DEVELOPMENT OF AN EXTRACTOR TO IMPROVE THE PROCESSING OF QUALITY HONEY HARVESTED FROM INDIGENOUS HIVES AND NATURAL COLONIES

BY

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DECLARATION

Declaration by the Candidate

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DEDICATION

This thesis is dedicated to my mother Mrs. Nelly Chelule, my late Father Mr. Nelson Chelule, my sister Mrs. Florence Cherono, my brothers Mr. Charles Cheruiyot, Mr. Gilbert Cheruiyot, Mr. Vincent Cheruiyot, Mr. Dennis Alima Tovesi and not forgetting my lovely daughter Miss. Darlene Mukoya Alima , for their unwavering support. Special dedication also goes to my colleagues, lecturers and many other people who supported me and made this project a success. I wish them God's blessings with great innovations and mind-blowing discoveries.

ABSTRACT

In Kenya, the estimated potential of honey production annually is 100,000 metric tonnes. This potential is not met due to highly productive areas remaining unexploited. Marigat in Baringo County is among the ASAL areas in Kenya where most residents engage in honey production as the major source of income. Apicultural activities thrive in the area due to abundance of natural bee flora, favourable climatic conditions and vegetation cover. Honey producers in the area keep their bees in the indigenous hives and natural colonies. Traditional methods are mainly used to harvest and process honey in the area. This is because, few/no studies have been done in the area to determine the important physical properties of honey significant in; characterizing honey from different sites of Marigat, development and validation of an extractor to improve the processing of quality honey harvested from indigenous hives and natural colonies. Twelve (12) samples of honey from four (4) sites of Marigat; Maoi centre, Lopoi junction, Marigat town and Koriema centre, were analysed to determine the moisture content, pH, relative density and total water-insoluble solids content of honey. The mean parameter values of these properties were 18.05 %, 3.9, 1.41 g/ml, and 0.22 % m/m, respectively. Their range values were 17.1 to 19.6 %, 3.3 to 4.2, 1.4045 to 1.4343 g/ml, and 0.07 to 0.61 % m/m, respectively. The critical F-values obtained from statistical tables of all quality parameters of honey were greater than the observed F-values. This shows that, there were no significant differences on the quality of honey analysed for the four (4) sites. Further, sixteen (16) samples of honeycombs were measured and the largest possible values were utilized in determining the size of honeycomb net buckets as well as that of the extractor. The extractor was also designed based on some physical properties of honey. For instance, no water bath was included in the design to minimize fermentation that would occur due to presence of moisture in honey. The mean pH value of honey from four (4) sites of Marigat was found to be acidic, hence, the materials chosen for fabrication of the extractor were based on this quality parameter. Stainless-steel grade 304 materials were chosen for fabrication due to their ability to resist corrosion. The mean total water-insoluble solids content value of honey guided in the selection of suitable screen sizes for filtering any impurities that would be present in honey. The filtering mesh and a strainer with 1.0 mm and 0.5 mm hole sizes were selected to sieve any impurities present. Moreover, performance evaluation of the machine was carried out based on the relative density of honey and mass of honeycombs. The mean value of relative density was utilized in the determination of mass flow rate of honey as well as efficiency of the machine. The mass flow rate of honey was found to be $5.99 \times 10^{-3}\ kg/s$, which was equivalent to $14.376\ kg/day$. Five (5) test runs were done within a period of eight (8) minutes each without breaking the honeycombs. The amount of power required by humans to operate the extractor for a period of 5 years was equivalent to 6.48×10^{-5} W. Efficiency of the extractor was found to be 99.83 %. From this study, the physical properties of Marigat honey were successfully used to characterize, develop and evaluate the performance of an improved honey extractor which can also be used to process honey in any other ASAL area in Kenya.

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LIST OF ABBREVIATIONS, ACRONYMS AND SYMBOLS

ADB	African Development Bank
ANOVA	Analysis of Variance
ASAL	Arid and Semi-Arid Land
BPGS	Board of Postgraduate Studies
CAC	Codex Alimentarius Commission
DF	Degrees of Freedom
EAS	East African Standards
ECC	European Community Council
H_2SO_4	Sulfuric Acid
IHC	International Honey Commission
KEBS	Kenya Bureau of Standards
KES	Kenya Shillings
KS	Kenya Standards
KTBH	Kenya Top Bar Hive
MS	Mean of Squares
NaOH	Sodium Hydroxide
NGOs	Non-Governmental Organizations

pH	Potential of Hydrogen
SE	Standard Error
SENG	School of Engineering
SS	Sum of Squares
TM	Test Method
UK	United Kingdom
UOE	University of Eldoret
USA	United States of America
UTS	Ultimate Tensile Strength

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CHAPTER ONE

INTRODUCTION

1.1 Background to the study

Bee is a winged insect that gathers pollen and nectar from flowers, produces honey for food and wax for other purposes. They usually stay in large colonies and obtain their energy and proteins from flower nectars and pollen respectively (Akinnuli, *et al.*, 2016). Bees are characterized by their potential to collect honey in large quantities which can then be harvested for human consumption and generation of income from sale of their products (Crittenden, 2011). Apiculture is the process of managing a colony of bees to produce honey, wax and other products (Kipruto, 2016). The process requires minimal space and no need for good soil hence complementing other farm activities (Carroll, 2006).

Honey is a sugary constituent produced naturally by bees from flower nectars. Bees gather and covert nectar by combing with particular substances of their own to produce honey. Honey is then deposited, dehydrated, stored and left in the honeycombs to mature (Ishaq, *et al.*, 2018). Its colour varies nearly from colourless to dark-brown depending on the source. Honey is an essential product of apiculture because it is quantitative and economical (Muli, *et al.*, 2007). It was the major product made by bees and consumed by humans apart from wax and propolis (Abadariki, *et al.*, 2013). Honey has been appreciated as a source of food because it is fit for human consumption (Ahmed, *et al.*, 2007). It has been used as a sweetener in making cakes, bread and drinks, among others. It is the main ingredient in alcoholic beverages like wine and beer, normally made with a mixture of honey, water and addition of yeast to allow for fermentation (Akinnuli, *et al.*, 2016).

It contains antibacterial constituents essential in the treatment of several illnesses like gastric disturbances, wounds, sore throat and burns (Vallianou, *et al.*, 2014). It helps in increasing milk production in dairy cows and is also used in most industries for making hand lotion and facial cleansers. Therefore, significance of the honey processing industry cannot be underestimated in a developing country like Kenya. Given the multi-dimensional array of benefits obtained from honey, investing in honey production is vital in improving the living standards of honey producers residing in rural areas.

In Kenya, the estimated honey production potential is 100,000 metric tonnes annually (Carroll and Kinsella, 2013). However, current annual production is at 25 metric tonnes due to highly productive areas remaining unexploited. The estimated potential is not met due to poor methods of harvesting, handling, extraction, storage as well as marketing of honey (Robert, 2010). The inexistence of an extractor to improve processing of quality honey harvested from indigenous hives and natural colonies, has resulted in most honey producers using traditional methods to harvest and process honey. This method produces poor quality honey due to the unhygienic way of handling honey. Honey producers squeeze honeycombs to extract honey using bare hands, hence leading to honey` contamination and impurities due to incomplete extraction. The method also involves the use of water baths to heat honeycombs, however, if this is not done wisely, would increase moisture content in honey leading to fermentation upon storage. Moreover, the beehive is usually burned down during harvesting hence destroying it completely. Several bees die and the remaining ones move to new sites to start over. This in turn, reduces their population and hence lowering honey production rates in the area (Robert, 2010). All these drawbacks as observed from poor harvesting, processing and storage conditions of honey, have led to low quality of honey produced in the rural areas and sold in the local markets at very low prices.

Kenya can earn foreign exchange of about 15 to 20 billion dollars annually if the production potential of honey is fully achieved (Robert, 2010). This can lead to creation of employment opportunities, alleviation of poverty levels, increased incomes from sale of honey both locally and internationally, and improved standards of living of the honey producers practising apiculture in the Arid and Semi-Arid (ASAL) areas in Kenya (Warui, *et al.*, 2019).

Bees build their honeycombs and produce honey in three (3) different types of beehives: indigenous or traditional, Kenya Top Bar (KTBH), and Langstroth hives (Carroll, 2006). They also build their honeycombs in the natural colonies. However, there is no frame in indigenous hives and natural colonies to hold the honeycombs built by bees during honey production. Therefore, honeycombs from these hives and colonies cannot be extracted using the existing extractors in the market. However, KTBH and Langstroth hives have frames that hold the honeycombs firmly, hence can be loaded onto the existing centrifuges to extract honey. During extraction, honey is usually thrown out from the honeycombs onto the extractor wall due to centrifugal force. After extraction, honeycombs are not destroyed during extraction hence returned to the hives for refilling, subsequently increasing the production capacity of honey. In Kenya, small-scale honey producers are low-income earners, hence cannot afford to purchase the modern beehives and centrifuges available in the market. For instance, the modern beehives cost between Kenya Shillings 5,000 to 8,000 per piece (Robert, 2010). The centrifuges are imported and very expensive too, costing between Kenya shillings 120,000-180,000 per piece (Bontempo, *et al.*, 2017). Therefore, beekeepers prefer using the traditional method which has extremely lowered honey marketing in the country.

The physical properties of honey from different regions have been used to classify, identify, characterize and establish the processing, packaging and storage conditions of honey (Robert, 2010). Physical properties of honey like moisture content, pH, relative density and total water-insoluble solids content of honey, among others are very important parameters governing the quality of honey produced in an area (Adebiyi, *et al.*, 2004). Honey quality is greatly affected by climatic conditions, floral sources and human factors like customs and know-how of producers during harvesting, handling, processing and storage techniques (Warui, *et al.*, 2019). Properties and composition of honey vary across different regions (Silva, *et al.*, 2013). The International Honey Commission (IHC), Codex Alimentarius Commission (CAC) and European Community Council (ECC) are organizations concerned with the management of international honey trade and have set strict requirements regarding the quality standards of honey for local consumption and export (Bogdanov, *et al.*, 2002; Codex, *et al.*, 2001; Nzula, 2018). These standards are based on the physical properties of honey including their methods of extraction and processing. Britain, Australia, Germany, USA, Nepal and India, among others are some of the countries in the world that have done substantial studies on their honey based on these properties. A honey extraction equipment have been developed in these countries based on the various properties of honey and favourable conditions have been set for its use (Robert, 2010). Some properties like pH of honey have been used during the selection of materials for designing a honey extractor (Adebiyi, *et al.*, 2004). The total water-insoluble solids content of honey has also been utilized in distinguishing between the honey extracted by traditional means and those extracted using the extractor machine.

1.2 Problem statement

Honey producers living in the rural areas of Marigat in Baringo County have no idea of the quality of honey they produce. Characterization of honey based on its physical properties has not been done by honey producers in the area to determine the quality of honey produced for consumption and sale. For instance, honey producers in the area heat honeycombs using water baths to melt wax and any other particles present in honey. This process exposes honey to fermentation during storage. Unfortunately, the process could increase moisture content if not done wisely. The impurities like wax, insect parts and debris extracted along with honey increases the amount of water-insoluble solids in the extract. Separation of these impurities requires extra cost. Therefore, there is little or no possibility of achieving competitive prices both locally and internationally due to the low quality of honey produced in the area. Institutions involved in poverty eradication programs like Non-Governmental Organizations (NGOs) have tried to engage honey producers residing in rural areas in different parts of the country on ways to increase honey production rates, but its quality remains questionable (Robert, 2010).

Most honey producers in the area have indigenous hives and natural colonies. Honeycombs from these hives and colonies are normally harvested and extracted using traditional methods. In Kenya, over 90 % of the beekeepers use traditional methods that presumably lead to honey of low quality (Chemwok, 2016). The process involves unhygienic method of squeezing the honeycombs using bare hands. This leads to contamination of honey and incomplete extraction with impurities in the extract. Honey produced in this manner is not fit for human consumption due to health risks associated with the process and does not attract international market standards.

Therefore, honey is sold in the local markets at very low prices of Kenya Shillings 700 per kg as compared to what is sold internationally at Kenya Shillings 2,199 per kg as quoted by Jamboshop, (2020). This method is also labour intensive, time-consuming and tiresome, which implies that more valuable time is spent on extracting honey of low quality. This way, poverty levels increase among the local producers. During the harvesting process, beehives are usually burned down hence destroying them completely, forcing bees to migrate to new sites to start over. This leads to low production rates of honey in the area due to reduced population of bees. According to Chemwok, (2016) indigenous hives have a bee population of 70 % and a yield of 16 kg of honey per hive in a year

The major drawback which forces the honey producers in the area to use traditional method to harvest and process their honey, is the inexistence of a honey extractor that is capable of extracting honey from honeycombs harvested from indigenous hives and natural colonies. The centrifugal extractors available in the market cannot be used to extract honey harvested from these hives and colonies. This is due to inexistence of a frame to securely hold the honeycombs built by the bees in these hives and colonies. However, honeycombs from the Kenya Top Bar Hive (KTBH) and Langstroth hives have frames that can be loaded onto the existing extractors to extract honey. These extractors and the modern beehives are very expensive to purchase since most of the honey producers in the rural areas are low-income earners. There is also low power distribution in the rural areas since most of the honey extractors available require a source of power to operate.

1.3 Hypothesis

1.3.1 Null hypothesis

H_0: Characterization, design and performance evaluation of an improved honey extractor can be done based on the physical properties of honey.

1.3.2 Alternative hypothesis

H_1: Characterization, design and performance evaluation of an improved honey extractor cannot be done based on the physical properties of honey.

1.4 Objectives of the study

1.4.1 Main objective

The main objective of this study was to develop an extractor to improve the processing of quality honey harvested from indigenous hives and natural colonies in Marigat, Baringo County.

1.4.2 Specific objectives

The specific objectives of this study were:

1. To characterize honey from different sites of Marigat based on the physical properties of honey like moisture content, pH, relative density and total water-insoluble solids content.
2. To develop and validate a honey extractor based on the physical properties of honey.

1.5 Justification of the study

The beekeeping and honey production sector in Kenya is widely practiced and managed by small-scale farmers. The role of this industry in boosting the economy of a country is overlooked. However, given the right investment, the industry can be a major booster in achieving the Big Four Agenda and realizing Kenya Vision 2030 (GoK, 2020). Marigat is an Arid and Semi Land (ASAL) where agricultural activities cannot thrive. Hence, beekeeping is a major practice in the livestock sub-sector. Most people living in the area depend on beekeeping as their major source of income (Kipruto, 2016). Therefore, honey should be characterized in the area to determine the quality of honey produced, set processing and storage conditions of honey. This, in turn, would attract both local and international markets and fetch high profits from the sale of honey. This also ensures improved standards of living of the honey producers living in the area and poverty eradication.

Limited studies have been reported on characterization of honey based on its physical properties to determine the quality of honey produced in the area. Honey quality is usually attributed to changing climatic conditions of a place, season of harvesting honey, level of honey maturity during harvest, handling of honey during processing and favourable storage conditions. Honey density varies depending on the amount of moisture present in honey. Honey stored in containers should be free from high moisture content to avoid fermentation. The amount of impurities in honey depends on water-insoluble solids present in honey. Therefore, characterization of honey based on its physical properties ensure that honey produced is of good quality and fit for human consumption, hence reducing health risks associated with contaminated, fermented and honey with impurities.

Marigat is dominated by indigenous hives and natural colonies as compared to the modern beehives. For instance, there are a total of 25,100 traditional log hives, 650 Kenya Top Bar, and 930 Langstroth beehives (GoK, 2013). However, limited or no research have been reported on extraction of honey from indigenous hives and natural colonies by use of an extractor. Most honey producers extract honey using traditional methods which have been rendered unhygienic. This is due to inadequate finances to purchase modern honey extractors available in the market, that are capable of extracting honey hygienically from modern beehives to meet the standards required to attract high profits. However, these modern extractors can only extract honey from KTBH and Langstroth hives because they have frames that can be loaded onto the extractor. That is not the case for honeycombs from indigenous hives and natural colonies, there is no frame to hold these combs, therefore cannot be loaded onto the existing extractors. Therefore, this necessitates for the development of an improved honey extractor with honeycomb net buckets to firmly secure the honeycombs harvested from indigenous hives and natural colonies during extraction. The extractor would ensure production of high-quality honey free from contamination, fermentation and impurities hence fit for human consumption and would eventually attract high profits from the sale of honey both locally and internationally.

Marigat is an ASAL area and it is hot most of the time. KTBH and Langstroth hives are mostly made of iron sheets at the top. The climate inside these hives is not favourable for bees to produce honey during hot periods. Therefore, most of the bees prefer producing honey in indigenous hives and natural colonies. Most of the honeycombs in the study area are harvested from these hives and colonies during hot periods. A study done by Chemwok, (2016) shows that, in Marigat, 70 % of bees occupy the traditional log hives as compared to 20 % and 6 % of bees occupying the KTBH and Langstroth beehives respectively. Hence, there is a need to focus on how to solve the problem of extracting honey hygienically from honeycombs harvested from indigenous hives and colonies.

1.6 Scope and limitations of the study

The scope of this study was limited to Marigat in Baringo County where honey producers practise beekeeping in small-scale farms. An extractor was designed based on some physical properties of honey to suit small-scale honey producers who are low-income earners and cannot afford to purchase modern honey extractors. The study was targeted towards developing an extractor capable of improving the processing of quality honey harvested from indigenous hives and natural colonies. The extractor was designed and its performance evaluated to suit other small-scale beekeepers residing in any other ASAL area in the country.

The cost of purchasing stainless-steel materials was high and rare to get within Eldoret. Therefore, all materials used for constructing the honey extractor were bought from Nairobi. However, Nairobi was among the Covid-19 hot spot zones in Kenya, hence was locked down due to Covid-19 restrictions imposed by the government. As a result, materials used for construction took so long to be received. Furthermore, fabrication was done in another Engineering Workshop within Eldoret Town, due to inadequate stainless-steel mig welding machines in the institution. Another challenge was the high cost of purchasing honeycombs used for research. For instance, the cost of honeycombs was Kenya Shillings 1,500 per piece. This was attributed to the fact that, during data collection, the varying climatic conditions greatly affected honey production rates in the study areas. It was a rainy season hence most vegetation in the area had shed flowers, leading to inadequate flower nectars. The procedural tests done in KEBS were also too costly i.e., Kenya Shillings 55,000.

CHAPTER TWO

LITERATURE REVIEW

2.1 Beekeeping and honey production

Rotich (2019) quoted that the capacity of honey production varies generally from one country to another. For instance, the highest production yields produced by China was 170,000 tonnes, while Argentina produced 45,500 tonnes. In Africa, Ethiopia is the leading honey producer, followed by Tanzania, while Kenya has high rates of honey consumption and some honey merchants import it from Tanzania when the demand cannot be met locally. Generally, the leading importers of honey in the world are mainly United States, Germany, Japan, United Kingdom and France. In 2017, honey production in the world was at 1.9 million tonnes with China having the highest percentage of 29 % of this total. Other major honey-producing countries were Turkey, United States, Iran and Ukraine. Appendix (III) shows production of natural honey as of 2017 from these countries (Faostat, 2016). In most African countries, honey mostly consumed is harvested from indigenous hives and processed using traditional methods.

In Kenya, 80% of the country comprises of Arid and Semi-Arid Lands (ASALs) which have high potential in honey production. Beekeeping is the main activity carried out in these areas due to the abundance of flowers. It is also the main source of income for honey producers living in the area. Non-ASAL or humid regions also practice beekeeping. Modern apiculture in Kenya begun towards the end of 1960 and has since become an important activity practised in the livestock sub-sector (Gichuki, 2015). The main beekeeping regions in Kenya include Baringo, Kakamega Forest, Taita Taveta, Mwingi, Nandi hills and Mbeere, etc.

