences were observed among treatments in terms of pH value of avocado fruit. Fruit obtained from supplementary honeybee pollination have higher pH as compared to the fruit produced from no supplementary pollination. The pH of fruit is increasing with increasing fruit maturity when acid concentration is declining (Gordon, 2011). The over mean of all treatment (6.35) is related to study of Helen (2019) and Kenbon (2017) who reported pH value of avocado 6.84±0.03 and 6.67 respectively in Ethiopia. Similarly the current result of pH value of avocado fruit juice evaluated is in agreement with the study of Camilo and Pablo (2018) and Tigis and Tolawak (2016) who reported that pH values of avocado in ranges of 6.58 and 7.14 and 6.4-7.17, respectively.

4.9.4. Titratable Acidity

In the study area the mean of Titratable acidity content for treatment 1, 2, 3, and 4 were 0.0086, 0.0075, 0.0068 and 0.0067 respectively (Table 11). Statistically, there is significant difference among treatments. This implies that honeybee pollination influenced titrable acidity of avocado fruit. Increased hive density per orchard has resulted in increased fruit maturity through improved pollination service. During fruit maturity, the titratable acidity of the fruit decreased. The reduced of TA of ripe fruit may be due to the consumption of organic acid for respiration as the fruit ripens (Salameh *et al.*, 2022). High values of TA in a typical fruit negatively linked to the flavor and acceptance of consumer.

The result of present study is in agreement with the finding of Pal *et al*. (2019) indicated that the fruit obtained from open pollination has lower acidity than the fruit produced from no pollination. The overall result of present investigation was consistent with the study of Hotessa (2021) who showed that values of TA of avocado (0.08±0.07) in Bule Hora. Titratable acidity is an indispensible physicochemical property for the quality of fruit. It can measure the shelf life of product and used against the attack of microorganisms (Masresha and Sisay, 2022).

Table 11. Quality parameters of avocado fruits

Types of treatment	Quality parameters of avocado fruits			
	Tss	Ta	Ph	DM
T1(0 hive)	2^{c}	0.0086^{a}	6.01^{b}	19.1^{d}
T2(2 hives)	2.5^{c}	0.0075^{b}	6.04^{b}	24.2^{c}
T3(4 hives)	2.8^{b}	0.0068^{b}	6.65^{a}	28.0^{b}
T4(6 hives)	3.5^{a}	0.0067^{b}	6.68^{a}	30.8^{a}
P value	0.001	0.0001	0.0001	0.0003

Where, TSS, total soluble solid, DM, dry matter, TA, titrable Acidity, pH, Power of hydrogen, Mean with different letters were significantly different at level of $p<0.05$

4.10. Honey yield

The minimum, maximum and over all mean values of honey yield harvested from the study area are presented in table 12. The highest average of the honey yield per hive was recorded from treatment two (17.66kg) and lowest mean values were obtained from treatment four (12.8kg). The total honey yield from treatment four was highest, followed by treatment three and two respectively. Statistically, variation ($p<0.05$) was observed in the mean values of honey yield per hive among honey obtained from all treatments. The result of this study revealed that as the number of honeybee hive increased, the honey yield harvested per hive was slightly reduced. This is due to honeybee competed for consuming the available honeybee forages.

The present result of the study is in agreement with the finding of Caroline (2018) who revealed that honey production is declining when honeybee colonies crowded together, result in competition of floral resources. The overall mean honey yield (14.8kg) of this study is higher than survey result and the investigation of Beyene *et al*. (2015) who showed that honey yield from transitional hive (12.51kg) and similar with study of Dinku *et al*. (2020) who stated that average of honey yield from Kenya top bar in Sidama region, Ethiopia. The difference of honey yield from the same hive type might be due to floral sources, agro-ecology and management.

Table 12. Honey yield

Parameter	Types of Treatments			
	Treatment 2	Treatment 3	Treatment 4	P value
Honey yield per hive	17.66 ± 0.77^{a}	14.13 ± 0.4^{b}	12.8 ± 1.4^{c}	0.0037
Honey yield per treatment	35.32 ± 1.6^{c}	56.52 ± 1.5^{b}	76.8 ± 2.8^{a}	0.002

Mean with different letters were significantly different at level of $p<0.05$

4.11. Pollen in honey

The result of pollen in honey analyzed from study area is presented in figure 8. Pollen determination of all treatment samples indicated that the mono flora of *Persea americana* honey which consisted of 55.27%, 64.86% and 56.96% for treatment two, three and four respectively. Similar to this finding other studies also evaluated avocado pollen percentage in avocado honey up to 60% reported by Terrab *et al.* (2004), 46.9% by Rodríguez *et al*. (2019), and 58% by Serra Bonvehi *et al*. (2019) in Spain. The result of evaluated honey samples pollen was classified according to their percentages, as dominant pollen, secondary pollen, important minor pollen and minor pollen.

The result from the farmers' sample indicated that all pollen analyzed was below 45% and classified as multi-floral honey. In this study, we documented that the pollen content of treatments and farmer beekeepers' *Apis mellifera* honey samples produced in the study areas. During the study period it is found that the majority of the study area honeys for all treatments were dominated by avocados. The importance of these plants in the honey is unsurprising, since Sidama region's agro-forest flora is ecologically dominated by avocado and many avocado species provide floral resources to honeybees. Melissopalynology, or the pollen analysis of honey, is widely used to verify the claimed geographic and floral origin of honey samples (Aronne & de Micco, 2010). Pollen analysis is also routinely conducted as part of food quality assurance procedures in some regions, especially the European Union.

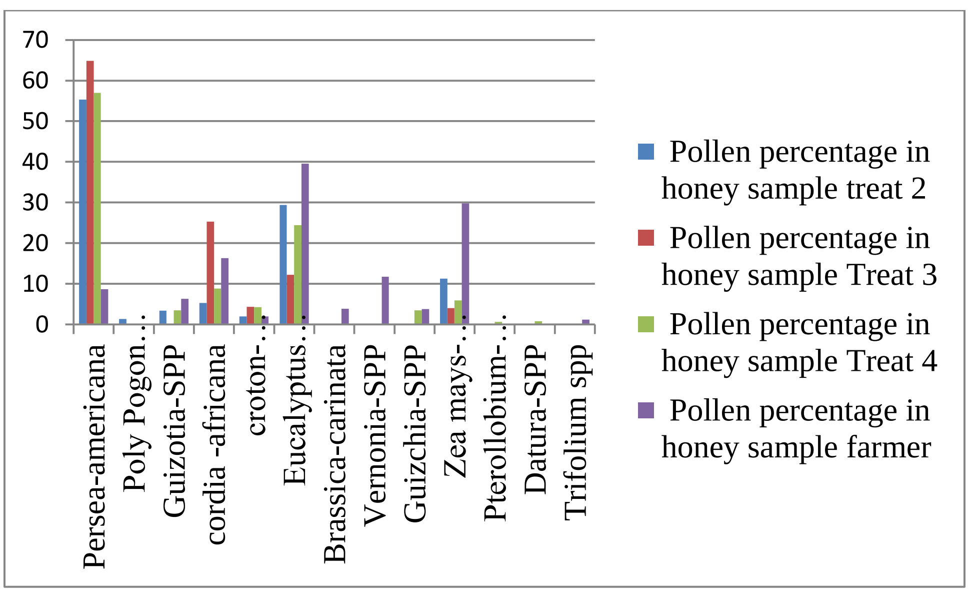

Figure 8. Pollen analyzed result

4.12 Physicochemical properties of Honey

The current Laboratory result of physiochemical properties of honey from all treatments is presented in Table 13. The overall mean of the honey sample of all treatments obtained indicated that physiochemical parameters expect electrical conductivity (0.98), the rest of the honey quality parameters such as moisture content (19.75%), Ash (0.5 g/100 g), HMF (18.16 mg/kg), pH (4.48), free acidity (28.2meq/kg), (glucose (31.52 g/100 g), Fructose (36.47 g/100 g), and sucrose (2.35 g/100 g) were evaluated in this study to comply national and internal standards. Statistically, there is no significant difference ($P > 0.05$) observed among treatments. This revealed that honey quality parameters were not influenced by the density of honeybee hives (2-6 hives per orchard). However, there is statistical variation ($p < 0.05$) observed between a honey sample of treatments and that of farmers for Ash, electrical conductivity, free acidity, HMF and Sucrose parameters.

The natural honey quality parameters, such as moisture content, ash, electric conductivity, pH and free acidity, hydroxy methyl furfural, Glucose, fructose, sucrose content have been strictly defined and constitute the quality indicators describing individual honey varieties (Juszczak *et al*., 2009). These identified factors vary by regional and climatic conditions. The physiochemical properties of honey have a great role in identifying the quality of honey and are important for the standardization of honey at national and international standards (Demeke, 2020).

Table 13. Laboratory result of honey analyzed from treatments

Parameters	Types of treatments			P value
	Treatment 2	Treatment 3	Treatment 4	
Moisture content (%)	19.76±0.6	20.06±0.8	19.46±0.6	0.61
Color(mm Pfund)	124.3±11.76	108.3±3.6	118.2±4.5	0.29
Ash(g/100 g)	0.47±0.02	0.526±0.04	0.523±0.09	0.55
PH	4.39±0.19	4.54±0.3	4.53±0.5	0.87
Electrical conductivity(mS/cm)	0.97±0.04	1.05±0.07	1.04±0.15	0.64
Free Acidity(meq/kg)	28.6±3.05	29±1	27±3.6	0.66
HMF (mg/kg)	18.7±5.5	19.1±8.9	16.65±5.4	0.925
Fructose(g/100 g)	38.65±2.2	34.9±2.7	35.87±1.8	0.20
Glucose(g/100 g)	30.4±1.2	32.1±0.7	32.06±0.57	0.112
Fructose to Glucose ratio	1.27±0.1	1.08±0.1	1.11±0.05	0.12
Sucrose(g/100 g)	2.44±0.8	2.27±0.7	2.32±0.52	0.92

4.12.1 Moisture Content

The minimum, maximum, and average moisture contents of the honey samples of all treatment analyzed in the present study are presented in Table 13. There is no significant difference ($p>0.05$) in moisture content evaluated among honey samples obtained from treatments. And also there is no significant difference between the honey samples of treatments and farmers. This might be due to the same environmental condition and season of honey production. The overall mean moisture content (19.76%) of analyzed honey samples of all treatments and farmers was under recommended values of QSAE (2005) and EU (2002). The result of the present finding is in agreement with the study of Dugda (2022), Abakorma *et al*. (2020), Aynalem (2020), and Chimdessa & Begna (2020) who reported that the percentage of moisture content of honey was 19.8, 20.03 ± 1.80, 20.34 and 19.88 ± 1.98, respectively in their study areas.

The moisture content of the present study was also compared with the moisture content of *Vernonia amygdalina* honey reported by Debela *et al*. (2020) in the Jimma zone area. However, the moisture contents of Avocado (*Persea-Americana*) honey of this finding was higher than that of Avocado (*Persea-Americana*) honey reported (16.42 ± 2.53) by García *et al*. (2018). The difference might be due to the harvesting season of honey, climatic condition and degree of maturity of honey (Mekuanint and Meareg, 2019). In this investigation, the higher moisture content of the honey obtained could be related to the season of honey harvested and the climatic condition of the area.