In Kenya, apiculture used to be done in the rural areas as the main business that contributes substantially to the improved living standards of most honey producers residing in these areas of the country. However, it is now a commercial enterprise that has greatly developed since many industries in Kenya are using bee products for other purposes. Beekeeping policies have been set up to monitor plans and emphasize on the best practices to be utilized in the honey industry with quality standards as the main goals. Beekeeping is now becoming a valuable industry in Kenya (Kuria, 2019).

In Kenya, 80% of the honey produced comes from indigenous hives (Kuria, 2019). However, a reasonable amount of bee products is obtained from the Kenya Top Bar and Langstroth hives. 20 % of Kenya's potential in honey production is estimated at 80 % with 100,000 metric tonnes being produced annually. However, only about 20 % of the country's potential has been achieved because most of the highly productive areas have not been exploited. Honey produced in the Arid and Semi-Arid Lands is about 80 %. Honey production in Kenya typically emanates from indigenous hives which are approximately 1.1 million. Total hives in the country are approximately 1.3 million (Muli, *et al.*, 2007).

2.2 Types of Beehives

Carroll and Kinsella (2013) stated that the most common type of beehive is a hollow log as shown in Plate 2.1. It is also known as fixed-comb hives, traditional hives or indigenous hives. Bees build their honeycombs on the sides of the hive. The second type of beehive is the top bar hive. This is where bees hang their combs from the top bars. Each top bar has the same width as the others. This enables bees to build one comb in each top bar. In this case, honeycombs can be removed from the hives without being destroyed. They are also called moveable comb hives.

A common type of this design is the Kenya Top Bar hive (KTBH). Frame hive is the third type of beehive designed to allow bees to build their honeycombs within each of the wooden frames. Each honeycomb can be moved in and out of the hive without being destroyed. Therefore, this hive is categorized as a moveable comb hive. A common type of this design is the Langstroth hive. Top bars and frame hives are also known as modern hives and are shown in Plate 2.2.

Plate 2.1: Indigenous bee hives/ traditional log hives

(Source: Author, 2020)

Plate 2.2: KTBH (left) and Langstroth beehives (right)

(Source: Author, 2020)

2.3 Physical properties of honey

The quality of honey produced is usually compared to the international standards as proposed in the International Honey Commission and Codex Alimentarius Commission. Honey has physical properties like moisture content, pH, relative density and total water-insoluble solids content, among others. (Kahraman, *et al.*, 2010).

2.3.1 Moisture content of honey

Moisture content of honey is a quality parameter associated with climatic conditions of an area, season of harvesting honey, and the level of honey maturity during harvest.

This parameter is usually measured using a refractometer. It is considered among the most abundant constituents of honey and is very significant because it influences honey quality during storage. High moisture content in honey tend to ferment during storage. Honey having less than 18% moisture content can be stored with minimal risk of fermentation. Moisture content in honey is influenced by some environmental factors like the weather of a place, nectar conditions, handling of honey during processing and storage conditions (Manyiloh, *et al.*, 2011). According to Yanniotis, *et al.* (2006), the moisture content values of honey should range from 14 % to 18%, and should not exceed the maximum permitted limit of 21% as set by the International Honey Commission and Codex Alimentarius Commission. Research on some Nigerian honey showed moisture content values ranging from 16.38 % to 30.82 %, which was similar to the values obtained from the USA honey (Adebiyi, *et al.*, 2004). A research done by Orina (2014) from Kakamega Forest, Embu, Mwingi, Ntubo, Tharaka Nithi and Timboroa, among others showed moisture content values ranging from 15.27 % to 20.29 %.

2.3.2 pH of honey

The pH of honey is significant in setting the processing and storage conditions of honey because it affects its shelf-life, texture and stability (Gomes, *et al.*, 2011). This parameter is also significant in selecting the materials for construction of honey processing equipment. Acidity in honey is influenced by the presence of gluconic, lactic, formic and oxalic acids. The presence of these organic acids is beneficial and acts as acaricides in controlling mites. The recommended value for the pH of honey is normally 3.9. However, the maximum permitted limit was established to be 5.0 by the European Union (EU), International Honey Commission and Codex Alimentarius Commission (Nanda, *et al.*, 2003).

Spanish honey has been reported to have pH values ranging from 3.55 to 4.79 with a mean value of 4.2. Nigerian honey as reported by Adebiyi, *et al.* (2004) showed considerable differences in pH values ranging from 4.31 to 6.02 with a mean of 4.75. Orina (2014) observed pH values of Kenyan honey to have a range values from 3.62 to 4.52 with a mean value of 4.07. Gluconic acid along with hydrogen peroxide gives honey its antibacterial activity.

2.3.3 Relative density of honey

The density of honey is a quality parameter that influences stratification. The maximum permitted limit of this parameter is normally 1.43 g/ml as established by the International Honey Commission and Codex Alimentarius Commission. The permitted limit value is slightly greater than the density of water, i.e., 1.41 g/ml. However, honey density varies with the amount of moisture present in honey. For instance, when honey with different densities are mixed in storage containers, they show distinct layers. Honey having higher moisture content settles over honey with lower moisture content. Therefore, honey should be mixed thoroughly during processing and packaging to avoid stratification. In the storage tanks, the final moisture content of honey varies depending on the relative density of different types of honey (Nanda, *et al.*, 2003; Robert, 2010).

2.3.4 Total water-insoluble solids content of honey

The total water-insoluble solids content represents the presence of wax particles, insect parts, pollen, vegetable debris, bee and filth particles (Mesbahi, *et al.*, 2019). Higher water-insoluble solids content in honey indicates poor collection, processing, filtration and may also be related to the low hygienic habit of bees in choosing the site for honeycomb deposition and honey storage (Aroucha, *et al.*, 2019). Determination of this parameter is significant in detecting any impurities that may be present in honey.

The maximum permitted limit of honey extracted by centrifugation is usually 0.1 g/100 g, whereas honey extracted by pressing the honeycombs has a maximum permitted limit of 0.5 g/100 g. Most countries extract honey by centrifugation. However, honey is mostly extracted by pressing the honeycombs in Kenya. Therefore, this parameter is significant in determining honey cleanness and distinguishing between pressed and centrifuged honey (Robert, 2010).

2.4 Physical characteristics of honeycombs

Nazzi, (2016) reported that the hexagonal shape of the honeycomb cells depends on the construction behaviour of bees and has attracted attention of humans for centuries. Bees build cylindrical cells that later transform into hexagonal prisms. It was observed that, hexagons possess the highest surface/perimeter ratio, compared to other polygons. Therefore, it was suggested that, honey bees build their hexagonal cells in order to achieve the best economy of the material.

2.5 Existing honey extractors

The existing centrifugal extractors in the market are either radial or tangential depending on how the honeycomb frames are arranged inside the extractor (Zohairy, 2019). These extractors give clean honey with fewer impurities such as pollen grains, wax, debris and insect parts. In radial extractors, there is no need to rearrange the frames once they have been loaded because honey is extracted simultaneously from both sides of the frame. Whereas, in tangential extractors, honey is emptied from one side of the frame when spinning, then turned around so that the other side of the frame is also emptied. There is no difference in the direction of rotation for both radial and tangential honey extractors.

Tangential, radial, automatic programmable and electrical-driven types of honey extractors have been developed in advanced countries such as United States, Germany, etc., (Abadariki, *et al.*, 2013). However, these extractors are of high cost to be purchased by indigenous honey producers (Akinnuli, *et al.*, 2016).

2.5.1 Manually-operated honey extractor

(Abadariki, *et al.*, 2013) developed an affordable and portable manually-operated honey extractor for extracting honey from frame hives as shown in Plate 2.3. The extractor was fabricated using locally available materials to reduce the cost of purchasing the machine by the honey producers. It was stated that the extractor produces honey for economic and medicinal purposes. It was also stated that the accessibility of the fabricated extractor would ensure increased production rates of honey into the market, reduced drudgery among the honey producers during processing, creation of employment opportunities for the jobless, and increased economy of a country through exportation of honey and its products. The physical properties of honey such as viscosity, density, hygroscopicity, surface tension and thermal properties were taken into consideration before designing and fabricating the extractor. The extractor was made simple and manually operated so that it could be installed at home or farm where breeding of honey bees is possible. The machine could be used in both rural and urban areas where there is no electricity. The fabricated extractor was 82 % efficient.

Plate 2.3: Centrifugal manually-driven (hand crank) 6 frame honey extractor

Source: (Sircar and Yadav, 2018)

2.5.2 Pedal-operated honey extractor

Akinnuli, *et al.* (2016) designed a pedal-driven honey extractor for extracting honey from frame hives as shown in Figure 2.1, which was an improvement of the formerly designed hand-driven extractor. The extractor was designed to accommodate a pedal mechanism. The efficiency of the designed extractor was found to be 85 % more efficient than the previous design which had an efficiency of 83.29 %. The operator cannot get tired easily because it can be cycled repeatedly as many times as possible to increase honey production. This would ensure improved standards of living for the honey producers from the sale of their products.

The designed extractor was found to be effective and could extract honey hygienically from the honeycombs. The machine could be operated by anyone and require less energy to drive the pedals.

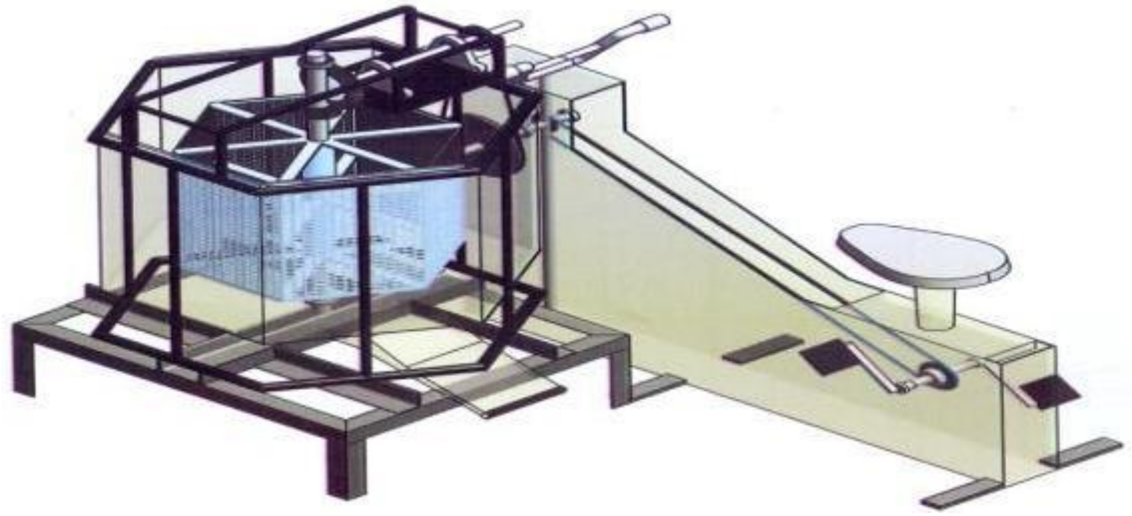


Figure 2.1: Isometric view of a pedal-operated honey extractor

Source: (Akinnuli, et al., 2016)

2.5.3 Electrically-operated honey extractor

Patrick and Oyejide (2018) designed and constructed an electrically operated honey extractor for frame hives as shown in Figure 2.2 using easily available and accessible materials to cut the cost of producing the machine. The designed extractor was deemed portable and could be operated by anyone without any special training or technical expertise. The extractor was designed to be used at any time of the day regardless of the temperature or climatic conditions. The efficiency of the machine was 68.16%.

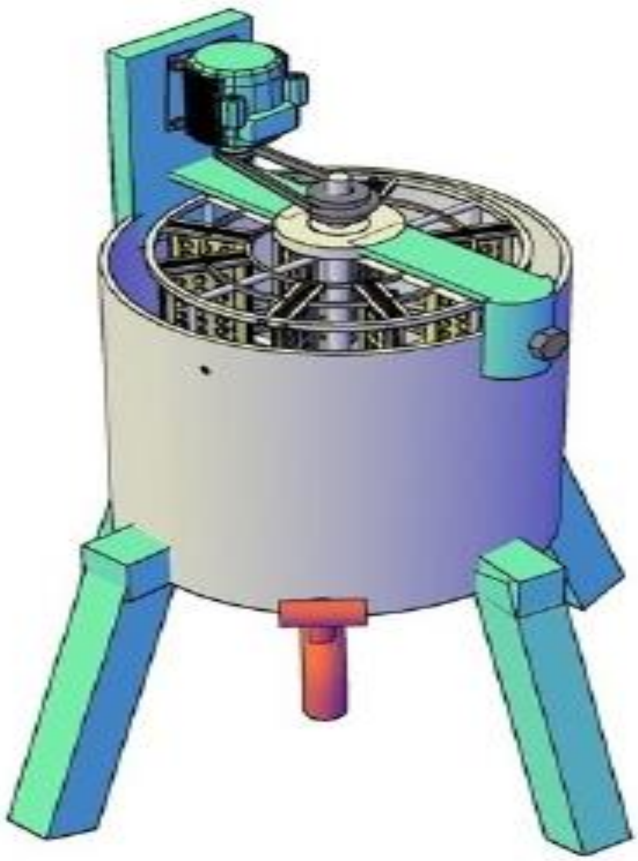


Figure 2.2: Exploded view of an electrically operated honey extractor

Source: (Patrick and Oyejide, 2018)

2.5.4 Mechanical screw press honey extractor

Maradun and Sanusi (2013) designed and fabricated a mechanical screw press honey extractor for extracting honey from both frame and log hives. The extractor was considered a good option for the existing methods of honey extraction. The extractor was found to be timely in its production and minimizes work load involved during honey extraction. The extractor was also found to reduce the risk of contamination due to contact with bare hands, overheating, over-exposure to the environment, and filtering medium as compared to the traditional method.

It was considered to be cheap hence could be purchased by the low-income honey producers, long-lasting and requires no special proficiencies in its operation. The designed extractor had an efficiency of 70.6 %, as compared to that of the weight and sieve method with an efficiency of 56.33 %. The extractor components were sourced from locally available materials. The extractor was recommended for both small and medium-scale honey producers.

Figure 2.3 shows the isometric projection of the screw press. Parts A, B, C, D, E and F represent the turning bar, threaded pressing shaft, flat iron bar, pressing chamber, discharge outlet and supporting frame respectively.

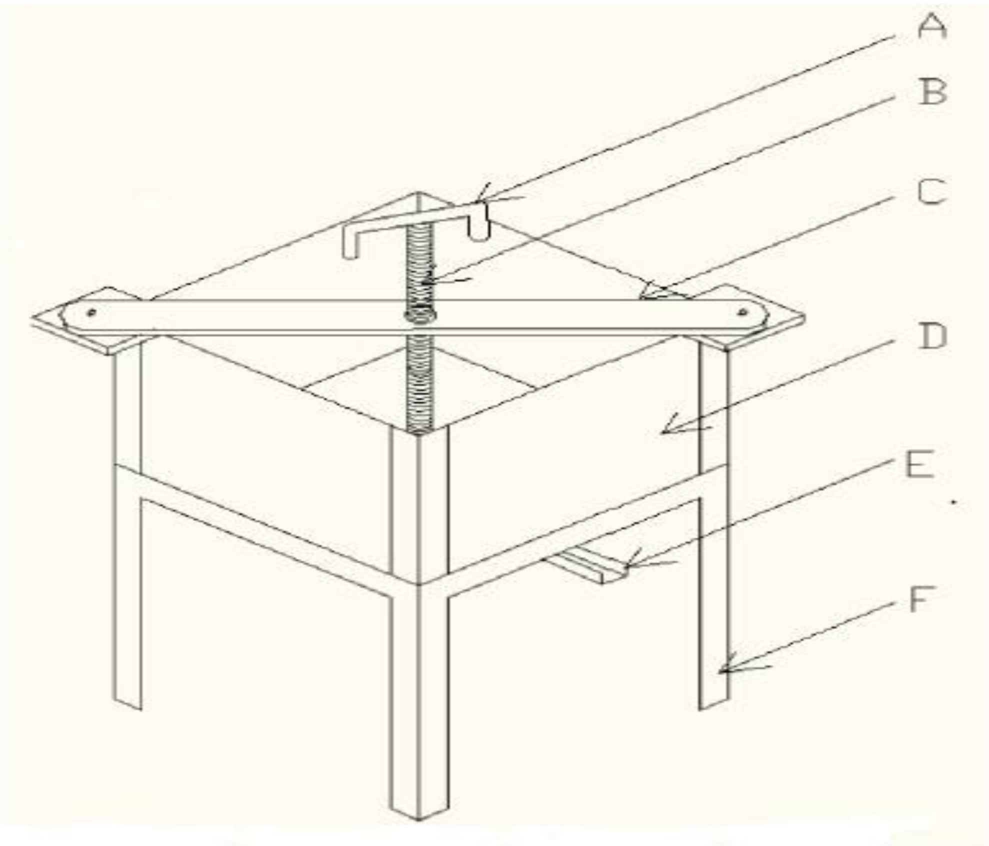


Figure 2.3: Isometric projection of a screw press

Source: (Maradun and Sanusi, 2013)

2.5.5 Vibratory honey extractor

Ola, *et al.* (2016) designed and fabricated a vibratory honey extractor for extracting honey from Kenya Top Bar hive (KTBH) as shown in Plate 2.4 to solve the problem of crushing the honeycombs along with the extract. The machine was made of stainless steel, mild steel and plastic materials. The machine operated at a speed of 483 rpm and a frequency of 50 Hz. It was able to extract honey in the preferred quality and quantity within 40 minutes of operation at an efficiency of 98.9%. It was found to produce good quality honey that has high market value thereby improving the livelihood of stakeholders in honey business industries.

Plate 2.4: Aerial view of the vibratory honey extractor

Source: (Ola, et al., 2016)

2.6 How long to spin a manually driven honey extractor

Holly, (2021) quoted that, it is important to spin a honey extractor for the right amount of time. Spinning the extractor using little time leads to incomplete extraction of honey from the honeycombs. Alternatively, spinning the extractor using much time, there is a higher risk of damaging the honeycombs. Honey producers have different opinions on how long to spin a honey extractor to completely extract honey. However, the general consensus is that, a honey extractor should be spun for 5 – 10 minutes (but can vary) to completely extract honey without destroying the honeycombs. Some few factors affecting the length of time to spin the honey extractor depends on the speed of the extractor and thickness of honey.

2.7 Human energy requirements and its applications

Riemer and Shapiro, (2011) quoted that, the concept of harvesting energy from human motion was based on the fact that, an average amount of energy used by the human body was approximately 1.07×10^7 Joules per day. This amount of energy can be produced from 0.2 kg of body fat. Human energy is normally derived from food e.g., carbohydrates, fats, and proteins among others. The considerable amount of energy released from the body in forms of heat and motion open the way for development of technologies that can harvest this energy for powering mechanical devices. The main challenge in developing such technologies lies in constructing a device that will harvest as much energy as possible while interfering only minimally with the natural functions of the body. Furthermore, such a device should ideally not increase the amount of energy required by a person to perform his/her activities.

The mechanical efficiency of the human body is estimated to be about 15-30 %, meaning that most of the energy consumed as food is released into the atmosphere as heat. Therefore, it seems logical to harvest this thermal energy and convert it into mechanical energy.

In the (Physics) book section it was quoted that, our own bodies just like any other living organisms, are energy conversion machines. Energy conversion implies that, the chemical energy stored in food is converted into work, thermal energy, and/or stored as chemical energy in fatty tissues. The fraction that goes into each form depends on how much humans eat and the level of physical activity. If more than what is needed by the body to do work and stay warm is taken, then the remainder goes into body fat.

2.8 Summary of literature review and research gap

(Abadariki, *et al.*, 2013; Akinnuli, *et al.*, 2016; Ola, *et al.*, 2016; Patrick and Oyejide, 2018) designed and fabricated honey extractors for extracting honey from modern beehives, i.e., KTBH and Langstroth hives. These beehives have frames that can be loaded onto the extractors. Alternatively, (Maradun and Sanusi, 2013) designed and fabricated a mechanical screw press honey extractor for extracting honey from both frame and log hives. However, this extractor crushes the honeycombs to produce honey. Though it is hygienic due to minimal hand handling, but leads to combs breakage and extraction of honey together with wax particles, insect parts and debris, among others.

Honey from traditional log hives and natural colonies have been widely extracted using traditional methods in Kenya (Chemwok, 2016; Robert, 2010). This is because there is no frame in these hives and colonies to be loaded onto the existing extractors.

Therefore, there is need to design and validate a honey extractor based on the physical properties of honey, to improve processing of quality honey harvested from indigenous hives and natural colonies. The improved extractor minimizes combs breakage due to the inclusion of honeycomb net buckets in the design that firmly hold the combs during extraction. The radial design and centrifugal force principle were adapted from the existing designs.

2.9 Conceptual Framework

Figure 2.4 shows the conceptual framework derived from specific objectives of the study. The chart shows how physical properties of honey were utilized in improving the processing of quality honey harvested from indigenous hives and natural colonies.

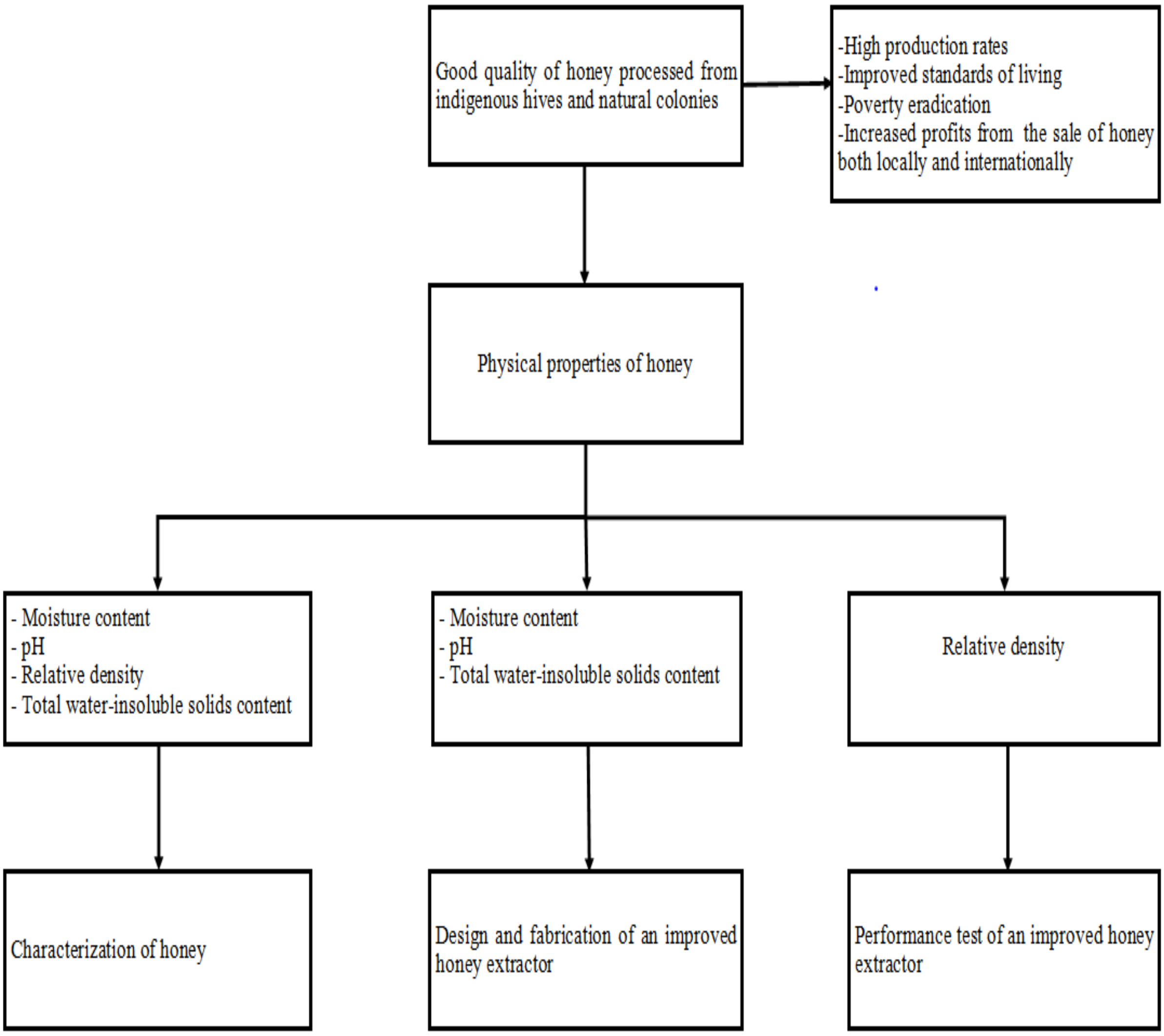


Figure 2.4: Conceptual Framework

(Source: Author, 2020)

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study area

The study was carried out in Marigat settlement located in the lowlands of Baringo County, Kenya. It is located about 20 km from Lake Baringo and Lake Bogoria. It lies between latitude $0^0 10' 0'' N$ and $0^0 50' 0'' N$, longitude $35^0 50' 0'' E$ and $36^0 20' 0'' E$ as shown in Figure 3.1. The altitudinal range of the area lies between 900 and 1200 m above sea level. The area is generally hot and dry throughout the year. Rainfall variability is very high with an annual average rainfall of about 650 mm. The rainfalls are experienced within one season of the year from April to August, followed by a prolonged dry season. The rainfall pattern is strongly influenced by local topography. Temperatures within the Sub-County vary from 30^0 to 35^0 C, but can rise to 37^0 C in January and March. Soils comprise mainly of clay loam and alluvial deposits (KEFRI, 2021).

Marigat is among the most popular honey-producing regions in Kenya. It is an Arid and Semi-Arid Land (ASAL), where most farmers practice beekeeping and livestock farming as their main source of income to improve their livelihoods. Agricultural activities cannot thrive in the area hence are not widely practiced. The climatic conditions and vegetation cover of the study area are favourable for beekeeping activities. The abundance of natural bee flora enhances honey production. Bees suck nectar from flowers to make honey. The area is dominated by indigenous hives and natural colonies (Kipruto, 2016).

The study focused on collection of honey from four sites of Marigat including; Maoi centre, Lopoi junction, Marigat town and Koriema centre. Figure 3.1 shows the coordinates of various study sites where data collection was undertaken.

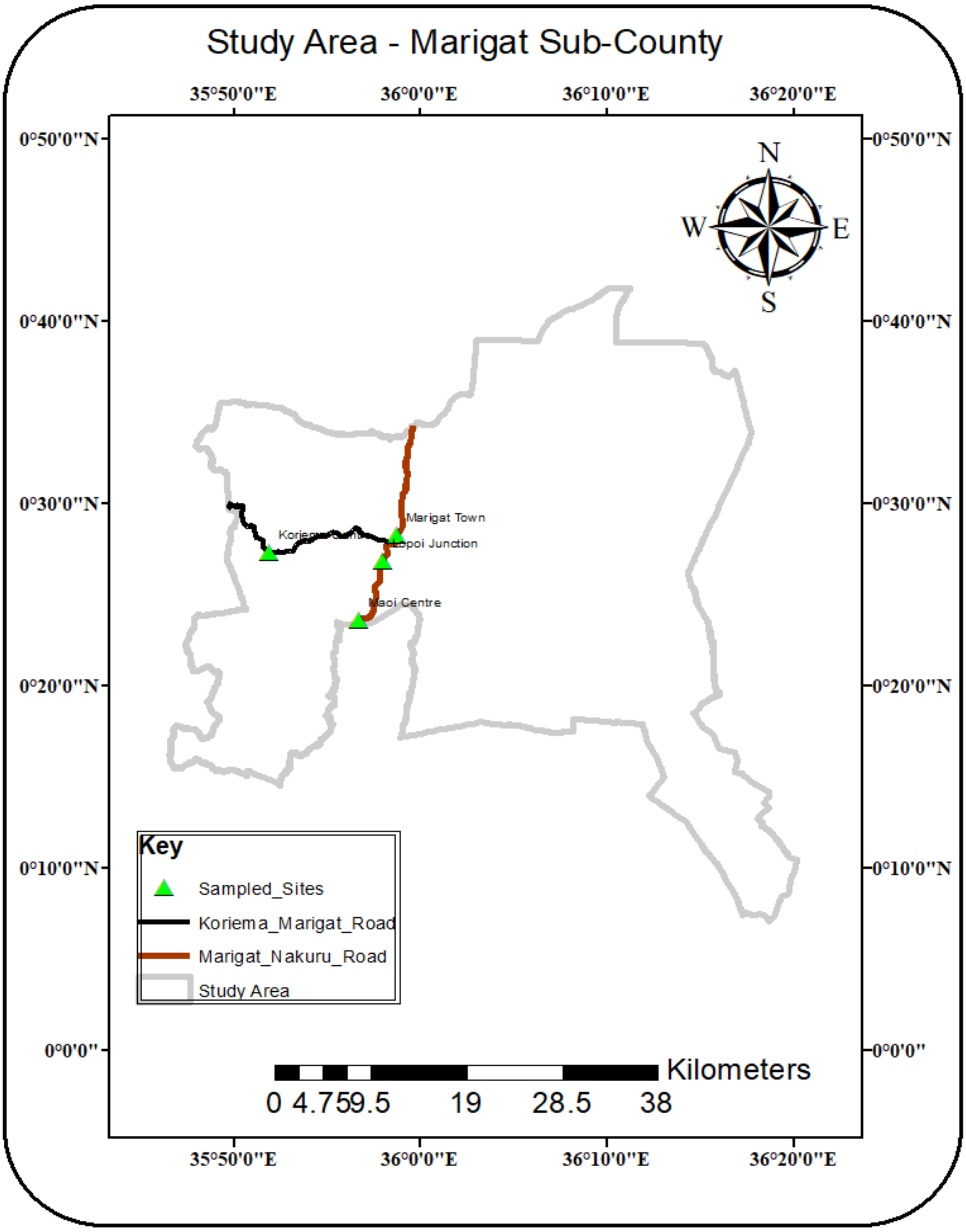


Figure 3.1: Marigat in Baringo County and the selected sites

(Source: Author,2020)

3.2 Characterization based on physical properties of honey

Characterization was done based on the physical properties of honey. The properties determined include moisture content, pH, relative density and total water-insoluble solids content. These properties were used to determine the quality of honey harvested from the indigenous hives and natural colonies and processed using traditional methods. The results found from each parameter were compared to the set standards and requirements established by the Kenya Bureau of Standards, International Honey Commission and Codex Alimentarius Commission. The parameters were then analysed per location using one-way Analysis of Variance (ANOVA) to detect their significant differences at 5 % level.

3.2.1 Honey samples acquisition and preparation

Twelve (12) samples of honey were collected randomly from honey producers residing in Maoi centre, Lopoi Junction, Marigat Town and Koriema centre as shown in Plate 3.1. All samples collected were processed from honeycombs harvested from the indigenous hives and natural colonies and extracted using traditional methods. Three (3) samples of honey were collected randomly from each of the four (4) sites bringing the total to twelve (12) samples as shown in Plate 3.1. Honey was then poured into hygienically clean 400 ml food-grade plastic containers with well labelled stoppered lids for uniformity, since different honey producers used different sizes of containers to store their honey. Samples were then taken to the testing department/sample control centre, Kenya Bureau of Standards in Kisumu County. All samples were tested as per the standards and procedures obtained from KS/EAS 36:2000. The results were recorded as shown in Appendix VI. A summary of the physical properties of honey, their measuring instrument and units, requirements and the test methods were presented as shown in Table 3.1.

Plate 3.1: Twelve (12) samples of honey collected from four (4) sites of Marigat

(Source: Author, 2020)

Table 3.1: Summary of the physical properties of honey, their measuring instruments, units, requirements and test methods

Parameter	Measuring Instrument	Units	Requirements	Test method
Moisture content	Abbematt 550 Refractometer	% by mass	22 maximum	EAS 36
pH	Hanna pH Meter		Not specified	TES/ING/TM/46
Relative density	Analytical balance, water bath (memmert), and pycnometer	g/ml	Not specified	TES/F&A/TM/43
Total water-insoluble solids content	Analytical balance-Shimadzu; electric air oven-memmert; vacuum pump	% by mass	0.5 maximum	KS 05-344

(Source: KEBS, 2020)

3.2.2 Determination of moisture content of honey

The principal procedure based on the refractometric method of Chataway (1932), which was later on revised by Wedmore (1955) was used in determining the moisture content of honey. The refractive index of test samples was determined using Abbematt 550 refractometer at a constant temperature of 20° C. The readings obtained were then converted to moisture content and expressed as percent m/m. This parameter was measured to determine the amount of moisture present in honey. High water content in honey reduces its shelf life due to high risk of fermentation upon storage. The maximum permitted limit of moisture content in honey as per the EAS 36 test method is 22 % as shown in Table 3.1.

3.2.3 Determination of pH values of honey

The pH values of honey were determined by applying the potentiometric titration method using standard NaOH solution. 5 g of honey was quantitatively transferred into a 50 ml volumetric flask and filled with water to the mark. 25 ml of this solution was pipetted into a 250 ml beaker then the initial pH measured using a pH meter. The solution was stirred gently, then 10 ml of 0.05 M NaOH solution was added into the beaker. The excess NaOH was titrated with 0.025 M of H_2SO_4 solution. This parameter was measured to determine the level of acidity in honey. The pH values of honey were measured using TES/ING/TM/46 test method as shown in Table 3.1. The recommended pH value of honey is usually 3.9.

3.2.4 Determination of relative density of honey

The apparatus used in determining the relative density of honey included a thermostatically controlled water bath maintainable at +27$\pm$1° C and a specific gravity bottle. The bottle was thoroughly cleaned and dried before weighing. Freshly boiled and cooled distilled water was then filled up to the mark. The bottle was maintained at 27$\pm$1° C and weighed. Water was poured then the bottle dried again while maintaining it at the same temperature. The bottle was then filled with honey sample and weighed again. The relative density of honey was measured using TES/F&A/TM/43 test method as shown in Table 3.1. The recommended relative density value of honey is usually 1.42 g/ml. The relative density of different honey samples was calculated using Equation 3.1.

$$\rho = \frac{m_h - m_e}{m_w - m_e} \tag{3.1}$$

Where, m_h is the mass of specific gravity bottle with honey sample (g),

m_e is the mass of an empty specific gravity bottle (g),

m_w is the mass of gravity bottle with water (g).

3.2.5 Determination of the total water-insoluble solids content of honey

Honey samples of about 20 g were dissolved in distilled water at 80° C and mixed well. The samples were weighed to the nearest 10 mg. A fine sintered glass crucible of 15 to 40 microns pore size was dried and weighed. The test solution was filtered through the crucible and washed thoroughly with hot water at 80° C until it was free from sugars according to Mohr Test. The crucible was then dried for one hour at a temperature of 135° C, cooled and weighed to the nearest 0.1 mg. This parameter was measured to determine the amount of impurities present in honey.

The maximum permitted limit of total water-insoluble solids content present in honey as per the TES/F&A/TM/43 standard is 0.5 % m/m as shown in Table 3.1 . The results were expressed as a percentage of water-insoluble solids and calculated using Equation 3.2.

$$s = (w - s) = \frac{x}{W} \times 100 \tag{3.2}$$

Where, w is the water content (%),

s is the insoluble solids content (%),

x is the weight gained by crucible (g) and,

W is the weight of honey sample.

3.2.6 Data analysis and presentation

One-way Analysis of Variance (ANOVA) was used to analyse the data obtained from measuring honey samples in the KEBS laboratory. ANOVA was done to detect if there were any significant differences on the quality of honey harvested from different sites at 5% level from statistical tables. Honey was analysed using the quality parameters of honey like moisture content, pH, relative density and total-water insoluble solids content. In this case, each of the physical properties of honey was the only factor under investigation. Data was presented in form of tables. Table 3.2 shows a summary of one-way analysis of variance computational formulas.

Table 3.2: Summary of one-way analysis of variance computational formulas

Source of variation	Sum of squares (SS)	Degrees of freedom (DF)	Mean squares (MS)	Variance ratios
Between treatments	$SS_B = \sum \frac{(T_j)^2}{n_j} - CF$	$c - 1$	$MS_B = \frac{SS_B}{c-1}$	$F_{observed} = \frac{MS_B}{MS_W}$
Within treatments	$SS_W = \sum {X_{ij}}^2 - \sum \frac{(T_j)^2}{n_j}$	$N - c$	$MS_W = \frac{SS_W}{N-c}$	
About grand mean	$SS_T = \sum {X_{ij}}^2 - CF$	$N - 1$	$MS_T = \frac{SS_T}{N-1}$	

Source: (Kothary, 2004)

From Table 3.2: $(T_j)^2$ is the square of each sample total and (n_j) is the number of items in the concerning sample,

$\sum {X_{ij}}^2$ is the sum of squares of all item values,

CF is the correction factor,

N is the total number of treatments and c is the number of treatment means.

Null hypothesis, H_0: The physical properties of honey from different sites of Marigat produce similar qualities.

Alternative hypothesis, H_1: The physical properties of honey from different sites of Marigat produce different qualities.

3.2.7 Honeycomb samples collection and measurements

Sixteen (16) samples of honeycombs were harvested randomly from four selected sites of Marigat. All samples were harvested from indigenous hives and natural colonies and taken to the University of Eldoret, Materials Laboratory to obtain various measurements. A tape measure, stainless-steel vernier calliper, and an electronic weighing balance machine calibrated in cm, mm and g were used to measure diameters 1 and 2 of the comb cells, thicknesses and mass of honeycombs, respectively. Average mass of the results obtained from measuring mass of honeycombs were utilized in determining the diameter of central vertical shaft as well as performance evaluation of the extractor.

3.3 Development and validation of a honey extractor based on physical properties of honey

3.3.1 Machine description and working principle

The developed honey extractor was made of vertical central solid shaft carrying the drive system mechanism. This solid shaft also accommodates four (4) honeycomb net buckets which secure firmly the matured honeycombs ready for extraction. The whole mechanism was housed in a stainless-steel cylindrical drum. The drive system mechanism consisted of bearings and straight bevel gears that transmits motion from the hand crank to the shaft, that drives the net buckets inside the drum. The driver gear set in motion the driven gear which invariably set the net buckets in motion.

The extractor operates by the principle of radial motion of the net buckets loaded with matured honeycombs. The net buckets were spun to rotation by utilizing the energy produced by human operating the machine. The rotational effect produced centrifugal force that triggered flow of honey out of the comb cells onto the extractor wall.

As the centrifugal force increases, the rate of honey outflow increases until the combs were empty. The hopper-shaped base eased the flow of extracted honey into the collector ready for packaging.

3.3.2 Components of the honey extractor

Figure 3.2 shows an exploded view of the developed honey extractor for improving the processing of quality honey harvested from indigenous hives and natural colonies. Table 3.3 also shows a summarized description of the various components of the developed honey extractor.