The honey harvested during the rainy season contains more moisture content as compared to honey harvested during the dry season. Moisture content is the key parameter to evaluate the quality of honey and influences viscosity, maturity, crystallization, flavor, shelf life and palatability of honey (Rajindran *et al*., 2022). Moisture content of honey is a good indicator for honey quality identification and it depends on several factors such as bee species, floral source, honey harvesting time, processing procedures, storage conditions, handling by beekeepers at harvesting period and environmental conditions such as climate, the water content of nectar and floral origin (Gomes *et al*., 2010).

4.12.2 Colour

According to the colour analysis, the average Pfund scale of a honey sample analyzed from all treatments and farmers in the study area is presented in Table 13. In the current finding, the color of honey sample analyzed from all treatments was characterized as dark and amber colour, which is in line with a previous study of Serra *et al*. (2019) who reported that the avocado honey was classified as dark amber colour. Similarly, Terrab *et al*. (2004), Dag *et al*. (2006), and García *et al*. (2018) mention that avocado honey color was varied from very dark to dark/amber colour.

The color of the honey sample of all treatments (dark and amber) was statistically different from the honey samples analyzed of farmer (amber). The difference in the color of honey was based on the flora origin used by honeybees. However, there is no significant difference among treatments. This result showed that by the increasing number of honeybee hives per orchard on the same agro ecology and floral sources there is no difference in honey color. The value of color (Pfund scale) in the study area lies within quality standards and has no effect on honey physiochemical properties. Color has a direct impact on the preference of the consumers towards the acceptance of honey and it is a particular importance in the international market (Rodríguez *et al*., 2019). Variations in the color of honey are related to its floral origin, mineral content, storage and product processing, climatic factors during nectar flow and the temperature at which the honey matures in the hive.

4.12.3 PH

The result of the current finding indicated that the pH value of treatment two, three, and four were 4.39±0.19, 4.54±0.3 and 4.53±0.5, respectively with the overall mean of pH value 4.48±0.45 (Table 13) which is in line with the ranges of international standards. The pH mean value of treatment (4.48) was higher than that of honey samples from the farmers (3.82). Statistically, no significant difference ($p>0.05$) was observed in the mean values of pH among honey samples obtained from all treatments and between farmers and treatments. The result of the present finding of pH values of Avocado honey is coherent with reports of Bentabol *et al*. (2014), García *et al*. (2018) and Serra *et al*. (2019) indicated that the pH value of Avocado was 4.71 ± 0.38, 5.23 ± 0.96 and 4.81, respectively. Kebede *et al.* (2017) at Silti district, Southern Ethiopia reported the pH value of honey sample (4.45 ±0.21) is related to the current study result.

The pH value the avocado honey in the study area was higher than the pH value of coffee honey (3.32) reported by Admassu *et al.* (2022). The difference in pH mean values of honey is related to acid found in bee floral origins (Abakorma *et al*., 2020). Honey is naturally acidic with pH value ranging from 3.7 to 4.5 for flower honey and 4.5 to 6.5 for honey dew honey (Bogdanov, 2007). Natural organic acid found in honey contributes low pH of honey, which is indispensible for prevention of microbial growth and extended shelf life of honey (Samarghandian *et al*., 2017).

4.12.4 Ash

The mean value of ash content honey samples analyzed for treatment two, three and four is presented in Table 13. The average ash content of honey analyzed from all treatments (0.5g/100g) and farmer (0.2g/100g) was below the maximum value of 0.6g/100g which specified by QSAE (2005) and EAS (2019). The overall mean ash content of a honey sample from all treatments was statistically highly significant ($p < 0.05$) than the ash content of farmer honey samples analyzed. The variation of ash content between treatments and the farmer might be due to minerals contained in the pollen collected (Dekamo *et al*., 2021). However, there is no significant difference ($p>0.05$) in ash content was observed among honey samples obtained from all treatments. This might be due to the similar flora types utilized by honeybees in the study area. This result of the present finding indicated that the mean value of ash content was not influenced by the density of the honeybee hive at the same floral origin of honey and geographical location.

Different investigators reported different mean values of ash contents. The present evaluation of avocado honey was higher than the study of Admassu *et al*. (2022), Abakorma *et al*. (2020), Mekuanint and Meareg (2019), and Alemayehu *et al.* (2022) who reported that the ash content of a honey sample about 0.21g/100g, 0.24g/100g, 0.21±0.0123g/100g and 0.23g/100g, respectively. This showed that avocado honey has a high value of ash content. Similar to this study Bentabol *et al*. (2014) in Spain and García *et al*. (2018) in Ecuador also reported avocado honey has a high value of ash contents. The ash content of honey is depends on the geographical and botanical origin of the honey and also related to the material contained in the pollen collected by the honeybees during foraging on the flora (Getachew, 2020). Ash content is related to color and it’s often observed that honeys with higher ash content are also those have darker color.