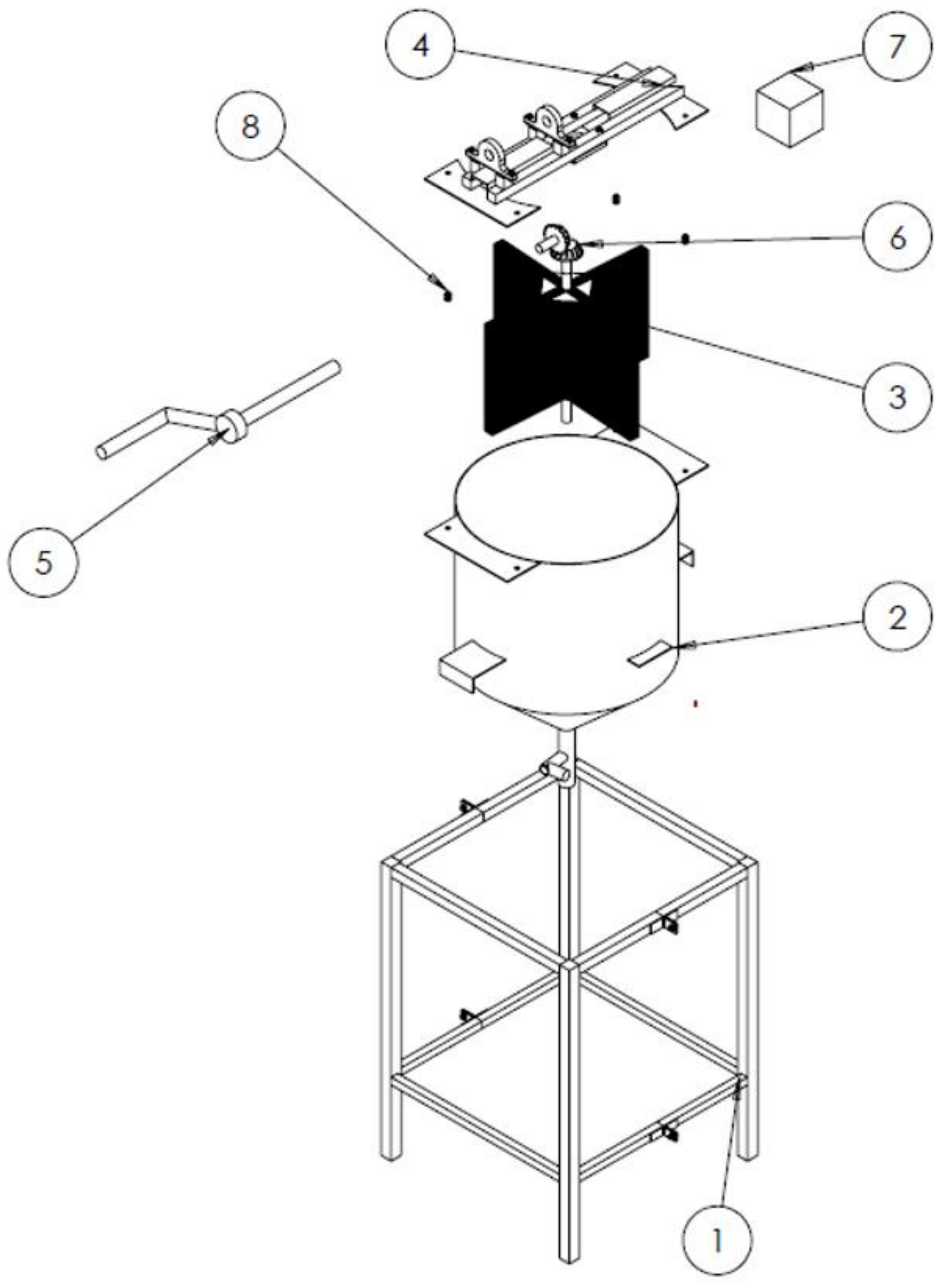


Figure 3.2: Exploded view of the developed honey extractor

(Source: Author, 2021)

Table 3.3: Components of the honey extractor

S. No.	Part Name	Description
1	Supporting Frame	Made of mild steel to support the extractor components
2	Cylindrical drum	Made of stainless-steel plate to house the honeycomb net buckets and holds the drive system support.
3	Honeycomb net buckets	Made of stainless-steel mesh and was designed to hold the honeycombs firmly during extraction to minimize combs breakage. The mesh had hole sizes of 4 mm and 1 mm diameter.
4	Drive system support	Holds the bearings and supports the whole of drive system components during extraction.
5	Hand crank	For spinning the honeycomb net buckets to trigger flow of honey from the comb cells onto the extractor wall.
6	Straight bevel gears	For transmission of motion and were designed at right angles. The driver and the driven gears had 18 and 10 number of teeth respectively.
7	Gear housing	For housing the straight bevel gears.
8	Bolts and nuts	For tightening the various parts of the extractor.
9	Filtering mesh	For sieving any impurities extracted with honey (insect parts, debris and wax particles).
10	Gate valve	For passage of honey onto the collecting container after extraction.

(Source: Author, 2021)

3.3.3 Design consideration and material selection

Various design considerations were put in place to enable efficient design of the extractor. The mean pH value of honey was significant in choosing the suitable materials for fabrication. For this case, the cylindrical drum, shafts, honeycomb net buckets, filtering mesh, gate valve and drive system support among others were made from stainless-steel grade 304 materials. These materials were chosen for fabricating the extractor due to their ability to resist corrosion and to avoid contamination of honey. This is because, honey is a food grade and acidic in nature. The criteria of selecting the materials were based on their durability, strength and suitability of the material for honey extraction. This ensures an increase on the shelf-life of equipment as well as reducing the cost of maintenance.

The mean total water-insoluble solids content of honey was utilized in the extractor design to ensure collection of pure honey. This parameter was significant in choosing the suitable screen sizes for filtering impurities like insect parts, debris and wax particles in honey. Stainless-steel filtering mesh and a strainer with hole sizes of 1.0 mm and 0.5 mm, respectively, were designed and placed just below the honeycomb net buckets to sieve any impurities present before collecting and packaging honey into 400 ml storage plastic containers with well-labelled stoppered lids. Heating mechanism like water bath, was not included in the design to avoid increasing moisture content in honey due to heating of honeycombs to melt wax. This way, the risk of fermentation during storage was minimized.

3.3.4 Determination of the size of extractor and honeycomb net buckets

Size of the honeycomb net buckets as well as size of the extractor were determined by utilizing the dimensions of largest possible values of results obtained from measuring the honeycombs. Diameter 1 (the longer side), diameter 2 (the shorter side), and the largest possible thickness value of the honeycombs measured were used to manipulate the height, length and width of the honeycomb net buckets respectively. The net buckets comprise of stainless-steel plates attached to the stainless-steel wire mesh and connected to the vertical central solid shaft.

Figure 3.3 shows honeycomb net bucket components. The buckets secure honeycombs firmly during extraction. Four honeycomb net buckets (Part 3) were welded onto the vertical central solid shaft (Part 1). The triangular plates (Part 4) were welded onto the net buckets to ensure stability during extraction. Also, the rectangular plates (Part 2) were firmly welded onto the edges of the net buckets to avoid hurting one’s self while loading the honeycombs.

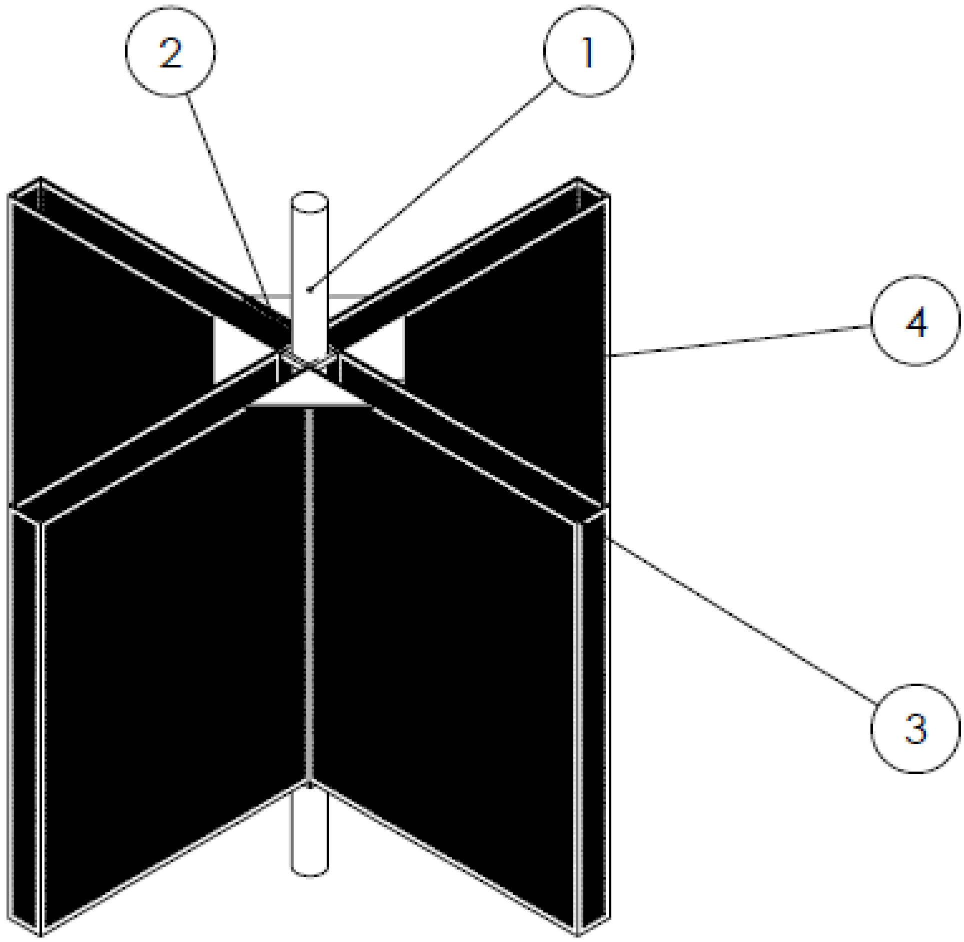


Figure 3.3: Honeycomb net buckets

(Source: Author, 2021)

3.3.5 Design models for the honey extractor

3.3.5.1 Determination of components accommodated by the shaft

The components accommodated by central vertical solid shaft were considered by determining the average mass of honeycombs, mass of stainless-steel wire mesh and plates as shown below.

a) Mass of honeycombs

The total mass of honeycombs was derived by summing up the masses (m_1 .... to m_6) as shown.

$$m_t = m_1 + m_2 + m_3 + m_4 + m_5 + m_6 \tag{3.3}$$

The average mass of honeycombs was then calculated as follows.

$$m_{av} = \frac{m_t}{6} \tag{3.4}$$

Therefore, the average mass of honeycombs accommodated by four (4) net buckets was computed as follows.

$$m_h = m_{av} \times 4 \tag{3.5}$$

b) Mass of stainless-steel rectangular plate grade 304

Given the length of stainless-steel plate (l_r), height (h_r) and thickness (w); The total height of stainless-steel plate for four (4) net buckets was calculated as shown.

$$h_t = 4(l_r + h_r) \tag{3.6}$$

The volume of stainless-steel plate was also calculated as shown.

$$V = l_r \times w \times h_r \tag{3.7}$$

Therefore, mass of stainless-steel plate was then computed as shown.

$$m_p = \rho \times V \tag{3.8}$$

Where, ρ is the density of stainless-steel plate and is equivalent to $7.9 \times 10^3 \mathrm{kg/m^3}$.

c) Mass of stainless-steel wire mesh grade 304

Given the wire mesh diameter (d) in mm and hole size (s_h), the mesh size was given by the following equation.

$$\text{mesh size} = \frac{25.4}{d \times s_h} \tag{3.9}$$

Given the roll width, w_1 in m, and total roll length, $l = 4\big((l \times 2) + w\big)$ m. Therefore, mass of bigger wire mesh was computed as shown.

$$m_{w1} = \frac{s_h \times d \times w_1 \times l_1}{2} \tag{3.10}$$

Given the roll width, w_2 in m, and total roll length, $l_2 = (4 \times l)$ m. Therefore, mass of smaller wire mesh was computed as shown.

$$m_{w2} = \frac{s_h \times d \times w_2 \times l_2}{2} \tag{3.11}$$

The total mass of wire mesh used was then calculated as shown.

$$m_w = m_{w1} + m_{w2} \tag{3.12}$$

d) Mass of stainless-steel triangular plates grade 304

Given the base (b), height of triangular plates, (h_{tr}) and length of triangular plates, (l_{tr}); Therefore, the volume of four triangular plates was given by the following equation.

$$V = \left(\frac{1}{2} \times b \times h_{tr} \times l_{tr}\right) \times 4 \text{ plates} \tag{3.13}$$

Therefore, mass of four triangular plates,

$$m_t = \rho \times V \tag{3.14}$$

e) Total mass of components accommodated by the shaft

The total mass of components accommodated by the central shaft was derived using equation 3.15.

$$m = m_h + m_p + m_w + m_t \tag{3.15}$$

3.3.5.2 Pitch angles for power transmission gears

The power transmission gears used were the straight bevel gears positioned at right angles. Therefore, pitch angles for the driver and driven gears were expressed as shown below.

a) Pitch angle for the driver gear

Knowing that, the pitch angle for the driver gear is given by Equation 3.16,

$$\theta_{P1} = \tan^{-1}\left(\frac{1}{V.R}\right) \tag{3.16}$$

But, Velocity ratio, $V.R = \frac{T_G}{T_P} = \frac{N_P}{N_G}$ (3.17)

Where, T_G = Number of teeth on the driven gear,

T_P = Number of teeth on the driver,

N_P = Number of revolutions per minute for the driver and,

N_G = Number of revolutions per minute for the driven gear.

b) Pitch angle for the driven gear

Knowing that the pitch angle for the driven gear is given by Equation 3.18,

$$\theta_{P2} = \theta_S - \theta_{P1} \tag{3.18}$$

Where, $\theta_S = 90^0$.

3.3.5.3 Formative number of teeth

The formative number of teeth for the driver and the driven gear are as shown respectively.

$$T_{EP} = T_P \sec\theta_{P1} \tag{3.19}$$

$$T_{EG} = T_G \sec\theta_{P2} \tag{3.20}$$

Where, $\sec\theta = \frac{1}{\cos\theta}$

3.3.5.4 Gear design

For a 20° full depth involute system, Lewis equation was applied in calculating the tooth form factors for the driver and driven gears as shown respectively.

$$y'_P = 0.154 - \frac{0.912}{T_{EP}} \tag{3.21}$$

$$y'_G = 0.154 - \frac{0.912}{T_{EG}} \tag{3.22}$$

Therefore, the allowable static stress of forged carbon steel case hardened for the driver and driven gears are as shown respectively.

$$\sigma_{OP} \times y'_P \tag{3.23}$$

$\sigma_{OG} \times y'_G$ (3.24)

Where, σ_{OP} and $\sigma_{OG} = 126$ MPa or $126\ \mathrm{N/mm^2}$

If the product $\sigma_{OG} \times y'_G$ is less than $\sigma_{OP} \times y'_P$, the driven gear is weaker. Therefore, the design should be based upon the driven gear and not the driver. But if the product, $\sigma_{OP} \times y'_P$ is less than $\sigma_{OG} \times y'_G$, then the design should be based upon the driver and not the driven gear.

3.3.5.5 Torque and power transmitted by the gear shaft on a rotary motion

Straight bevel gears were used to transmit power and motion between the intersecting shafts, i.e., the vertical and horizontal shafts, designed at right angles (90^0). The gears were cut by form cutters.

Knowing that, the angular velocity and torque are given by the following equations respectively,

$$\omega = \frac{2\pi N_G}{60} \tag{3.25}$$

$$T = F_c r \tag{3.26}$$

Where, r is the radius of the extractor in m, and F_c is the centrifugal force in N and was computed using the following equation.

$$F_c = \frac{mV^2}{r} \quad \text{(3.27}$$

But velocity was determined as shown.

$$V = \omega r \tag{3.28}$$

Therefore, power transmitted by the gear shaft on a rotary motion was then computed as shown.

$$P = T\omega \tag{3.29}$$

3.3.5.6 Determination of module

The following expressions shows a step-by-step procedure that was used to determine the module when the driven gear was weaker than the driver. The same procedure was repeated for determining the module when the driver gear was weaker than the driven gear.

a) Tangential load on the driven gear was given by the following equation.

$$W_T = \frac{2T}{D_G} = \frac{2T}{mT_G} \tag{3.30}$$

Where, D_G is the pitch circle diameter of the driven gear and m is the module both in mm.

b) The pitch line velocity was derived as shown.

$$v = \frac{\pi D_G.N_G}{60} = \frac{\pi m.T_G.N_G}{60} \tag{3.31}$$

c) The velocity factor for teeth cut by form cutters was given by the following equation.

$$C_v = \frac{3}{3+v} \tag{3.32}$$

d) The length of pitch cone element was expressed as shown.

$$L = \frac{D_G}{2\sin\theta_{P2}} \tag{3.33}$$

e) Face width was then calculated as shown.

$$b = \frac{1}{3} \times L \tag{3.34}$$

f) Alternatively, from Lewis equation, the tangential load on the gear was computed as shown.

$$W_T = (\sigma_{OG} \times C_v) b. \pi m. y'_G \left(\frac{L-b}{L}\right) \tag{3.35}$$

From Equation 3.35, the expression for finding the module (m) in mm was solved by hit and trial method.

3.3.5.7 Pitch circle diameters

The pitch circle diameters of the driven and driver gears were then computed using the following equations respectively.

$$D_G = m. T_G \tag{3.36}$$

$$D_P = m. T_P \tag{3.37}$$

3.3.5.8 Determination of shaft diameters for the driver and the driven gear

Let shaft diameters for the driver and driven gears be d_P and d_G respectively; Therefore, the following expressions were used to compute diameter for the driver gear and the same procedure was repeated for determining the shaft diameter for the driven gear.

Knowing that,

a) Torque, $T = \frac{P \times 60}{2\pi \times N_P}$ (3.38)

b) Mean radius, $R_m = \left(L - \frac{b}{2}\right)\left(\frac{D_p}{2L}\right)$ (3.39)

c) The tangential force acting at mean radius, $W_T = \frac{T}{R_m}$ (3.40)

d) Therefore, the axial and radial forces acting on the gear shaft were computed as shown respectively.

$$W_{RH} = W_T \tan\Phi \, . \sin\theta_{P1} \quad (3.41)$$

$$W_{RV} = W_T \tan\Phi \, . \cos\theta_{P1}$$

(3.42)

e) Bending moment due to axial and radial forces combined, and then due to the tangential force acting at the mean radius were computed as shown respectively.

$$M_1 = (W_{RV} \times \text{Overhang}) - (W_{RH} \times R_m) \quad (3.43)$$

$$M_2 = W_T \times \text{Overhang} \quad (3.44)$$

f) From Equation 3.43 and 3.44, the resultant bending moment was computed as shown.

$$M = \sqrt{(M_1)^2 + (M_2)^2} \quad (3.45)$$

g) For shafts subjected to both twisting and bending moments, the equivalent twisting moment for the driver according to maximum shear stress theory was computed as shown.

$$T_e = \sqrt{M^2 + T^2} \quad (3.46)$$

Alternatively, $T_e = \frac{\pi}{16} \times \tau \times {d_p}^3$ (3.47)

h) The equivalent bending moment for the driver according to maximum normal stress theory was computed as shown.

$$M_e = \frac{1}{2}\left(M + \sqrt{M^2 + T^2}\right) = \frac{1}{2}(M + T_e \tag{3.48}$$

Alternatively, $M_e = \frac{\pi}{32} \times \sigma_b \times {d_p}^3$ (3.49)

From these expressions, the diameter of the driver shaft was evaluated. Where, the allowable shear stress, $\tau = 0.6 \times \text{UTS} = 0.6 \times 586 = 351.6\ \text{N/mm}^2$ and the allowable bending stress, $\sigma_b = 586\ \text{N/mm}^2$. The Ultimate Tensile Strength value was obtained from Table 7.1. The larger diameter value from twisting and bending moments equations was selected.

i) Taking a factor of safety of 2, the allowable shear stress and bending stress were calculated as shown respectively.

$$\tau = \frac{\tau_u}{\text{F.S}} = \frac{351.6}{2} = 175.8\ \text{N/mm}^2 \tag{3.50}$$

$$\sigma_b = \frac{\sigma_{bu}}{\text{F.S}} = \frac{586}{2} = 293\ \text{N/mm}^2 \tag{3.51}$$

3.3.5.9 Bearing selection

The choice of bearing type was selected based on dynamic load capacity calculated from the desired life.

a) Desired life of a bearing

The desired life of a bearing in hours was computed as shown.

$$L_H = N_h \times N_d \times N_y \tag{3.52}$$

Where, N_h is the number of operating hours per day,

N_d is the number of operating days in a week and,

N_y is the number of operating years in months.