4.12.5 Electrical conductivity

The result of the current finding showed that the highest electrical conductivity was seen in treatment honey (0.98 mS.cm) with a range of 0.82-1.05 mS.cm while that of farmer honey (0.49 mS.cm) had a lower electrical conductivity (Table 14)

In the current research, there is no significant difference ($p>0.05$) observed among treatments. However, the present results showed that the average electrical conductivity in treatment (0.98mS.cm) was significantly greater than the farmers' honey sample (0.58 mS/cm). This difference in electrical conductivity could be attributed to the variations in mineral content that, which is influenced by floral sources of honey samples (Linah, 2021). The standard regulation a set maximum limit of electrical conductivity for blossom honey below 0.8 mS/cm, however, some mono-floral honey showed above the limit. The result of the current finding was similar to the study of Rodríguez *et al*. (2019), Bentabol *et al*. (2014), and García *et al*. (2018) who reported the mean value of electrical conductivity of avocado honey 1.1 mS/cm, 0.99 mS/cm and 1.31 mS/cm, respectively. The current result of the study was higher than the finding of Tigistu *et al*. (2021) who reported the mean value of electrical conductivity of a honey sample (0.58 ±0.03 mS/cm) and also Gebremedhin (2020) in Kaffa Zone reported 0.377 mS/cm which is less than the present finding.

The mean value of the electrical conductivity varies depending on the geographical and botanical conditions (Abakorma *et al.*, 2020). Honey conductivity is a great indicator of the types of honey from its original form; whether formed from nectar (with some differentiation according to species) or honeydew (Bogdanov *et al*, 2002). Electrical conductivity is an excellent parameter for identifying pureness of honey. It has been found to assist in the determination of the botanical origin of honey, as well as correlating with ash content, pH, acidity, minerals, proteins and other substances in honey (Bogdanov *et al.*, 2002). A strong correlation was observed between the ash content and electrical conductivity ($r=0.98$). Both ash content and electrical conductivity were based on the mineral contents of honey. The correlation between ash and electrical conductivity indicated that when the ash contents of honey increased the electrical conductivity of honey was also increased.

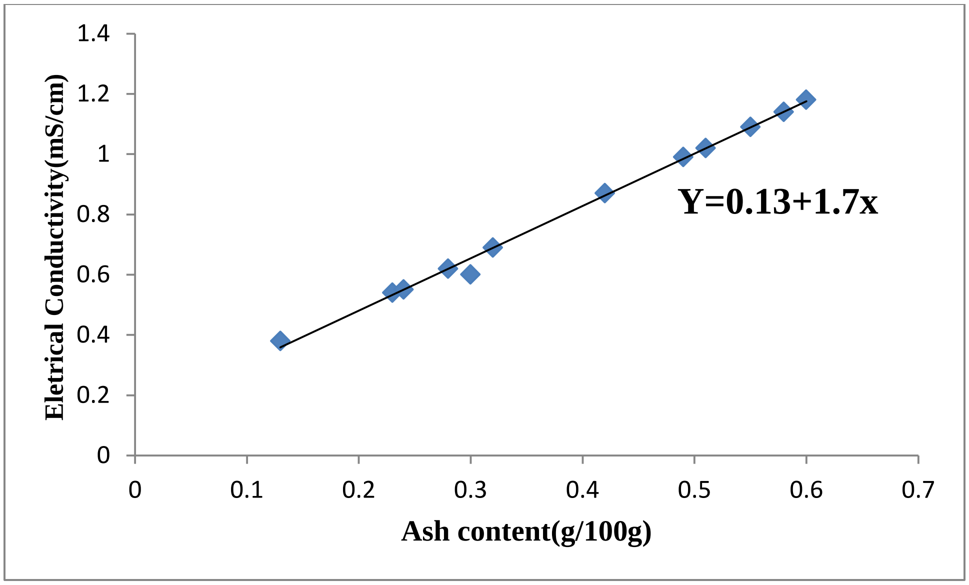

Figure 9. Regression of electrical conductivity on Ash

4.12.6. Free Acidity

The mean of free acidity of honey samples analyzed of all treatments and farmers are presented in table 13. According to this study result, there was no significant difference ($p > 0.05$) in the amount of free acidity among honey samples analyzed from all the treatments. This showed that an increase in honeybee hives in avocado orchards does no effect on the free acidity of the honey samples. The mean of analyzed honey samples of all treatment (28.2meq/kg) were less than a honey sample of farmer (37.3meq/kg) in the content of free acidity (Table 14). This might be due to undesirable fermentation of sugar, floral origin, harvesting methods and cleanness of storage material. A value of free acidity represents organic acid present in honey (Demeke, 2020), which contributes to honey characteristics like flavor and aroma. Some acids produced in honey though source of nectar.

The current result is in line with finding of Serra *et al*. (2019) who reported the free acidity of avocado honey in the range of 27.7-29.25 meq/kg in southern Spain. Meseret (2018) and Dema (2022) who showed that the free acidity of *Giuzotia scabra* honey (27.6±5.34 meq/kg) and Gemachis forest honey (27.57 meq/kg) in West Shoa and West Hararghe Zone, respectively, which is similar to this the present finding. Tilahun and Tewodros (2023) in Northeastern Ethiopia also reported similar values of free acidity of honey (28.22 meq/kg). The present study result of free acidity is less than the finding of Gebremedhin (2020) who reported mean values of free acidity which ranges from 35.5-46.7 meq/kg and Abera *et al*. (2017) who showed that free acidity of *Croton macrostchyus* (54.88 meq/kg). However, the result of present study was higher than the investigation of Chimdessa & Begna (2020) who showed that the mean values of honey samples in Western Ethiopia. The variation of free acidity might be due to season of honey production, storage condition and floral origin of honey (Aschalew *et al*., 2020). The observed mean value of free acidity of honey sample was lie within acceptable limit (40 mg/kg) specified by QSAE (2005), EAS (2019) and EU (2002). So, the honey sample analyzed have acceptable quality concerning in its free acidity value and ability to inhibit the growth of microorganism.