Therefore, life of a bearing in revolutions was calculated as shown.

$$L = 60 \times N \times L_H \tag{3.53}$$

Where, N is the speed in revolutions per minute (rpm)

b) Basic dynamic equivalent load

The dynamic equivalent radial load (W) under combined radial (W_R) and constant axial (W_A) loads, were calculated as shown.

$$W = X.V.W_R + Y.W_A \tag{3.54}$$

Where, X and Y are the radial and axial load factors respectively, and V is the rotational factor.

The values of X and Y for dynamically loaded bearings were obtained from Table 7.6.

Also, $W_R = W_{RV}$ and $W_A = W_{RH}$.

In order to determine the value of X and Y, the ratios W_A/W_R and W_A/C_O were computed.

Where, C_O is the static load capacity.

c) Basic dynamic load rating

From the life of bearing formula,

$$L = \left(\frac{C}{W}\right)^{k} \times 10^{6} \tag{3.55}$$

Where, $k = 3$ for ball bearings. Therefore, the basic dynamic load rating was derived as shown.

$$C = W\left(\frac{L}{10^{6}}\right)^{\frac{1}{3}} \tag{3.56}$$

3.3.6 Performance evaluation of the developed honey extractor

The designed and fabricated honey extractor was taken to one of the honey-producing farms in Marigat to evaluate the extractor performance. The set-up of extractor was done by assembling the parts since they were disassembled to ease transportation of the machine to the site. Matured honeycomb cells harvested from the indigenous hives and natural colonies were uncapped using a knife and then loaded into the net buckets that firmly secure the combs during extraction. The top of extractor was closed and then manually spun a hundred (100) times using a hand crank. It was observed that, the centrifugal force threw honey out of the comb cells onto the extractor wall. The stainless-steel filtering mesh designed just below the net buckets and a strainer sieved all the impurities present in honey. The flow of honey was smooth because of the hopper-shaped design. Honey extracted from the machine was free from contamination because honey was not handled with bare hands, unlike in the traditional methods where honey is usually squeezed using bare hands to extract honey.

3.3.6.1 Power required by humans to operate the extractor

a) Power required by humans to operate the extractor in Watts (W) without getting tired was calculated as follows.

$$P = \frac{w}{t} \tag{3.57}$$

Where, w is the work done by humans in Joules (J) and, t is the time taken to operate the extractor in seconds (s).

b) Work done was derived as shown.

$$w = W \times d_H \tag{3.58}$$

Where, W is the average weight of humans operating the extractor in Newtons (N), and d_H is the handle distance of the extractor in metres (m).

c) The time taken to operate the extractor was calculated using Equation 3.59 as shown.

$$t = N_h \times N_d \times N_y \times 3600s \tag{3.59}$$

Where, N_h is the number of operating hours per day,

N_d is the number of operating days in a week and,

N_y is the number of operating years in months.

3.3.6.2 Mass flow rate of honey from the extractor

The mean relative density value of honey and mass of honeycombs were significant in determining the mass flow rate of honey from the extractor.

Mass flow rate was determined by calculating the volume of honeycomb net buckets. It took a period of 8 minutes equivalent to 480 seconds of spinning the hand crank a hundred times to completely empty the honeycombs without breaking them. On the day of testing the extractor performance, 5 test runs were done within a period of 8 minutes each.

Therefore, mass flow rate of honey from the extractor was calculated using Equation 3.60.

$$m_f = \rho \times V \tag{3.60}$$

Where,

m_f is the mass flow rate of honey in kg/s

ρ is the density of honey in kg/m^3.

V is the volumetric flow rate of honey from the honeycomb net buckets in m^3/s and was calculated as shown in Equation 3.61.

$$V = \frac{\text{mass of honeycombs}}{\text{density of honey}}\ m^3/s \tag{3.61}$$

3.3.6.3 Efficiency of the honey extractor

Efficiency of the machine was determined by finding the ratio of output to the input and expressed as a percentage. From the results obtained for mass of honey extracted per day as the output, and mass of honeycombs processed in a day as the input, the ratio gave the efficiency of the machine. According to Akinnuli, et al. (2016), the efficiency of the honey extractor was calculated using Equation 3.62.

$$\varepsilon = \frac{\text{mass of honey extracted}}{\text{mass of honeycombs processed}} \times 100\ \% \tag{3.62}$$

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Characterization based on physical properties of honey

This section presents the results obtained from testing each of the physical properties of honey and tabulated as shown. ANOVA was then used to analyse the results.

4.1.1 Moisture content of honey

The results obtained for moisture content of honey samples from different sites are presented in Table 4.1.

Table 4.1: Mean and standard error values for moisture content

Study Site			
Maoi Centre	**Lopoi Junction**	**Marigat Town**	**Koriema Centre**
Moisture Content (%)			
18.4	15.0	18.4	18.4
18.6	18.1	17.8	18.0
18.4	17.1	18.8	19.6
18.5±0.1	**16.7±1.1**	**18.3±0.4**	**18.7±0.6**

(Source: KEBS, 2020)

From Table 4.1, moisture content of honey from Maoi centre, Lopoi junction, Marigat town and Koriema centre varied from 18.4 to 18.6 %, 15.0 to 18.1 %, 17.8 to 18.8 % and 18.0 to 19.4 % with mean and standard error (SE) values of 18.5±0.1 %, 16.7±1.1 %, 18.3±0.4 % and 18.7±0.6 %, respectively.

All samples of honey analysed from these sites were below the maximum permitted limit of 22 % as set in the Kenya Standards (2020). However, all samples from Maoi centre, one sample from Lopoi junction, two samples from Marigat town and two samples from Koriema centre were above the permitted range of 14 to 18 % as set by the international organizations and were not exceeding the permitted maximum limit of 21 %. The rest of the honey samples were within the permitted range of 14 % and 18 %. Honey samples obtained from Koriema centre had the highest mean value of 18.7 % with that from Lopoi junction having the lowest mean value of 16.7 %. The difference in moisture content values were attributed to the changing climatic conditions, season of harvesting honey, level of honey maturity and storage conditions.

4.1.1.1 Data analysis for moisture content of honey

In this case, moisture content was the only factor under investigation and results presented in Table 4.2.

Table 4.2: Moisture content of honey per location

Location	Moisture content (%)		
	Test 1	Test 2	Test 3
Maoi centre	18.4	18.6	18.4
Lopoi junction	15.0	18.1	17.1
Marigat town	18.4	17.8	18.8
Koriema centre	18.4	18.0	19.6

(Source: KEBS, 2020)

From Table 3.2, the formulars shown were utilized in determining the F-values for moisture content and the results summarized as shown in Table 4.3.

Table 4.3: Moisture content of honey analysis

Source of variation	Sum of Squares (SS)	Degrees of Freedom (DF)	Mean Squares (MS)	Variance ratios
Between treatments	1.745	2	$MS_B = \frac{1.745}{2} = 0.8725$	$F_{observed} = \frac{0.8725}{1.365} = 0.64$
Within treatments	12.285	9	$MS_W = \frac{12.285}{9} = 1.365$	
About grand mean	14.03	11	$MS_T = \frac{14.03}{11} = 1.2755$	

(Source: Author, 2020)

4.1.1.2 Hypothesis

From Table 4.3, $\mathrm{F_{observed}} = 0.64$ and at 5 % significance level from statistical tables $\mathrm{F_{0.05(2.9)}} = 4.26$. Therefore, $\mathrm{F_{Critical}} > \mathrm{F_{Observed}}$.

Accept the null hypothesis and conclude that there is sufficient evidence to say that all honey samples from different sites have no significant differences in their moisture content percentage present in honey. This was attributed to the fact that all study sites were in Marigat which is among the ASAL areas in Kenya, hence exhibits the same climatic conditions, processing and storage conditions. Moreover, honey was harvested in the same season of the year hence same level of maturity could have been attained.

4.1.2 pH values of honey

The results obtained for pH of honey for different sites are presented in Table 4.4.

Table 4.4: Mean and standard error values for pH

Study Site			
Maoi Centre	**Lopoi Junction**	**Marigat Town**	**Koriema Centre**
		pH	
4.0	3.3	3.6	4.0
4.2	3.9	3.8	3.9
4.1	4.0	3.9	4.0
4.1±0.1	**3.7±0.3**	**3.8±0.1**	**4.0±0.1**

(Source: KEBS, 2020)

The results from Maoi centre, Lopoi junction, Marigat town and Koriema centre varied from 4.0 to 4.2, 3.3 to 4.0, 3.6 to 3.9 and 3.9 to 4.0 with mean and standard error values of 4.1±0.1, 3.7±0.3, 3.8±0.1 and 4.0±0.1 respectively. All samples from Maoi centre, one sample from Lopoi junction and two samples from Koriema centre were above the recommended pH value of 3.9. The rest of the values were within the recommended pH value. However, the mean pH values for all sites were within the maximum permitted limit of 5.0 as set by the international organizations. The results also show that Maoi centre had the highest mean pH value of 4.1 with that from Lopoi junction having the lowest value of 3.7. This shows that honey from Lopoi junction was more acidic than honey from other study sites. The acidic nature of honey was attributed to the presence of organic acids (Nanda, *et al.*, 2003).

4.1.2.1 Data analysis for pH of honey

In this case, pH was the only factor under investigation and results presented in Table 4.5.

Table 4.5: pH values of honey per location

Location	pH Value		
	Test 1	**Test 2**	**Test 3**
Maoi centre	4.0	4.2	4.1
Lopoi junction	3.3	3.9	4.0
Marigat town	3.6	3.8	3.9
Koriema centre	4.0	3.9	4.0

(Source: KEBS, 2020)

Table 4.6 shows a summary of results obtained from determining the F-values for pH of honey.

Table 4.6 pH of honey analysis

Source of variation	Sum of squares (SS)	Degrees of freedom (DF)	Mean squares (MS)	Variance ratios
Between treatments	0.17	2	$MS_B = \frac{0.17}{2} = 0.085$	$F_{observed} = \frac{MS_B}{MS_W} = \frac{0.085}{0.051} = 1.67$
Within treatments	0.46	9	$MS_W = \frac{0.46}{9} = 0.051$	
About grand mean	0.63	11	$MS_T = \frac{0.63}{11} = 0.057$	

(Source: Author, 2021)

4.1.2.2 Hypothesis

From Table 4.6, $\mathrm{F_{observed}} = 1.67$ and at 5 % significance level from statistical tables $\mathrm{F_{0.05(2.9)}} = 4.26$ therefore, $\mathrm{F_{Critical}} > \mathrm{F_{Observed}}$.

Accept the null hypothesis and conclude that there is sufficient evidence to say that all honey samples from different study locations have no significant differences in their pH values. This could be attributed to the fact that the study locations lie in the same geographical location. They exhibit the same vegetation cover with same floral nectar characteristics. They also have same organic acids which make pH values to be similar.

4.1.3 Relative density of honey

The results obtained for relative density of honey for different sites are presented in Table 4.7.

Table 4.7: Mean and standard error values for the relative density

Study Site			
Maoi Centre	**Lopoi Junction**	**Marigat Town**	**Koriema Centre**
Relative Density (g/ml)			
1.4129	1.4343	1.4125	1.4128
1.4123	1.4154	1.4160	1.4153
1.4126	1.4192	1.4103	1.4045
1.4126±0.0002	**1.4230±0.0071**	**1.4129±0.0020**	**1.4109±0.0040**

(Source: KEBS, 2020)

The results show that honey from Maoi centre, Lopoi junction, Marigat town and Koriema centre varied from 1.4123 to 1.4129 g/ml, 1.4154 to 1.4343 g/ml, 1.4103 to 1.4160 g/ml and 1.4045 to 1.4153 g/ml with mean and standard error values of 1.4126±0.00024 g/ml, 1.4230±0.0071 g/ml, 1.4129±0.0020 g/ml and 1.4109±0.0040 g/ml, respectively.

All samples from Maoi centre, Marigat town and Koriema centre, and two samples from Lopoi junction were below the recommended relative density value of 1.42 g/ml and the maximum permitted limits of 1.43 g/ml as set by the International Honey Commission and Codex Alimentarius Commission. Only one sample from Lopoi junction was above these limits. However, honey samples obtained from this site had the highest value of 1.4230 g/ml which was slightly within the maximum permitted limits. Whereas, honey samples from Koriema centre had the lowest value of 1.4109 g/ml. The relative density of honey is a quality parameter that is influenced by the amount of moisture present in honey. The low density of honey observed from all study locations except for Lopoi junction (B1) shows that honey obtained from these locations tends to have higher moisture content.

4.1.3.1 Data analysis for relative density of honey

In this case, the relative density was the only factor under investigation and presented as shown in Table 4.8.

Table 4.8: Relative density of honey per location

Location	Relative density (g/ml)		
	Test 1	Test 2	Test 3
Maoi centre	1.4129	1.4123	1.4126
Lopoi junction	1.4343	1.4154	1.4192
Marigat town	1.4125	1.4160	1.4103
Koriema centre	1.4128	1.4153	1.4045

(Source: KEBS, 2020)

Table 4.9 shows a summary of the results obtained from determining the F-values for relative density of honey.

Table 4.9: Relative density of honey analysis

Source of variation	**Sum of squares (SS)**	**Degrees of freedom (DF)**	**Mean squares (MS)**	**Variance ratios**
Between treatments	4	2	$MS_B = \frac{4}{2} = 2$	$F_{observed} = \frac{2}{-0.001} = -2000$
Within treatments	-0.01	9	$MS_W = \frac{-0.01}{9} = -0.001$	
About grand mean	3.99	11	$MS_T = \frac{3.99}{11} = 0.36$	

(Source: Author, 2021)

4.1.3.2 Hypothesis

From Table 4.9, $F_{observed} = -2000$ and at 5 % significance level from statistical tables $F_{0.05(2.9)} = 4.26$ therefore, $F_{Critical} > F_{Observed}$

Accept the null hypothesis and conclude that there is sufficient evidence to say that all honey samples from different study locations have no significant differences in their relative densities. Therefore, when honey from these study locations are mixed together and stored, they show no distinct layers. Similar relative densities can also be attributed to the fact that the study locations experience similar climatic conditions.

4.1.4 The total water-insoluble solids content of honey

The results obtained for total water-insoluble solids content of honey for different sites are presented in Table 4.10.

Table 4.10: Mean and standard error values for the total water-insoluble solids content of honey per location

Study Site			
Maoi Centre	**Lopoi Junction**	**Marigat Town**	**Koriema Centre**
Total Water-insoluble Solids Content (% m/m)			
0.14	0.07	0.10	0.17
0.30	0.11	0.29	0.09
0.37	0.19	0.61	0.15
0.27±0.08	**0.12±0.04**	**0.33±0.18**	**0.14±0.03**

(Source: KEBS, 2020)

The results show that, total water-insoluble solids content of honey from Maoi centre, Lopoi junction, Marigat town and Koriema centre varied from 0.14 to 0.37 % m/m, 0.07 to 0.19 % m/m, 0.10 to 0.61 % m/m and 0.09 to 0.17 % m/m with mean and standard error values of 0.27±0.08 % m/m, 0.12±0.04 % m/m, 0.33±0.18 % m/m and 0.14±0.03 % m/m, respectively. Honey samples from all study sites were within the maximum permitted limit of 0.5 % m/m for honey extracted by pressing as set by KEBS and international organizations. Honey samples obtained from Marigat town had the highest mean total water-insoluble solids content of 0.33 % m/m with that from Lopoi junction having the lowest mean value of 0.12 % m/m. The mean values from all sites were above the permitted limit of 0.1 % m/m for honey extracted by centrifugation as set by KEBS and international organizations. This indicates that extraction of honey was done using the traditional method of pressing the honeycombs rather than using a honey extractor. This led to incomplete extraction ending up with impurities like insect parts, debris and wax observed in honey.

4.1.4.1 Data analysis for total water-insoluble solids content of honey

In this case, the total water-insoluble solids content was the only factor under investigation and presented as shown in Table 4.11.

Table 4.11: Total water-insoluble solids content of honey per location

Location	Total water-insoluble solids content (% m/m)		
	Test 1	**Test 2**	**Test 3**
Maoi centre	0.14	0.30	0.37
Lopoi junction	0.07	0.11	0.19
Marigat town	0.10	0.29	0.61
Koriema centre	0.17	0.09	0.15

(Source: KEBS, 2020)

Analysis of variance was used to compute the F-value of the total water-insoluble solids content as shown in Table 4.12.

Table 4.12: The total water-insoluble solids content of honey analysis

Source of variation	Sum of squares (SS)	Degrees of Freedom (DF)	Mean squares (MS)	Variance ratios
Between treatments	0.09	2	$MS_B = \frac{0.09}{2} = 0.045$	$F_{observed} = \frac{MS_B}{MS_W} = \frac{0.045}{0.02} = 2.25$
Within treatments	0.18	9	$MS_W = \frac{0.18}{9} = 0.02$	
About grand mean	0.27	11	$MS_W = \frac{0.27}{11} = 0.025$	

(Source: Author, 2021)

4.1.4.2 Hypothesis

From Table 4.12, $F_{observed} = 2.25$ and at 5 % significance level from statistical tables $F_{0.05(2.9)} = 4.26$ therefore, $F_{Critical} > F_{Observed}$.

Accept the null hypothesis and conclude that there is sufficient evidence to say that all honey samples from different study locations have no significant differences in their total water-insoluble solids content. This is because similar method of honey extraction was involved hence showing similar amounts of water-insoluble matter or impurities in honey. Most honey producers in the area use traditional methods to extract honey from honeycombs. Honey extracted by this method has a high amount of water-insoluble matter like insect parts, debris and wax.

4.1.5 Dimensions and mass of honeycombs

Table 4.13 shows the results obtained from measuring the diameters and thicknesses of honeycombs.

Table 4.13: Diameters and thicknesses of honeycombs

S. No	Diameter 1 (cm)	Diameter 2 (cm)	Thickness 1 (cm)	Thickness 2 (cm)
1	27.0	20.0	2.2	2.2
2	26.0	20.0	2.2	2.1
3	26.0	20.0	1.8	2.1
4	25.5	20.0	2.1	2.1
5	27.0	20.5	2.1	2.1
6	26.5	20.0	2.5	2.1
7	28.0	20.0	2.1	2.0
8	27.0	19.0	2.1	2.2
9	25.0	16.5	2.1	2.0
10	27.0	21.0	2.2	2.1

(Source: Author, 2020)

The results obtained from measuring mass of honeycombs were taken to the nearest gram (g) and presented as shown in Table 4.14.