4.12.7 Hydroxymethylfurfural (HM) Aldehyde

As indicated in Table 13 the level of HMF for treatment two ,18.7 meq /kg, for treatment three , 19.1 meq /kg, for treatment four ,16.65 meq /kg and with over all mean value of 18.16± 7.15meq /kg. The HMF level of this result was found to the acceptable quality standards set by QSAE (2005), EAS (2019) and EU (2002), which is less acceptable limits (40 mg/kg).

The amount of HMF evaluated in honey sample did not show significance difference ($P > 0.05$) among honey samples collected from treatments. This result indicated that, as honeybee hive density increases in the orchards there is no change in the level of HMF among all treatments for the same environmental condition and storage condition. However, there is a significant difference between treatments and the farmer honey samples analyzed. The result of the current study is within agreement with a finding of Destaw *et al*. (2020) who reported HMF values of honey harvested on June. Mohamed *et al*. (2018) also reported HMF level of acacia honey was about 17.5 ± 2.08 mg/Kg, which was related to the current of avocado honey evaluated. However, the result of the present investigation was less than the finding of García *et al*. (2018) who reported HMF level of avocado honey about 27.16 ± 30.43 in the Andean Region of Ecuador.

The variation of HMF level of honey was based on age, heat and storage condition of honey (Pauliuc *et al*., 2020). The amount of HMF in honey is one of important indicators of overheated and freshness of honey. In honey, HMF is an indicator of quality which assists in the identification of freshness when in low concentrations. Poor condition of storage and excessive heating during honey extraction and processing may result into high HMF (Linah, 2021).

4.12.8 Sugars

The sugar evaluated of honey sample is presented in Table 13. From sugar type's fructose, glucose and sucrose were evaluated for each honey samples of treatments and farmers. Sugar is the major component of honey and its values is related to the stage of maturity and botanical origin of honey (Abera *et al*., 2017). The monosaccharide's glucose and fructose represent around 85% of the carbohydrates present in honey produced by the Apis genus, and are known as reducing sugars, which have the ability to reduce copper ions in an alkaline solution. Fructose has a high hygroscopicity and adds to the sweetness of honey, while glucose, due to its poor solubility, tends to influence crystallization (Gomes *et al*., 2010). Normally fructose is predominant as honey with high fructose rates can remain liquid for a long time, or never crystallize. The disaccharides sucrose and maltose represent 10% of the sugars present in honey (Bogdanov *et al*, 2002). The use of correct storage condition and appropriate processing methods keep the original values sugar of honey.

4.12.8.1 Fructose

The fructose contents of honey samples of treatments ranged from 35.87±1.8g/100 g to 38.65±2.2g/100 g with an overall mean of 36.47±2.6g/100 g (Table 13). These values were above the minimum limits fructose contents of honey described by national and international standards. Statistically, there is no variation among treatments. This indicated that an increasing number of honeybee hives up to 6 in orchards had no difference in the amount of fructose content in the same environmental condition and floral sources. Among the monosaccharide sugars in honey, the fructose content was found to be higher than that of glucose.

The result of this study was nearest to Serra *et al*. (2019) who reported the fructose contents of avocado honey was 38.06 ± 0.68g/100 g. Debela *et al*. (2020) and Pauliuc *et al*. (2020) reported an average value of *coffea Arabica* and sunflower honey 36.26±1.3g/100g and 36.74±1.533g/100 g, respectively, which is similar to current study result. The current result of study was higher than the finding of Admassu *et al*. (2022) who stated mean values of fructose content in *coffea arabica* (32.77 ± 6.06g/100g). The difference in the average fructose content is based on the floral source of honey (Hawine, 2020).

4.12.8.2 Glucose

The overall mean of glucose content of avocado honey was 31.38±1.15g/100g (Table 13). Statistically, no variation ($p>0.05$) was observed in the mean values of glucose contents among honey samples obtained from all treatments and also there is no difference ($p>0.05$) observed between farmers and treatments (Table 13). This result indicated that increasing the hive density per orchards is not influenced glucose contents. The current result of this finding was similar to the study of Admassu *et al*. (2022) and Debela *et al*. (2020) who reported that Glucose content of *Coffee Arabica* honey were 31.9 g/100g and 31.24 ± 2.09g/100g, respectively. Similarly, Belay *et al*.(2017) reported 31.65± 1.37g/100g glucose contents in *Croton macrostachyus* honey in Ethiopia. The glucose content in honey was the second most abundant sugar in this study.

A comparable result was reported by Bentabol *et al*. (2014) which indicated that the mean value of glucose content of Avocado is 30.22 ± 1.27g/100g in Spain. Meseret (2018) and Abera et al. (2017) showed that glucose content in *Guizotia scabra* honey (36.48±1.94g/100g) and *Leucas abyssinica* (37.20 ± 0.35g/100g) in Ethiopia which is larger than the present result of study. However, Pauliuc *et al*. (2022) who reported glucose content in acacia honey (25.93g/100g) which is less than the result of current instigation. The variation in glucose values of honey depend on types of flower utilized by honeybees.

4.12.8.3 Fructose to glucose ratio

According to the current investigation result, F/G ratio was within range of 1.08 -1.27. The overall mean 1.15 of F/G ratio indicated that the F/G ratio value is above 1.0, it means that the ability of honey crystallizes in the study area will be slow. This finding is in line with the study of Bentabol *et al*. (2014) who reported f/g ratio of avocado honey was 1.27 in Spain. A significant difference was not observed among the honey samples evaluated. Fructose to glucose ratio indicates the ability of honey to crystallize. Honey crystallization is faster when the fructose to glucose ratio is below 1.0 and is slows when this ratio is more than one (Meseret, 2018). The F/G ratio value of the present finding is under recommended values EAS (2019), which is the minimum value of F/G ratio 1.

4.12.8.4. Sucrose

The highest concentration of sucrose content (2.44± 0.7 g/100 g) was found in treatment two and the lowest (2.27 ± 0.8 g/100g) in treatment one (Table 13). However, there is no significant difference in sucrose contents between treatments. This showed that the amount of sucrose contents was not influenced by the density of honeybee hive. In this study, the overall mean of sucrose contents (2.35 ± 0.7 g/100 g) of treatments were significantly less than the sucrose contents of the farmer honey sample (3.61±0.33g/100 g) (Table 13). The difference might be due to degree of honey maturity. As the degree of honey maturity increases, the amount of sucrose content found in honey decreases, these indicate that the level of sucrose decreases with the maturity of honey (Demeke, 2020). According to Belay *et al*. (2017)) third most dominant sugar in Ethiopian mono floral honeys is sucrose.

Honey maturity and adulteration are determined by sucrose amount. The sucrose contents of all honey samples of the present investigation was less than 5%, which is the maximum limit of honey specified by QSAE (2005), EAS (2019) and EU (2002). The low sucrose content of the present finding indicates that honey is free from adulteration and harvested at the proper time. The present result of the study is similar to a finding of Tigistu *et al*. (2021) and Destaw *et al*. (2020) who reported the mean of sucrose contents in kempata tambaroo Zone and in Dawuro zone, respectively. Similarly, Belay *et al*. (2017) also reported the mean of sucrose in *Croton macrostachyus* honey (2.57± 0.22 g/100g) in Ethiopia, which is related to the present study. Fiseha *et al*. (2021), Gobessa *et al*. (2012), Kebede *et al*. (2017) and Admassu *et al*. (2022) reported 4.41±1.098 g/100 g, 6.1 ± 3.4 g/100 g, 4.1±1.2 g/100 g and 3.5 g/100 g mean value of sucrose contents of a honey sample respectively, which was higher than the current study. This might be due to honey adulteration and maturity (Destaw *et al*, 2020).

Table 14. Comparison of honey sample analyzed

Parameters	Treatment honey	Farmer honey	P value	National standards	International standards.
Moisture content (%)	19.75^{a}	20.78^{a}	0.42	17.5-21	21
Color(mm Pfund)	117^{a}	98^{b}	0.009		
Ash(g/100 g)	0.5^{a}	0.2^{b}	0.0006	0.6	0.25-1
PH	4.48^{a}	3.82^{a}	0.32	4.5	3.2-4.6
Electrical conductivity(mS/cm)	0.98^{a}	0.49^{b}	0.0003	0.8	0.8
Free Acidity(meq/kg)	28.2^{b}	37.33^{a}	0.043	40	50
HMF (mg/kg)	18.16^{b}	37.3^{a}	0.028	40	40
Fructose(g/100 g)	36.47^{a}	37.65^{a}	0.17		
Glucose(g/100 g)	31.52^{a}	32.51^{a}	0.509	Above 60	60-70
Fructose to Glucose ratio	1.15^{a}	1.15^{a}	0.20		
Sucrose(g/100 g)	2.35^{b}	3.61^{a}	0.043	<5	<5

Mean with different letters were significantly different at level of $p<0.05$

Figure 10. Image of sample prepared for honey analyzed in laboratory.

4.13. Honeybee colony Swarming and Absconding during the study period.

From nine selected apiary site only from one site (two hives per orchards) honeybee colony swarming was occurred. During minor season of honey production, there was less honeybee swarming activities observed. According to the survey result, the majority of honeybee colony swarming was happened during major honey production (November and December) which is may be attributed to the abundance of flora and related production of high population of honeybees which might result in shortage of space in the hive. Availability and types of bee flora and level of colony management practice are used to evaluate the colony strength of honeybee (Dema, 2022). Honeybee swarming means reproduction process of honeybee. Swarming activities of the honeybee colonies were evaluated through number of swarms produced during the study period.

In the study area honeybee colony absconding was not occurred in all treatments. This is might be as result of good season honeybee colony management (protecting hive from pests and predators and avoiding honeybee colony from excessive sun, wind and rain in the selected site). From the major problems in honeybee production practices the major one is colony absconding (Soresa and Negasu, 2020). It's occurred when honeybee colony disturbance and shortage of bee forages happened.

4.14. Partial Budget Analysis

The result of partial budget analysis among treatment is presented in Table 15. Based on partial budget analysis, the highest net return was recorded from treatment three (30,263.08 ETB) and treatment four (34,669.85 ETB) while the lowest net befit was obtained from treatment one (orchards without hive). By introducing two, four and sex hives per orchards, the net return of farmer increased as compared to orchards without hive. The result of this investigation showed that as the density of honeybee hive per orchard increased, the net return also increased. This implies that increasing honeybee hive density per orchard improved pollination services which are used as increased the fruit yield of avocados. Similar to the present study Bereket (2022) in Northern Ethiopia reported that the highest net return is generated in honeybee-pollinated than open-pollinated and self-pollinated.