Table 4.14: Mass of honeycombs

S. No	Mass (g)
1	814
2	503
3	654
4	551
5	746
6	1067
Total	**4335**
Average	**722.5**

(Source: Author, 2020)

From Table 4.14, the total mass of honeycombs, $\mathrm{m_t} = 4335\ \mathrm{g}$ and average mass of honeycombs, $\mathrm{m_{av}} = 722.5\ \mathrm{g}$ or 0.72 kg. Therefore, the average mass of honeycombs accommodated by four (4) honeycomb net buckets was then calculated as shown.

$$\mathrm{m_h} = 0.72 \times 4 = 2.88\mathrm{kg}$$

4.2 Development and validation of a honey extractor based on physical properties of honey

4.2.1 Design considerations of the developed extractor

The honey extractor was designed by utilizing the largest possible values of honeycombs as shown in Table 4.13. Therefore, the largest possible diameter 1, diameter 2 and thicknesses of the comb cells gave the height, length and width of honeycomb net buckets, respectively as shown in Figure 4.1. From this, the size of the extractor was then manipulated and designed as shown in Figure 4.2

Therefore, Figure 4.1 shows the dimensions of honeycomb net buckets as follows.

a) Length of honeycomb net buckets, $l = 21$ cm or 210 mm

b) Width of the net buckets, $w = 2.5$ cm or 25 mm

c) Height of the net buckets, $h_b = 28$ cm or 280 mm

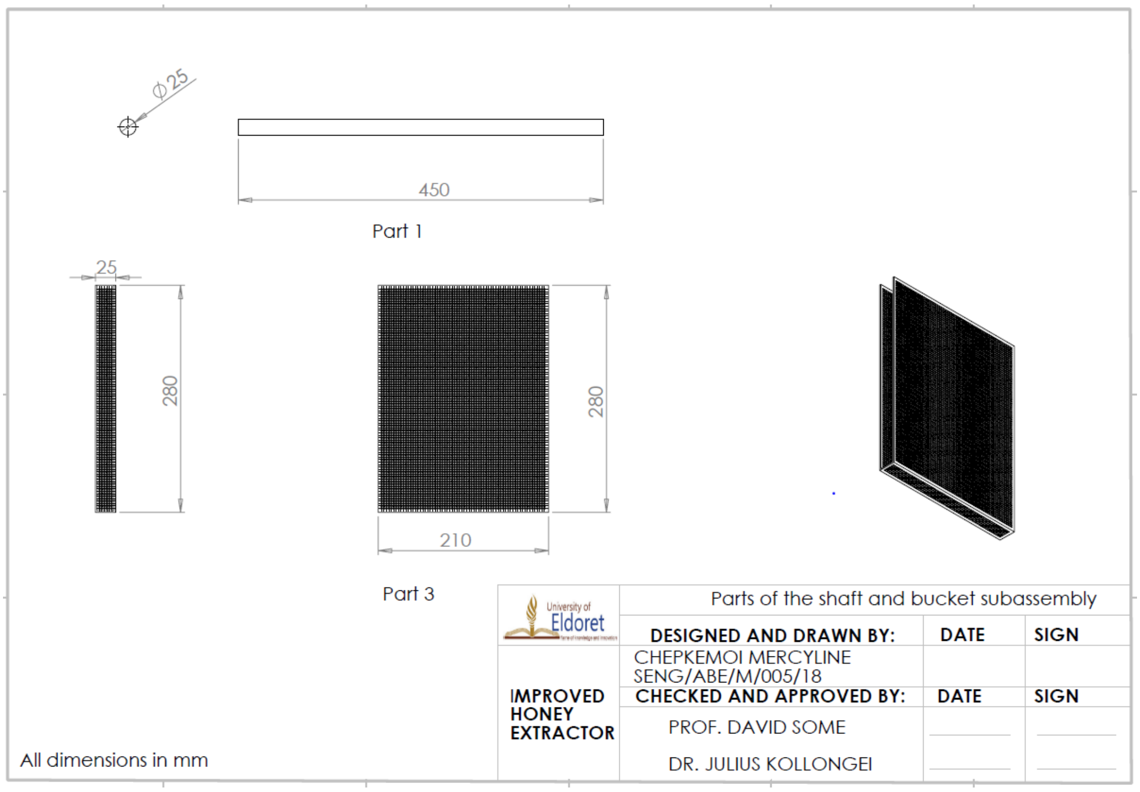


Figure 4.1: Dimensions of the honeycomb net buckets

(Source: Author, 2021)

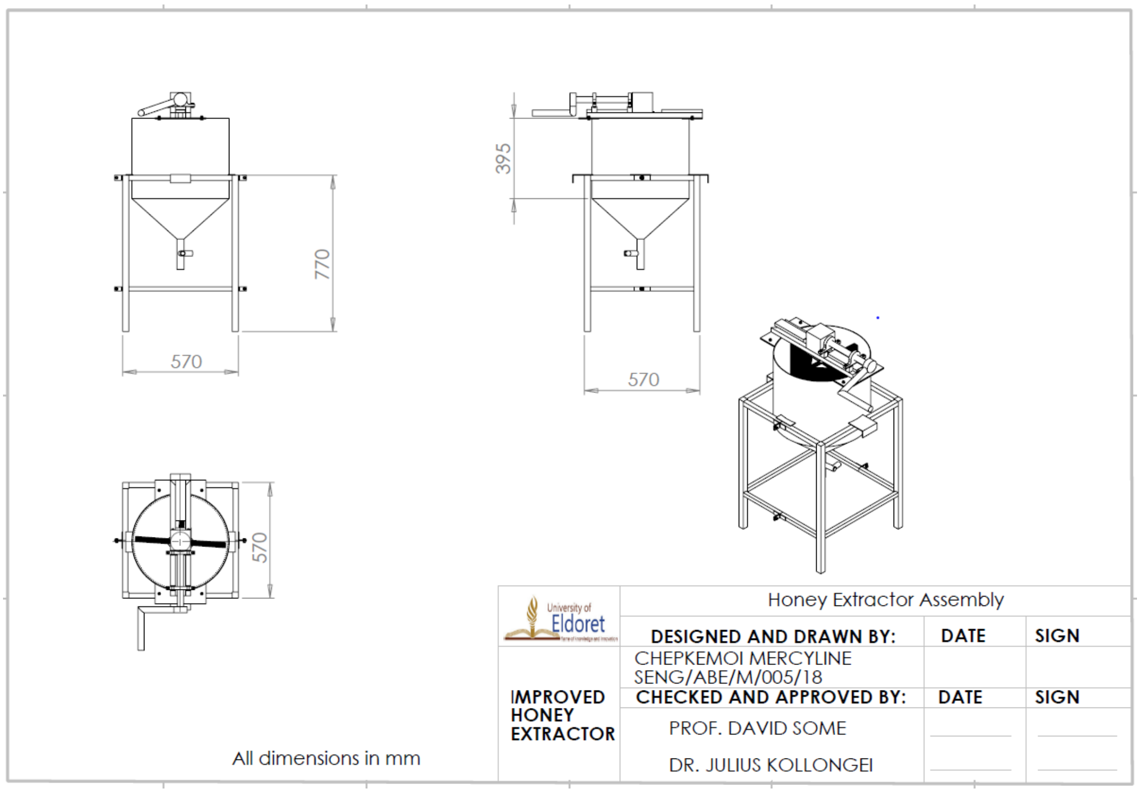


Figure 4.2: Side and top views of the developed honey extractor

(Source: Author, 2021)

4.2.2 Design of honeycomb net buckets

4.2.2.1 Mass of stainless-steel rectangular plate grade 304

Given the length of stainless-steel plate, $l = 20$ mm or 2 cm and thickness, $w = 1$ mm or 0.1 cm. Therefore, the total height of stainless-steel plate for four (4) net buckets was computed as follows.

$$h_t = 4(21 + 28)\text{cm} = 196\text{cm or } 1960\text{mm}$$

Therefore, volume of stainless-steel plate was computed as shown.

$$V = 2 \times 0.1 \times 196 = 39.2\ \text{cm}^3 \text{ or } 3.92 \times 10^{-5}\text{m}^3$$

Given the density of stainless-steel (ρ) = $7.9 \times 10^3 \text{kg/m}^3$; mass of stainless-steel rectangular plate was calculated as follows.

$$\mathrm{m_p} = 7.9 \times 10^3 \times 3.92 \times 10^{-5} = 0.31\mathrm{kg}$$

4.2.2.2 Mass of stainless-steel wire mesh grade 304

Given the wire mesh diameter (d) = 1 mm and hole size = 4 mm,

$$\text{Mesh size} = \frac{25.4}{1+4} = 5 \text{ mesh/inch}$$

Given the roll width, $\mathrm{w_1} = 28$ cm or 0.28 m and total roll length,

$$\mathrm{l_1} = 4\big((21 \times 2) + 2.5\big) = 178 \text{ cm or } 1.78 \text{ m.}$$

Therefore, mass of bigger wire mesh,

$$\mathrm{m_{w1}} = \frac{5 \times 1 \times 1 \times 0.28 \times 1.78}{2} = 1.25\mathrm{kg}$$

Given the roll width, $\mathrm{w_2} = 2.5$ cm or 0.025 m and total roll length,

$$\mathrm{l_2} = 4 \times 21 = 84 \text{ cm or } 0.84 \text{ m}$$

Therefore, mass of smaller wire mesh,

$$\mathrm{m_{w2}} = \frac{5 \times 1 \times 1 \times 0.025 \times 0.84}{2} = 0.05\mathrm{kg}$$

The total mass of wire mesh used thus, was computed as follows.

$$\mathrm{m_w} = 1.25 + 0.05 = 1.30 \text{ kg}$$

4.2.2.3 Mass of stainless-steel triangular plates grade 304

The volume of triangular plates with 1mm or 0.1 cm thickness, 5.5 cm base length and 5.5 cm height was computed as follows.

$$\mathrm{V} = \frac{1}{2} \times 5.5 \times 5.5 \times 0.1 = 1.5125\ \mathrm{cm}^3$$

Therefore, volume of four triangular plates, $1.5125 \times 4 = 6.05\ \mathrm{cm}^3$ or $6.05 \times 10^{-6}\ \mathrm{m}^3$

On the other hand, mass of stainless-steel triangular plates was determined as shown.

$$\mathrm{m_t} = 7.9 \times 10^3 \times 6.05 \times 10^{-6} = 0.05\ \mathrm{kg}$$

4.2.2.4 Total mass of components accommodated by the shaft

Therefore, the total mass of components accommodated by the central vertical solid shaft was calculated as shown.

$$\mathrm{m} = 2.88 + 0.31 + 1.30 + 0.05 = 4.54\ \mathrm{kg}$$

4.2.3 Design models for the honey extractor

4.2.3.1 Pitch angles for power transmission gears

Let the number of revolutions per minute for the driver, $\mathrm{N_P}$ =100 rpm, and the number of revolutions for the driven gear, $\mathrm{N_G}$ = 200 rpm.

But, velocity ratio,

$$\mathrm{V.R} = \frac{100}{200} = 0.5$$

Therefore, Pitch angle for the driver,

$$\theta_{P1} = \tan^{-1}\left(\frac{1}{0.5}\right) = 63.43^0$$

Pitch angle for the driven gear,

$$\theta_{P2} = 90^0 - 63.43^0 = 26.57^0$$

4.2.3.2 Formative number of teeth

For a $20°$ full depth involute system, the selected minimum number of teeth on the driver was, T_P = 18 teeth, thus, the number of teeth on the driven gear was derived as shown.

$$T_G = V.R \times T_P = 0.5 \times 18 = 9 \text{ teeth say } 10 \text{ teeth}$$

Therefore, formative number of teeth for the driver,

$$T_{EP} = 18 \times \sec 63.43^0 = \frac{18}{\cos 63.43} = 40.24$$

Formative number of teeth for the driven gear,

$$T_{EG} = 10 \times \sec 26.57^0 = \frac{10}{\cos 26.57} = 11.18$$

4.2.3.3 Gear design

Tooth form factor for the driver,

$$y'_P = 0.154 - \frac{0.912}{40.24} = 0.131$$

Tooth form factor for the driven gear,

$$y'_G = 0.154 - \frac{0.912}{11.18} = 0.072$$

Therefore, $\sigma_{OP} \times y'_P = 126 \times 0.131 = 16.51$ and $\sigma_{OG} \times y'_G = 126 \times 0.072 = 9.07$

Since the product $\sigma_{OG} \times y'_G$ was less than $\sigma_{OP} \times y'_P$, the driven gear was considered weak. Therefore, the design was based on the driven gear and not the driver.

4.2.3.4 Torque and power transmitted by the gear shaft on a rotary motion

Knowing that, the angular velocity, $\omega = \frac{2\times3.142\times200}{60} = 20.95\ \mathrm{rad/s}$ and $r = 0.21$ m; Therefore, velocity was calculated as shown.

$$V = \omega r = 20.95 \times 0.21 = 4.4\ \mathrm{m/s}$$

Also knowing that, the centrifugal force,

$$F_c = \frac{4.54 \times 4.4^2}{0.21} = 418.54\ \mathrm{N}$$

Therefore, torque was computed as shown.

$$T = 418.54 \times 0.21 = 87.89\ \mathrm{Nm}\ \text{or}\ 87.89 \times 10^3\ \mathrm{Nmm}$$

Thus, the power transmitted by gear on a rotary motion was then derived as shown.

$$P = 87.89 \times 20.95 = 1841.3\ \mathrm{W}\ \text{or}\ 1.84\ \mathrm{kw}$$

4.2.3.5 Determination of module when the driven gear is weaker than the driver

a) Tangential load on the gear,

$$\mathrm{W_T} = \frac{2 \times 87.89 \times 10^3}{\mathrm{m} \times 10} = \frac{17578}{\mathrm{m}}\ \mathrm{N}$$

b) Pitch line velocity,

$$\mathrm{v} = \frac{3.142 \times \mathrm{m} \times 10 \times 200}{60} = 104.73\ \mathrm{m\ mm/s} = 0.105\ \mathrm{m\ m/s}$$

c) Velocity factor,

$$\mathrm{C_v} = \frac{3}{3 + 0.105\ \mathrm{m}}$$

d) Length of the pitch cone element,

$$\mathrm{L} = \frac{\mathrm{m} \times 10}{2\sin 26.57^0} = \frac{\mathrm{m} \times 10}{0.8946} = 11.18\ \mathrm{m\ mm}$$

e) Face width,

$$\mathrm{b} = \frac{11.18\ \mathrm{m}}{3} = 3.73\ \mathrm{m\ mm}$$

f) Alternatively, tangential load on the driven gear was derived as shown.

$$\frac{17578}{\mathrm{m}} = 126\left(\frac{3}{3 + 0.105\ \mathrm{m}}\right) \times 3.73\ \mathrm{m} \times 3.142 \times \mathrm{m} \times 0.072\left(\frac{11.18\ \mathrm{m} - 3.73\ \mathrm{m}}{11.18\ \mathrm{m}}\right)$$

$$\frac{17578}{\mathrm{m}} = 70.85\ \mathrm{m}^2\left(\frac{3}{3 + 0.105\ \mathrm{m}}\right)$$

$$\frac{17578}{\mathrm{m}} = \frac{212.55\ \mathrm{m}^2}{3 + 0.105\ \mathrm{m}}$$

$$17578(3 + 0.105\ \text{m}) = 212.55\ \text{m}^3$$

$$52734 + 1845.69\ \text{m} = 212.55\ \text{m}^3$$

g) Solving the expression by hit and trial method, the module was found to be 7 mm as shown.

$$\text{m} = 6.75\ \text{mm say 7 mm}$$

4.2.3.6 Pitch circle diameters

Pitch circle diameter of the driven gear,

$$D_G = 7 \times 10 = 70\ \text{mm}$$

Pitch circle diameter of the driver,

$$D_P = 7 \times 18 = 126\ \text{mm}$$

4.2.3.7 Shaft diameter for the driver

Let the shaft diameter for the driver $= d_P$. Therefore,

a) Torque on the driver,

$$T = \frac{1841.3 \times 60}{2 \times 3.142 \times 100} = 175.81\ \text{Nm or } 175808\ \text{Nmm}$$

b) Length of the pitch cone element,

$$L = 11.18 \times 7 = 78.26\ \text{mm}$$

c) Face width,

$$b = 3.73 \times 7 = 26.11\ \text{mm}$$

d) Mean radius of the driver,

$$\mathrm{R_m} = \left(78.26 - \frac{26.11}{2}\right)\left(\frac{126}{2 \times 78.26}\right) = 65.21 \times 0.81 = 52.82\ \mathrm{mm}$$

e) Therefore, the tangential force acting at the mean radius was calculated as shown.

$$\mathrm{W_T} = \frac{175808}{52.82} = 3328.44\ \mathrm{N}$$

f) Axial force acting on the driver shaft,

$$\mathrm{W_{RH}} = 3328.44\ \times \tan 20^0 \times \sin 63.43^0 = 1083.51\ \mathrm{N}$$

g) Radial force acting on the driver shaft,

$$\mathrm{W_{RV}} = 3328.44\ \times \tan 20^0 \times \cos 63.43^0 = 541.87\ \mathrm{N}$$

Figure 4.3 shows a free body diagram with forces acting on the gears mounted on the shaft.

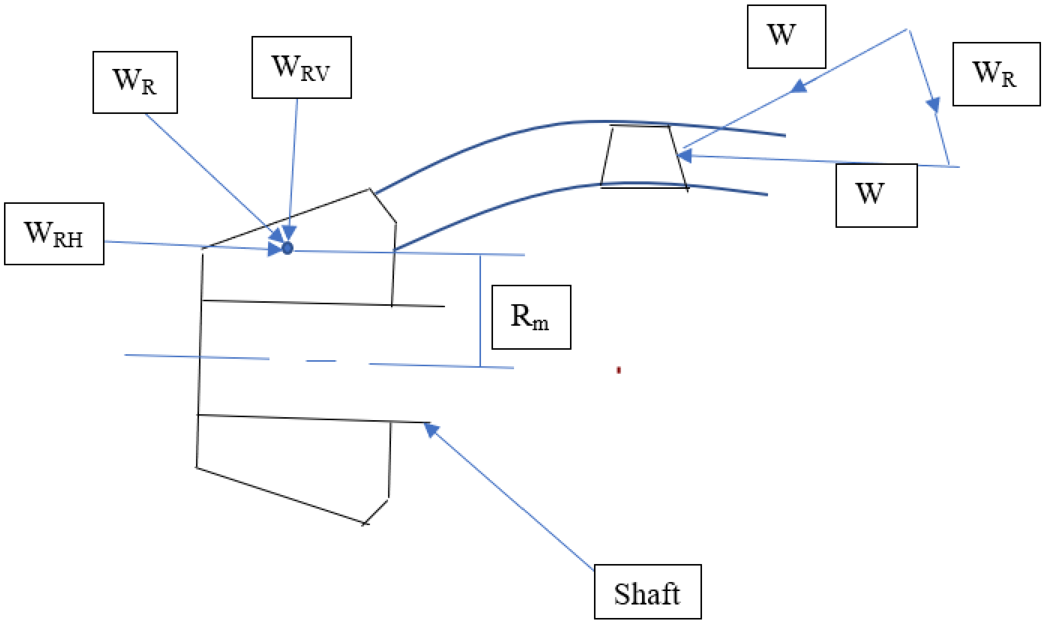


Figure 4.3: Free body diagram

(Source: Author, 2021)

h) Bending moment due to W_{RH} and W_{RV},

$$M_1 = (541.87 \times 100) - (1083.51 \times 52.82) = 54187 - 57231 = -3044 \text{ Nmm}$$

Where, Overhang distance $= 100$ mm

h) Bending moment due to W_T,

$$M_2 = 3328.44 \times 100 = 332844 \text{ Nmm}$$

i) Therefore, the resultant bending moment,

$$M = \sqrt{(-3044)^2 + (332844)^2} = 332858 \text{ Nmm}$$

j) For shaft subjected to both twisting and bending moments, the equivalent twisting moment,

$$T_e = \sqrt{332858^2 + 175808^2} = 376434 \text{ Nmm}$$

k) The equivalent bending moment,

$$M_e = \frac{1}{2}(332858 + 376434) = 354646 \text{ Nmm}$$

4.2.3.8 Diameter of the driver shaft when subjected to twisting moment

a) Alternatively, the equivalent twisting moment,

$$376434 = \frac{3.142}{16} \times 175.8 \times {d_p}^3$$

$${d_p}^3 = \frac{376434 \times 16}{3.142 \times 175.8} = 10904 \text{ mm}$$

b) Therefore, diameter of the driver shaft due to twisting,

$$d_p = \sqrt[3]{10904} = 22.17 \text{ mm}$$

Diameter of the driver shaft when subjected to bending moment

Alternatively, the equivalent bending moment,

$$354646 = \frac{3.142}{32} \times 293 \times {d_p}^3$$

$${d_p}^3 = \frac{354646 \times 32}{3.142 \times 293} = 12327.4 \text{ mm}$$

Therefore, diameter of the driver shaft due to bending,

$$d_p = \sqrt[3]{12327.4} = 23.10 \text{ mm}$$

Taking the larger value of the two, diameter of the driver shaft due to bending was selected. Therefore,

$$d_p = 23.10 \text{ mm say } 25 \text{ mm}$$

4.2.3.9 Shaft diameter for the driven gear

The same procedure for calculating the driver shaft diameter was followed.