Table 15. Partial analysis

Variables	Treatments			
	1	2	3	4
Density of hives /treatments	0	2	4	6
Total hives cost /treatments ETB	-	2000.00	4000.00	6000.00
Honeybee colony cost	-	500	1000	1500
Cost for material of shade construction	-	3,160	3,380	3,800
Labor cost for honey harvesting	-	300	500	650
Labor cost for fruit harvesting	1,350.36	3,480.46	3,780.12	3,826.35
Packing material	350	1280	1450	1600
Cost for transporting	750	2200	2350	2520
TVC (ETB)	2450.36	12,920.46	16,460.12	19,896.55
Total fruit yield per orchard(kg)	2165	2817.6	3201.6	3767.2
Total honey yield per orchard (Kg)	-	35.32	56.52	76.8
Total benefit from fruit (ETB)	20,980	31,811.2	35,419.2	39,206.4
Total benefit from honey	-	7064	11,304	15,360
Total return (TR)(ETB)	20,980	38,875.2	46,723.2	54,566.4
Net return (NR) (ETB)	18,529.64	25,955.2	30,263.08	34,669.85
ΔTR (ETB)	-	17,895.2	25,743.2	33,586.4
ΔTVC (ETB)	-	10,470.1	14,009.76	17,446.19
ΔNR (ETB)	-	7,425.56	11,733.44	16,140.21
MRR (%)	-	70.9	83.75	92.5

5. CONCLUSION

Beekeeping was practiced as sideline activities with other agricultural activities in the study area. High potential of bee keeping and traditional (forest and backyard), intermediate (transitional) and frame beehive (Modern) are three types of honey production systems practiced in the study area. The main sources of honeybee colony of beekeepers in the study area were swarm catching by using indigenous experience. Supplementing other pollinator with honeybee hives could be considered as a valuable strategy to increase pollination services which enhanced fruit set and productivity. Quality parameters (length, weight, TSS, DM, pH and TA) of avocado fruit were improved by honeybee pollination. Introducing two, four and sex hives per orchards, fruit production of avocado increased by 28.81, 45.02 and 79.56%, respectively, compared to the control or an orchards without hive.

The highest average of honey yield per hive was recorded from two hives per orchard (T2) and lowest mean values was obtained from six hives per orchard (4). Due to honeybee competed for consuming the available honeybee forages, honey yield per hive was decreased based on increasing density of honeybee hive throughout the orchards. Pollen determination of all treatment samples indicated that *Persea americana* classified as dominant pollen and other pollen types was obtained below 45%.

Honey quality parameters were not influenced by density of honeybee hive in the study area. Honey collected from the treatments was different by Ash, electrical conductivity, free acidity, and HMF and Sucrose parameters as compared to the farmers honey samples. Laboratory evaluation indicated that physicochemical parameters of honey sample (treatments and farmer) from study area were acceptable in national (Quality and Standards Authority of Ethiopia) and international (Codex Alimentarius Commission and EU) standards. The current study clearly indicates that Avocado is not only important for fruit productions, but also used for honey production. Therefore, the integration of Avocado orchards with beekeeping is recommended to produce both fruit and honey, which is used to improve lively hoods of farmers through poverty reduction, as sources of food for home consumption and increasing the income generation of farmers.

Recommendation

Based on the current study, the following recommendations are suggested for avocado and honeybee integrated production systems for the farmer.

- ✓ Strengthening of training on pollinator of avocado pollination to address the knowledge and skill gap on supplementary honeybee-pollination for avocado.
- ✓ The idea of fruit pollination should include in the national fruit production strategic plan to increase the production of fruit.
- ✓ Dara otilcho district Livestock and Fishery Development Office should give enough attention on adequate supply of transitional and improved frame bee hives and encouraging participation of households in honey production.
- ✓ Promoting sustainable awareness regarding to the improving management practices of bee keeping and environmental conservation to increase production and quality of honey.
- ✓ To increase the job opportunity in terms of honey production, the district should be focused on support micro and small enterprises in beekeeping and create awareness on beekeeping.
- ✓ Beekeepers should adopt using transitional and frame hive which is for colony management and increase the honey productivity.
- ✓ Based on the present study, quality of honey in the study area were within the ranges of Ethiopian and EU standards. Therefore, it is necessary to expand production level and improve the honey market channels in study area.
- ✓ To enhance productivity and production of honey the Ethiopia government policy encourages private investors in honey production, processing and marketing.
- ✓ Promoting the link between honey producers and processors to maximize the honey and honey product, this can fulfill the standard of export product.

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APPENDIX

Appendix 1 Questionnaires

HAWASSA UNIVERSITY SCHOOL OF GRADUATE STUDIES

The objective of this questionnaire is designed to collect the necessary data information regarding to collect the existing practices toward to EVALUATION OF HONEYBEE HIVE DENSITY ON THE AVOCADO (PERSEA AMERICANA MILL) FRUIT PRODUCTION AND HONEY QUANTITY AND QUALITY DURING AVOCADO FLOWERING IN DARA OTILICHO DISTRICT SIDAMA REGIONAL STATE, ETHIOPIA

Name of woreda…………………. Name of kebele…………………….

1. General information

1.1 Name of respondents………………………………….Family size……..

. 1.1.1 Age 15-30…..., 31-45…., 46-60……, Above 60…….

1.1.2 Sex Male……. Female………

1.1.3 Religion of household

1. Orthodox 2. Muslim 3. Protestant 4. Catholic 5. Other specify.

1.1.4 Marital status: 1. Married 2. Single 3. Widowed 4. Divorced

1.1.5 Educational level of household

1.Illiterate, **2**. Basic education **3**. Grade 1-4, **4**. Grade 5-8, **5**. Grade 9-12.

2 Bee keeping

2.1 Do you have honeybee colonies? 1 yes 2 no

If yes what types of hive and how many honeybee colonies do you have?

1. Traditional------------- 2.Transitional---------------- 3. Modern---------

2.2 Do you construct hives 1 Yes 2 No

If yes list the major material used for hive construction?

1…......, 2……………., 3………….., 4……………, 5…………..