Let shaft diameter for the driven gear = d_G. Therefore,

a) Torque on the driven gear,

$$T = \frac{1841.3 \times 60}{2 \times 3.142 \times 200} = 87.90 \text{ Nm or } 87904 \text{ Nmm}$$

b) Length of the pitch cone element,

$$L = 11.18 \times 7 = 78.26 \text{ mm}$$

c) Face width,

$$b = 3.73 \times 7 = 26.11 \text{ mm}$$

d) Mean radius of the driven gear,

$$R_m = \left(78.26 - \frac{26.11}{2}\right)\left(\frac{70}{2 \times 78.26}\right) = 65.21 \times 0.45 = 29.34 \text{ mm}$$

e) The tangential force acting at the mean radius,

$$W_T = \frac{87904}{29.34} = 2996.05 \text{ N}$$

f) Axial force acting on the driven gear shaft,

$$W_{RH} = 2996.05 \times \tan 20^0 \times \sin 26.57^0 = 487.76 \text{ N}$$

g) Radial force acting on the driven gear shaft,

$$W_{RV} = 2996.05 \times \tan 20^0 \times \cos 26.57^0 = 975.31 \text{ N}$$

h) Bending moment due to W_{RH} and W_{RV},

$$M_1 = (975.31 \times 100) - (487.76 \times 29.34) = 97531 - 14310.88 = 83220 \text{ Nmm}$$

i) Bending moment due to W_T,

$$M_2 = 2996.05 \times 100 = 299605 \text{ Nmm}$$

j) Therefore, the resultant bending moment,

$$M = \sqrt{(83220)^2 + (299605)^2} = 310948 \text{ Nmm}$$

k) Since the shaft was subjected to both twisting and bending moments, the equivalent twisting moment,

$$T_e = \sqrt{310948^2 + 87904^2} = 323134 \text{ Nmm}$$

l) The equivalent bending moment,

$$M_e = \frac{1}{2}(310948 + 323134) = 317041 \text{ Nmm}$$

4.2.3.10 Diameter of the driven gear shaft when subjected to twisting moment

a) Alternatively, the equivalent twisting moment,

$$323134 = \frac{3.142}{16} \times 175.8 \times {d_G}^3$$

$${d_G}^3 = \frac{323134 \times 16}{3.142 \times 175.8} = 9360.04 \text{ mm}$$

b) Therefore, diameter of the driven gear shaft due to twisting,

$$d_G = \sqrt[3]{9360.04} = 21.07 \text{ mm}$$

4.2.3.11 Diameter of the driven gear shaft when subjected to bending moment

a) Alternatively, the equivalent bending moment,

$$317041 = \frac{3.142}{32} \times 293 \times {d_G}^3$$

$${d_G}^3 = \frac{317041 \times 32}{3.142 \times 293} = 11020.25 \text{ mm}$$

b) Therefore, diameter of the gear shaft due to bending moment,

$$d_G = \sqrt[3]{11020.25} = 22.25 \text{ mm}$$

Taking the larger value of the two, diameter of the driven gear shaft due to bending was selected. Therefore,

$$d_G = 22.25 \text{ mm say } 25 \text{ mm}$$

4.2.4 Bearing selection

4.2.4.1 Desired life of the bearing

Since the average life of the bearing was estimated to be 5 years operating at 5 hours per day and at least 3 days in a week, therefore, the desired life of bearing in hours was computed as follows.

$$L_H = 5 \times 3 \times 12 \times 5 = 900 \text{ hours}$$

Therefore, life of the bearing in revolutions was computed as shown.

$$L = 60 \times N \times L_H = 60 \times 100 \times 900 = 5400000 \text{ revolutions}$$

4.2.4.2 Basic dynamic equivalent load

Since the value of basic static load capacity (C_O) was not known, the value of $\frac{W_A}{C_O} = 0.5$ was taken. From Table 7.6, the values of X and Y corresponding to $\frac{W_A}{C_O} = 0.5$ and $\frac{W_A}{W_R} = \frac{1083.51}{541.87} = 1.9996$, which was greater than $e = 0.44$ were; $X = 0.56$ and $Y = 1$

The rotational factor (V) for most of the bearings is 1. Given the radial load, $W_R = 541.87$ N, axial load, $W_A = 1083.51$ N and speed, $N = 100$ rpm. The basic dynamic equivalent radial load was calculated as shown.

$$W = (0.56 \times 1 \times 541.87) + (1 \times 1083.51) = 1387 \text{ N}$$

From Table 7.4 in Appendix V, it is shown that, for uniform and steady load, the service factor (K_s) for ball bearings is 1.0. Therefore, the bearing was selected for $W = 1387$ N.

4.2.4.3 Basic dynamic load rating

The basic dynamic load rating was derived as shown.

$$\mathrm{C} = 1387\left(\frac{5400000}{10^6}\right)^{\frac{1}{3}} = 2433 \text{ N or } 2.433\text{kN}$$

From Table 7.5, bearing number 200 having $\mathrm{C} = 4$ was selected.

4.2.5 Developed honey extractor

The detailed design drawings of an improved honey extractor are as shown in Appendix I. Solid works software was used in designing the drawings. Plate 4.1 shows the developed honey extractor.

Plate 4.1: Developed honey extractor

(Source: Author, 2021)

4.2.6 Performance Evaluation of the developed honey extractor

A performance test of an improved honey extractor was carried out in one of the beekeeping farms in Marigat as shown in Plate 4.2. It took 8 minutes to fully extract honey from the comb cells which was in line with the argument by Holly, (2021) that, a manually-driven honey extractor should be spun for 5 to 10 minutes, to completely empty the honeycombs with minimal combs breakage, but it varies depending on the speed of extractor and thickness of honey.

In general, the machine was in good condition, portable, easy to assemble and disassemble, very easy to operate and affordable to small-scale honey producers. Alternatively, the machine can be used in any other ASAL area in the country. It was purely made of stainless-steel materials to avoid rusting because honey is a food grade and acidic in nature.

The bill of quantities presented in Appendix II shows that, the cost involved in constructing the improved honey extractor was Kenya Shillings 53,100, which was far much less than the cost of the imported extractors costing between Kenya Shillings 120,000-180,000 per piece. The machine ensures timeliness in honey production and reduces drudgery involved in squeezing the honeycombs to extract honey. This contributes to high production rates and ensures honey of high quality is extracted to meet both local and international market standards. It would also improve the living standards of honey producers residing in the rural areas hence eradicating poverty.

4.2.6.1 Power required by humans to operate the extractor

The weight difference of beekeepers operating the extractor was estimated to be between 50 kg and 100 kg, since not all beekeepers who operate the machine have the same weight. Therefore, an average weight of 75 kg per human which was equivalent to $(75 \times 9.81) = 735.72$ N was considered. The handle distance of the extractor from the human arm to the centre was 285mm, equivalent to 0.285 m. Therefore, work done by humans to operate the extractor was calculated as follows.

$$\mathrm{w} = 735.72\ \mathrm{N} \times 0.285\ \mathrm{m} = 209.69\ \mathrm{Nm\ say}\ 210\ \mathrm{J}$$

The developed extractor was expected to work 5 hours a day, at least 3 days in a week, and for 5 years of operation, equivalent to 60 months. Therefore, the time of operating the extractor was calculated as follows.

$$\mathrm{t} = 5 \times 3 \times 60 \times 3600 = 3240000\ \mathrm{s}$$

Thus, power required by humans to operate the extractor without getting tired for a period of 5 years was calculated as follows.

$$\mathrm{P} = \frac{210}{3240000} = 6.48 \times 10^{-5}\ \mathrm{W\ or}\ 6.48 \times 10^{-5}\ \mathrm{kw}$$

4.2.6.2 Mass flow rate of honey from the improved honey extractor

From the KEBS results obtained, the mean relative density of honey was obtained as 1.41 $\mathrm{g/ml}$ or 1410 $\mathrm{kg/m^3}$. From the measurements done in University of Eldoret, School of Engineering, Materials Laboratory, the average mass of honeycombs was obtained as 722.5 g or 0.72 kg occupying one net bucket.

For four nets, mass of honeycombs was 2.88 kg. Therefore, the volumetric flow rate of honey within a period of 8 minutes equivalent to 480 s was derived as shown.

$$\mathrm{V} = \frac{2.88}{1410} = 2.04 \times 10^{-3}\ \mathrm{m}^3$$

The volumetric flow rate of honey in one second,

$$\mathrm{V} = \frac{2.04 \times 10^{-3}}{480} = 4.25 \times 10^{-6}\mathrm{m}^3/\mathrm{s}$$

Therefore, mass flow rate of honey,

$$\mathrm{m_f} = 1410 \times 4.25 \times 10^{-6} = 5.99 \times 10^{-3}\ \mathrm{kg/s}$$

In one day, 5 test runs were achieved within a period of 8 minutes each. Therefore, the number of seconds to empty the net buckets,

$$= 5 \times 8 \times 60 = 2400\ \mathrm{seconds}$$

The mass flow rate of honey per day,

$$\mathrm{m_f} = 5.99 \times 10^{-3} \times 2400 = 14.376\ \mathrm{kg/day}$$

4.2.6.3 Efficiency of the honey extractor

$$\text{mass of honey combs processed per day} = 2.88 \times 5 = 14.4\ \mathrm{kg/day}$$

Therefore, efficiency of the honey extractor,

$$\varepsilon = \frac{14.376}{14.4} \times 100\ \% = 99.83\ \%$$

The improved honey extractor was 99.83 % efficient. This is because there were negligible friction losses on the straight bevel gears.

Plate 4.2: Performance test of an improved honey extractor

(Source: Author, 2021)

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

5.1.1 Objective 1: Characterization based on physical properties of honey

From the study, the physical properties of honey played a major role in characterizing honey obtained from different sites of Marigat. These properties also determined the quality of honey produced and were compared to the standards set by both KEBS and the international organizations.

Higher moisture content of 18.05 % in honey was attributed to the fact that, honey producers in the area use water baths to heat honeycombs and melt wax. Alternatively, relative density of honey depends on the amount of moisture present in honey. The low mean pH value of 3.9, shows that honey from Marigat was acidic. Higher water-insoluble solids value of 0.22% m/m in honey proved that, extraction was done by pressing the honeycombs rather than using an extractor.

The critical F-values obtained from statistical tables of all quality parameters of honey were greater than the observed F-values. This proved that, there were no significant differences at 5 % level. Therefore, all honey samples from different sites produced similar qualities. This was attributed to the fact that, the study sites lie in the same geographical location with same climatic conditions, vegetation cover and floral nectar characteristics.

5.1.2 Objective 2: Development and validation of a honey extractor based on physical properties of honey

5.1.2.1 Design and fabrication of an improved honey extractor

The physical properties of honey were successfully applied in the design and fabrication of an improved honey extractor. For instance, the mean value of 18.05 % moisture content proved that, Marigat honey was more susceptible to being exposed to moisture by use of water baths to heat honeycombs. This concept informed the need to avoid inclusion of heating mechanism on the design. The mean pH value of 3.9 was found to be acidic, hence the need to select stainless-steel grade 304 materials for fabrication due to their ability to resist corrosion. The choice of suitable filtering medium was based on the mean value of water-insoluble solids in honey which was found to be 0.22 % m/m. This informed the need to include a filtering mesh of 1mm diameter to sieve any impurities present in honey. Moreover, the largest possible dimensions of honeycombs were successfully applied in determining the size of honeycomb net buckets as well as the size of extractor. The mass of honeycombs also played a role in determining the size of vertical shaft used.

5.1.2.2 Performance evaluation of the developed honey extractor

The mean relative density value of honey and mass of honeycombs, were successfully utilized in the determination of mass flow rate of honey as well as the efficiency of the improved honey extractor. The amount of power required by humans to operate the extractor for a period of 5 years was equivalent to 6.48×10^{-5} W. The extractor was able to extract 14.376 kg/day and was estimated to be 99.83 % efficient due to negligible friction losses from the straight bevel gears.

The extractor was in good condition, portable and very easy to assemble and disassemble during cleaning of the various extractor components.

5.2 Recommendations

The recommendations from study for further research include:

1. The design should be improved by introducing a solar heating mechanism that can be used during days of low temperatures.
2. The honeycomb net buckets should be increased in number to ensure high production rates of honey.
3. Food-grade plastic materials should be used in constructing the extractor to reduce the cost incurred in purchasing stainless-steel materials.
4. The government should adopt the design to be used by small-scale honey producers in any other ASAL area in Kenya.

REFERENCES

Abadariki, S.O., Fasan, J.O. and Akinnuli, B.O. (2013). Design, fabrication and performance evaluation of an indigenenous honey extractor. *Journal of Emerging Trends in Engineering and Applied Sciences, 4*(1), 1-6.

Adebiyi, F.M., Akpan, I., Obiajunwa, E.I. and Olaniyi, H.B. (2004). Chemical/physical characterization of Nigerian honey. *Pakistan Journal of Nutrition, 3*(5), 278-281.

Ahmed, J., Prabhu, S.T., Raghavan, G.S. and Ngadi, M. (2007). Physico-chemical, rheological, calorimetric and dielectric behavior of selected Indian honey. *Journal of Food Engineering*, *79*(4), 1207-1213.

Akinnuli, B.O., Awopetu, O.O., Ikubanni, P.P. and Agboola, O.O. (2016). Development of Pedal Operated Honey Extractor. *Current Journal of Applied Science and Technology*, 1-10.

Aroucha, E.M., Silva, M.C., Leite, R.H., Santos, F.K., Oliveira, V.R., Araújo, N.O., *et al*. (2019). Physicochemical, antioxidants and sensorial properties of Melipona subnitida honey after dehumidifying. *Journal of Food Processing and Technology*, *10*(3), e1000781.

Bogdanov, S., Martin, P. and Lullmann, C. (2002). Harmonised methods of the International Honey Commission. *Swiss Bee Research Centre, FAM, Liebefeld*.

Bontempo, L., Camin, F., Ziller, L., Perini, M., Nicolini, G. and Larcher, R. (2017). Isotopic and elemental composition of selected types of Italian honey. *Measurement*, *98*, 283-289.

Carroll, T. (2006). A beginner's guide to beekeeping in Kenya. *Baraka Agricultural Training College: Nakuru, Kenya*.

Carroll, T. and Kinsella, J. (2013). Livelihood improvement and smallholder beekeeping in Kenya: the unrealised potential. *Development in Practice, 23*(3), 332-345.

Chataway, H.D. (1932). The determination of moisture in honey. *Canadian Journal of Research, 6*(5), 532-547.

Chemwok, C.K. (2016). *Factors influencing Honey Production in Marigat, Baringo County Kenya.* Moi University.

Codex, A.C., Commission, J.F.W.C.A. and Programme, J.F.W.F.S. (2001). *Codex Alimentarius Commission* (Vol. 9): Bernan Assoc.

Crittenden, A.N. (2011). The importance of honey consumption in human evolution. *Food and Foodways, 19*(4), 257-273.

Faostat. (2016). Food and agriculture organization of the united nations, 2010. *Roma, Italy*.

Gichuki, J. (2015). *Beekeeping Training Manual for Beginners*.

GoK. (2013). *Economic survey*.

GoK. (2020). *Implementation of the Big Four Agenda*.

Gomes, T., Feás, X., Iglesias, A. and Estevinho, L.M. (2011). Study of organic honey from the northeast of Portugal. *Molecules, 16*(7), 5374-5386.

Holly. (2021). How to use a honey extractor. Retrieved 10th November, 2021

Ishaq, R., Azmat, H., Omair, M., Sheikh, A.K. and Tanwani, A.K. (2018). Comparison of honey with alcohol as a fixative in fine needle aspiration cytology. *International Journal of Pathology*, 15-18.

Jamboshop. (2020). Impact honey 100 % pure forest honey-1kg. Retrieved 11/21/2021, from Jambo Shop Limited:

Kahraman, T., Buyukunal, S.K., Vural, A. and Altunatmaz, S.S. (2010). Physico-chemical properties in honey from different regions of Turkey. *Food Chemistry, 123*(1), 41-44.

KEFRI. (2021). *Small-scale soap productio from aloe vera in Koyonin, Marigat Sub-county, Kenya*. Nairobi.

Kenya Standards, E.A.S. (2020). *Honey Specification*. Nairobi: Kenya Bureau of Standards (KEBS).

Khurmi, R.S. and Gupta, J.K. (2005). *A textbook of machine design*: Eurasia.

Kipruto, C.C. (2016). *Factors Influencing Honey Production In Marigat, Baringo County-Kenya.* Moi University.

Kothary, C.R. (2004). *Research Methodology*: New Age International Pvt. Ltd.

Kuria, A.M. (2019). *Challenges of Bee Farming in Kenya*.

Manyiloh, C.E., Clarke, A.M. and Ndip, N. (2011). An overview of honey: Therapeutic properties and contribution in nutrition and human health. *African Journal of Microbiology Research, 5*(8), 844-852.

Maradun, U.M. and Sanusi, U.M. (2013). Comparative effects of screw press for honey extraction for small-scale honey processing. *Nigerian Journal of Technology, 32*(1), 144-147.

Mesbahi, M.A., Ouahrani, M.R., Rebiai, A., Amara, D.G. and Chouikh, A. (2019). Characterization of Zygophyllum album L Monofloral Honey from El-Oued, Algeria. *Current Nutrition & Food Science, 15*(5), 476-483.

Muli, E., Munguti, A. and Raina, S.K. (2007). Quality of honey harvested and processed using traditional methods in rural areas of Kenya. *Acta Veterinaria Brno, 76*(2), 315-320.

Nanda, V., Sarkar, B.C., Sharma, H.K. and Bawa, A.S. (2003). Physico-chemical properties and estimation of mineral content in honey produced from different plants in Northern India. *Journal of Food Composition and analysis, 16*(5), 613-619.

Nazzi, F. (2016). The hexagonal shape of the honeycomb cells depends on the construction behavior of bees. *Scientific reports*, *6*(1), 1-6.

Nzula, M.C. (2018). Evaluation of Apiculture in the context of food security and environmental management in Kathonzweni Division, Makueni County, Kenya.

Ola, A.I., Adewumi, A.D., Adewumi, O.O., Oluwalana, E.O., Adewumi, B.A. and Emmanuel, S.A. (2016). Development of a Vibratory Honey Extractor. *LAUTECH Journal of Engineering and Technology*, *10*(2), 48-52.

Orina, I.N. (2014). *Quality and safety characteristics of honey produced in different regions of Kenya.* Jomo Kenyatta University of Agriculture and Technology, Nairobi.

Patrick, O.I. and Oyejide, J.O. (2018). Design and Construction of Honey Extractor. *IJISET - International Journal of Innovative Science, Engineering & Technology*, *5*(5), 1-10.

Physics. Work, energy and power in humans: Lumen

Riemer, R. and Shapiro, A. (2011). Biomechanical energy harvesting from human motion: theory, state of the art, design guidelines, and future directions. *Journal of neuroengineering and rehabilitation*, *8*(1), 1-13.

Robert, B.M. (2010). *Characterization of Kenyan Honey and a Design Model for Processing Equipment.* Kenyatta University, Nairobi.

Rotich, E.J. (2019). *Physicochemical Characterization of Honey from Selected Counties in Kenya.* University of Nairobi, Nairobi.

Silva, T.M., dos Santos, F.P., Evangelista-Rodrigues, A., da Silva, E.S., da Silva, G.S., de Novais, J.S., *et al.* (2013). Phenolic compounds, melissopalynological, physicochemical analysis and antioxidant activity of jandaíra (Melipona subnitida) honey. *Journal of Food Composition and analysis, 29*(1), 10-18.

Sircar, A. and Yadav, K. (2018). *Application of geothermal water for honey processing.* Paper presented at the 43rd Workshop on Geothermal Reservoir Engineering.

Vallianou, N.G., Gounari, P., Skourtis, A., Panagos, J. and Kazazis, C. (2014). Honey and its anti-inflammatory, anti-bacterial and anti-oxidant properties. *Gen Med (Los Angel), 2*(132), 1-5.