2.3 When the following activities occur in your locality?

Colony Swarming Months……………

Honey harvesting period Months……………

Frequency of harvesting per year number………………..

2.4. How much amount of honey did you harvest in kg/hive/year from

Traditional hives.......... transitional/ top- bar hives …………….

modern/frame hives? ………..

2.4Where do you keep your bee colonies? (Site or placement of hive)

1 in the Backyard 2 Under the eave of the house

3 Hanging on trees near homestead

2.5 What is the main contribution of honey production to your households?

1. For income generation 2. For home consumption 3. Home consumption and Medicine 4 others specify

2.6 How do you get colony to start beekeeping practices? Source of bees

1. By catching swarming bee 2 Gift from parents

3. Buying honeybee colony 4. Caves and forests

2.7 Do inspect honeybee colony? 1 yes 2 No

IF answer is yes which type of inspection?

1. Internal & external hive inspection 2 external inspection only

2.8 Do you know what bees eat/collect from a flower?

1 Yes 2 No

2.9 Do you give your colony supplementary feed ?

1. Yes__ 2.No___

If yes, what type of feeds do you give?

List it.1…………..

2………………

3…………

3.7 What are the major honeybee floras in your area? List

No	Local/ Common name of the plant	Type of the plant (Tree, shrub herb, cultivated crop)	Flowering time (months)	Source (nectar, pollen, propolis)
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

3 Avocado

3.1 How much hectare of avocado orchard do you have?

3.2What types of avocado does your household grows in the field?

Local………… exotic……………….local and exotic…………

3.3 What is the time of avocado flowering? Months……………………………...

3.4 How much total fruit production (quintal per tree) does your household harvest from avocado per season? ----------kg

3.5 Do you know the effect of honeybee on avocado fruit production?

1 Yes 2 No

3.6 What are the avocado pollinators in orchards?

1 Wind……… 2 insects ….. 3 others (specify)…………

3.7 What is the preferred visitation time of the diverse pollinators of avocado trees grown in orchards in Dara district)? Morning…… AM after noun…PM

3.8 How many times avocado give flower per year? 1… 2…. 3……

Appendix 2 ANOVA Table for Honey yield from treatments

Source	DF	Sum of squares	Mean squares	F value	P value
Model	4	28.80320000	14.40160000	16.3	0.0037
Error	4	5.27360000	0.87893333		
Corrected Total	8	34.0768000			

Appendix 3 ANOVA Table for length and weight

Parameters	Source	DF	Sum of squares	Mean squares	F value	P value
Fruit length	Model	5	64.63493333	21.54497778	44.13	0.001
	Error	6	3.90553333	0.4881916		
	Corrected Total	11	68.54046667			
Fruit weight	Model	5	9788.33333	3262.77778	30.66	0.0001
	Error	6	851.33333	106.4166		
	Corrected Total	11	10639.6666			

Appendix 4 ANOVA Table for fruit quality parameters

Parameters	Source	DF	Sum of squares	Mean squares	F value	P value
PH	Model	5	1.57033333	0.52344444	68.57	0.0001
	Error	6	0.06106667	0.0076333		
	Corrected Total	11	1.6314000			
DM	Model	5	227.0025000	75.667500	171.65	0.0001
	Error	6	3.5266667	0.440833		
	Corrected Total	11	230.529166			
TSS	Model	5	3.51000000	1.17000000	48.83	0.001
	Error	6	0.12375000	0.02062500		
	Corrected Total	11	3.70166667			
TA	Model	5	0.00000990	0.00000330	22.25	0.0003
	Error	6	0.00000119	0.0000001		
	Corrected Total	11	0.00001109			

Appendix 5 ANOVA Table for physiochemical properties of honey.

Parameters	Source	DF	Sum of squares	Mean squares	F value	P value
Moisture content	Model	5	2.88090000	0.96030000	1.03	0.42
	Error	6	7.46506667	0.93313333		
	Corrected Total	11	10.34596667			
Ash	Model	5	0.21849167	0.07283056	17.98	0.0006
	Error	6	0.03240000	0.00405000		
	Corrected Total	11	0.2508916			
Electrical Conductivity	Model	5	0.65295833	0.21765278	20.60	0.0004
	Error	6	0.08453333	0.0105666		
	Corrected Total	11	0.73749167			
Free Acidity	Model	5	193.6666667	64.5555556	10.06	0.043
	Error	6	51.3333	6..4166667		
	Corrected Total	11	245.0000000			
PH	Model	5	1.04642500	0.34880833	1.37	0.32
	Error	6	2.03386667	0.2542333		
	Corrected Total	11	3.0802916			
HMF	Model	5	872.392467	290.797489	5.14	0.028
	Error	6	452.907200	56.6134		
	Corrected Total	11	1325.29966			
Glucose	Model	5	7.74593333	2.58197778	0.84	0.509
	Error	6	24.58013333	3.07251667		
	Corrected Total	11	32.32606667			
Fructose	Model	5	25.82910000	8.60970000	2.09	0.17
	Error	6	32.95446667	4.11930833		
	Corrected Total	11	58.78356667			
Fructose to glucose ratio	Model	5	0.05656667	0.01885556	1.92	0.209
	Error	6	0.07873333	0.00984167		
	Corrected Total	11	0.1353000			
Sucrose	Model	5	3.68949167	1.22983056	4.33	0.043
	Error	6	2.27173333	0.28396667		
	Corrected Total	11	5.96122500			

Appendix 6 Image taken during the study.

Image taken during household survey data collection.

Kenyan top bar hive used for treatments.

A B C

Image taken during laboratory analysis of honey (A color , B sugar and C ash)

Image taken during laboratory analysis of fruit