Warui, M.W., Hansted, L., Gikungu, M., Mburu, J., Kironchi, G. and Bosselmann, A.S. (2019). Characterization of Kenyan honeys based on their physicochemical properties, botanical and geographical origin. *International journal of food science, 2019.*

Wedmore, E.B. (1955). The accurate determination of the water content of honeys: Part I. Introduction and Results. *Bee world, 36*(11), 197-206.

Yanniotis, S., Skaltsi, S. and Karaburnioti, S. (2006). Effect of moisture content on the viscosity of honey at different temperatures. *Journal of Food Engineering, 72*(4), 372-377.

Zohairy, A.M. (2019). Simple and Inexpensive Method to Modify Bee Honey Extractor with Moving Baskets to Radial Extractor easy to Jaw and Install on, or without Baskets. *Journal of Plant Protection and Pathology, 10*(5), 261-268.

APPENDICES

Appendix I: Honey Extractor Engineering Design and Assembly Drawings

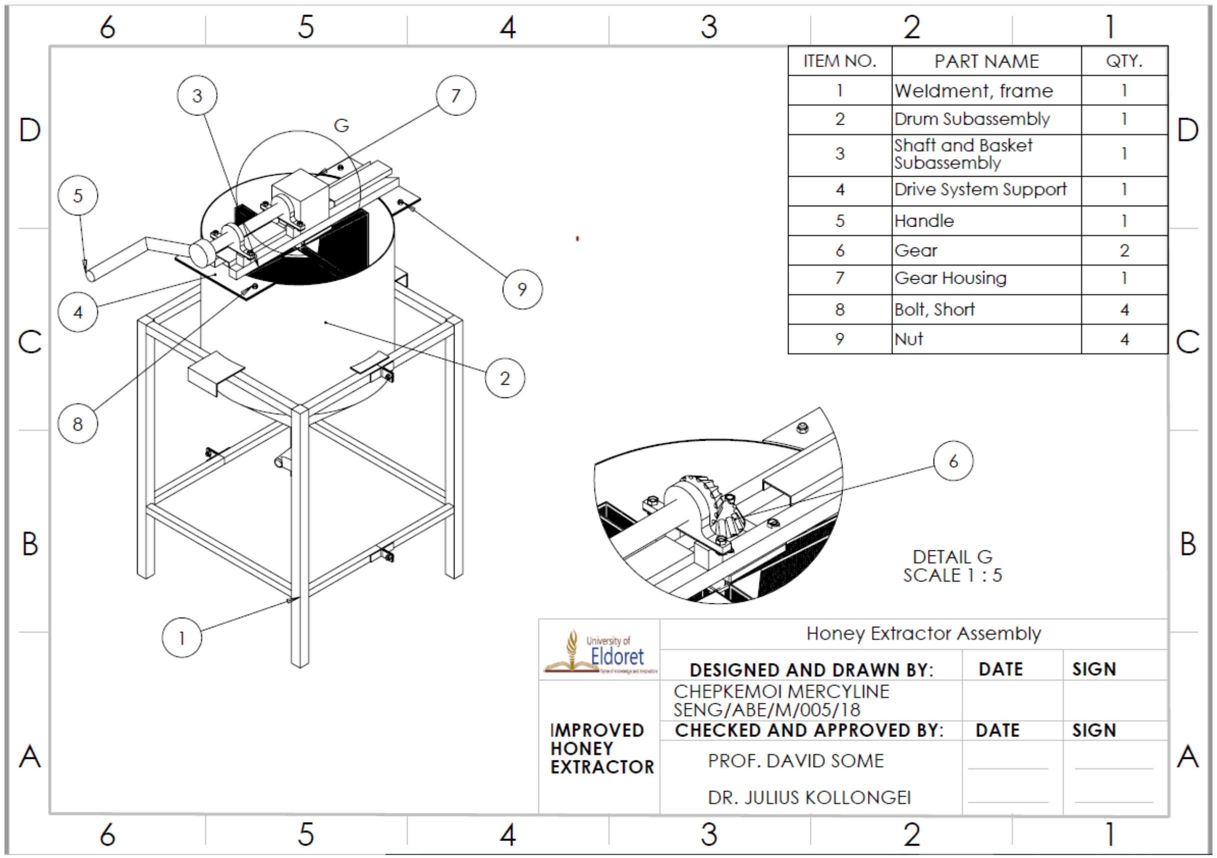


Figure 7.1: Honey extractor assembly and parts

(Source: Author, 2021)

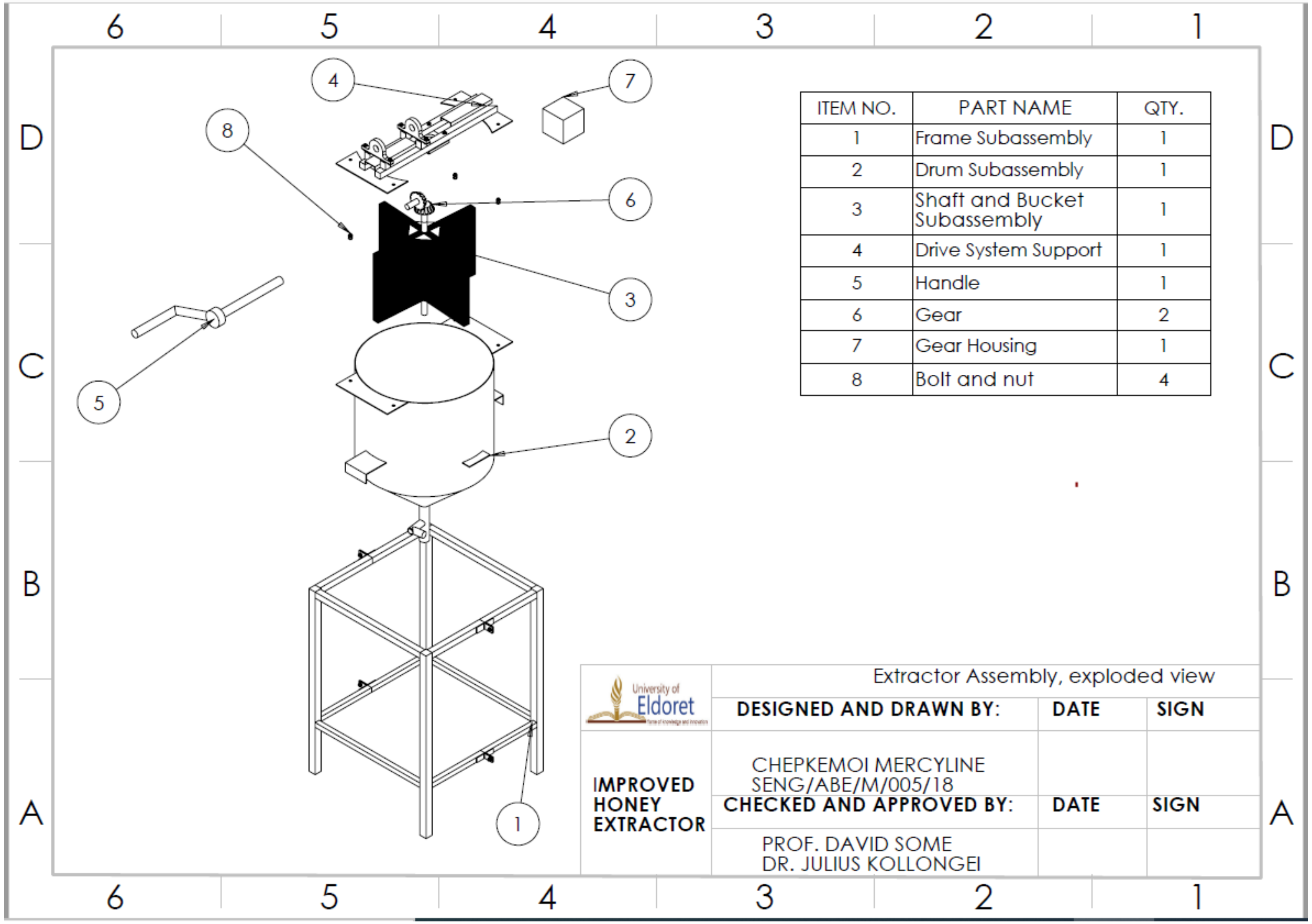


Figure 7.2: Exploded view of the developed honey extractor

(Source: Author, 2021)

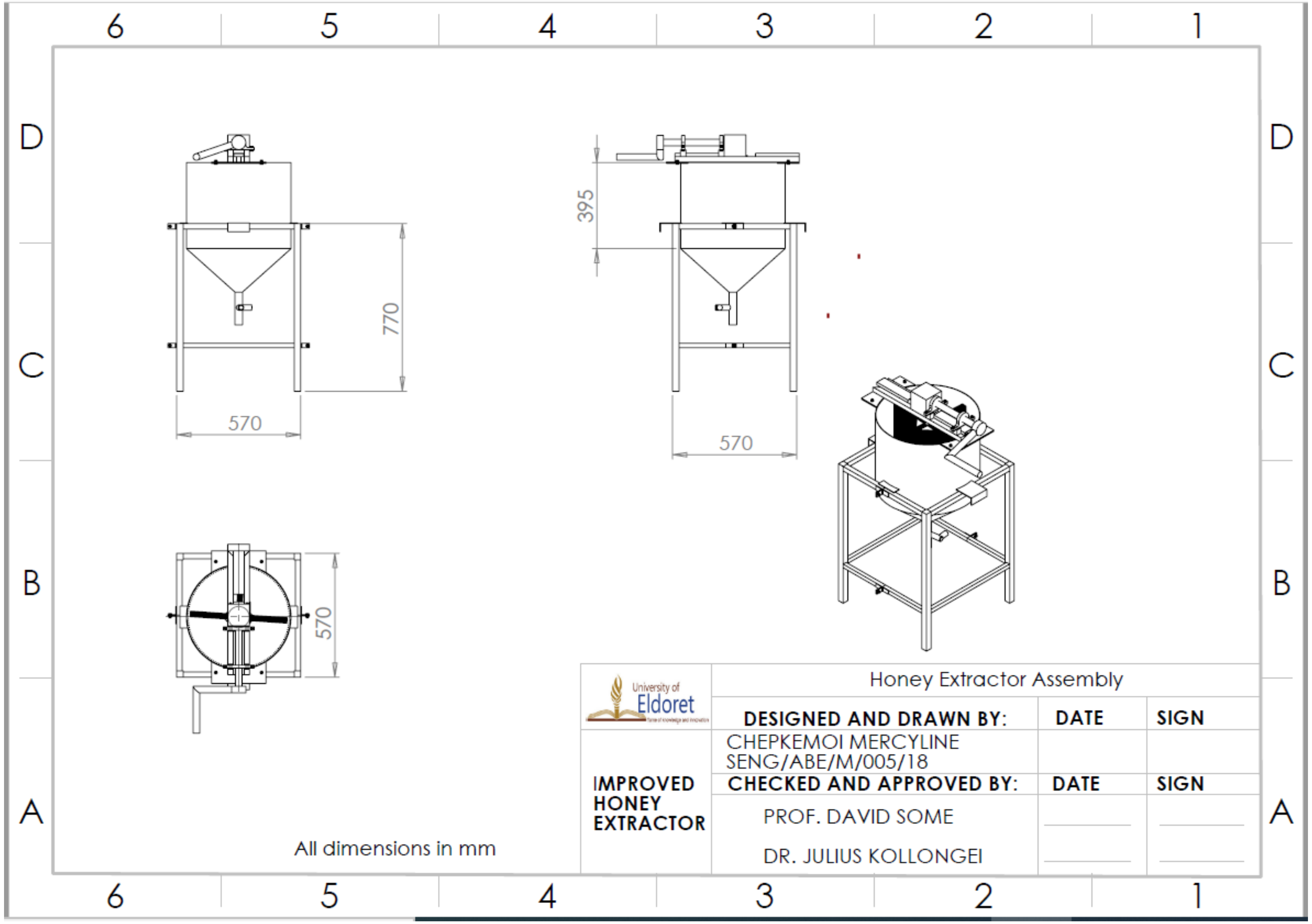


Figure 7.3: Dimensions of the honey extractor assembly (side and top views)

(Source: Author, 2021)

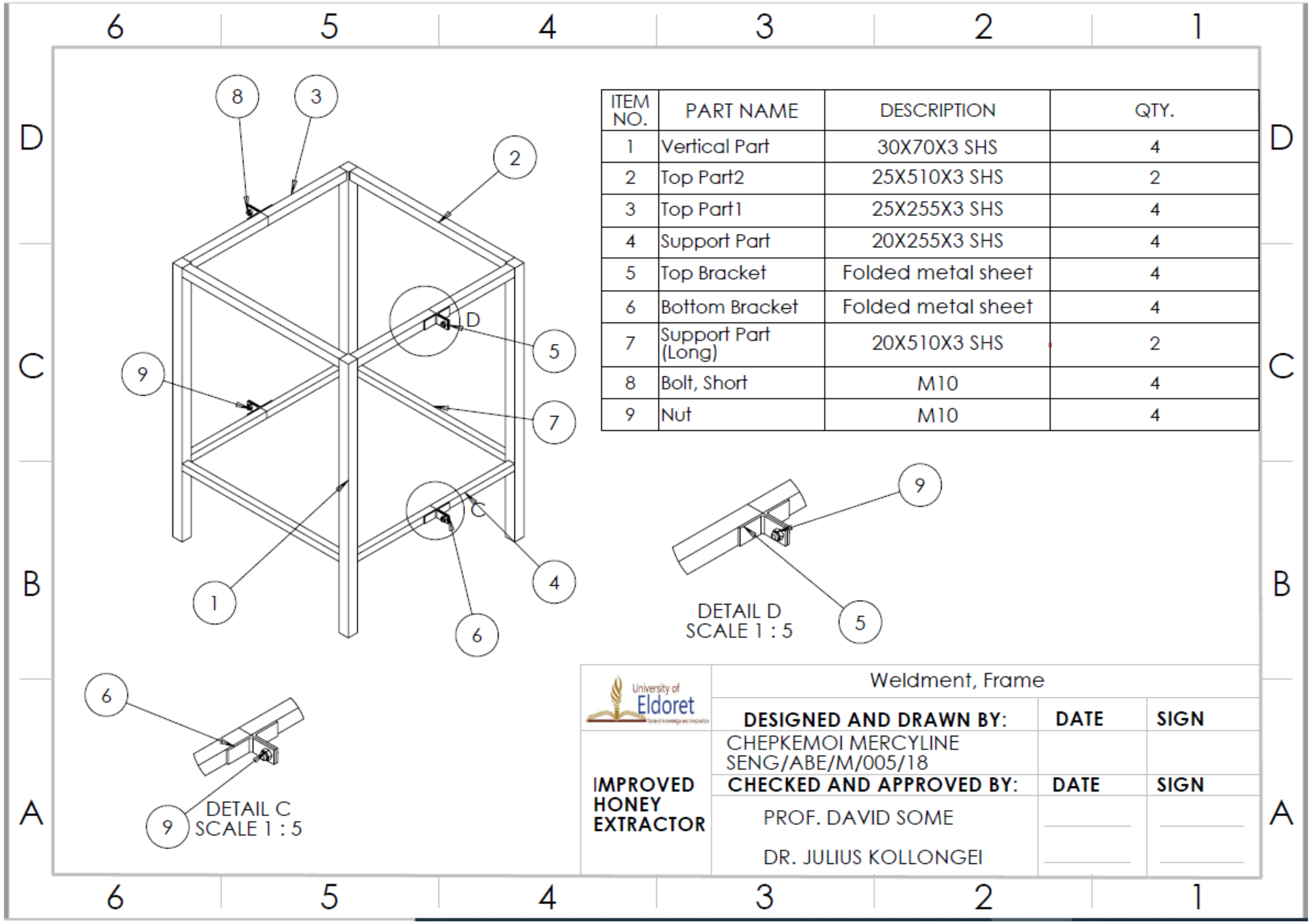


Figure 7.4: Parts of the supporting frame

(Source: Author, 2021)

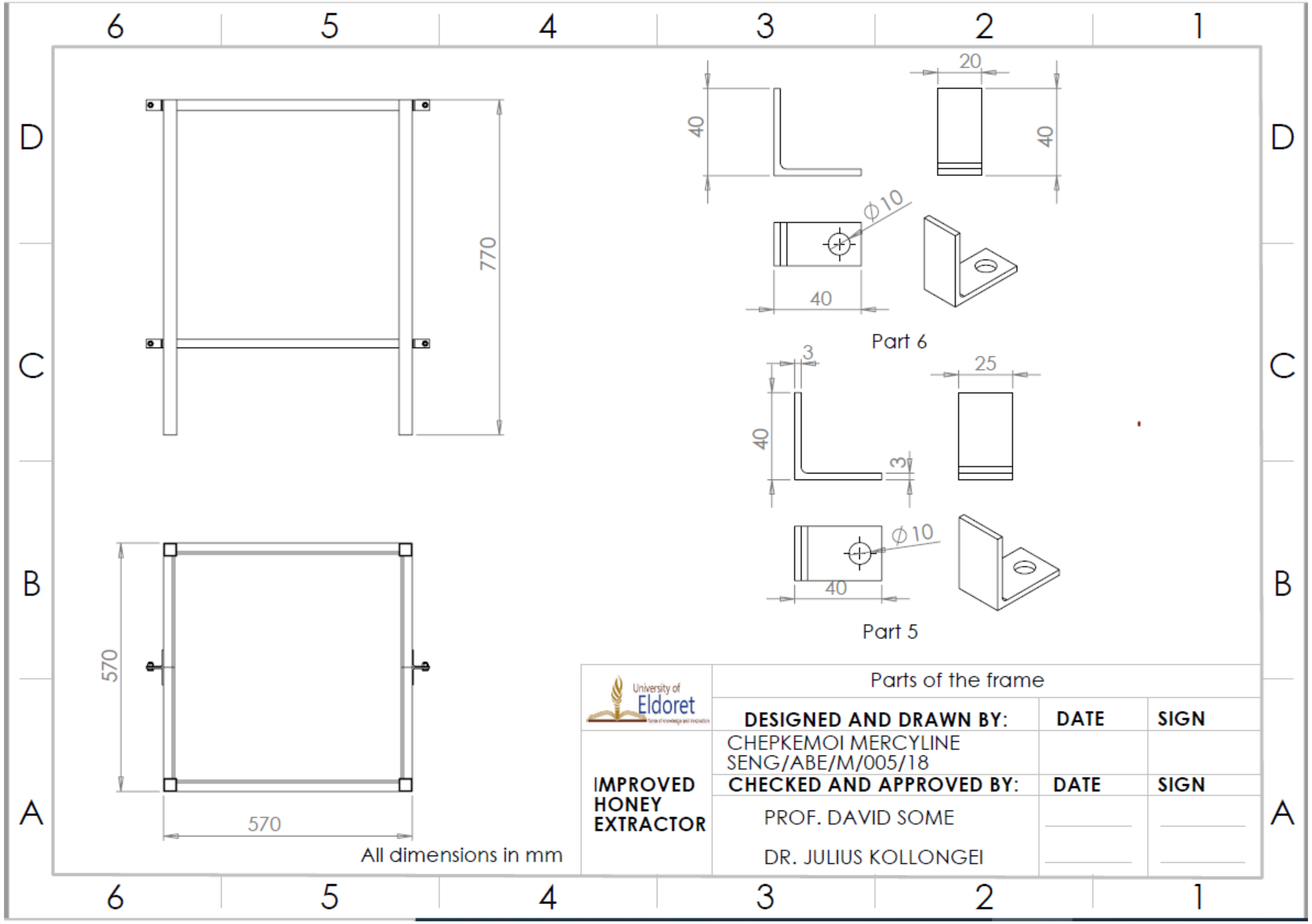


Figure 7.5: Dimensions of parts of the frame

(Source: Author, 2021)

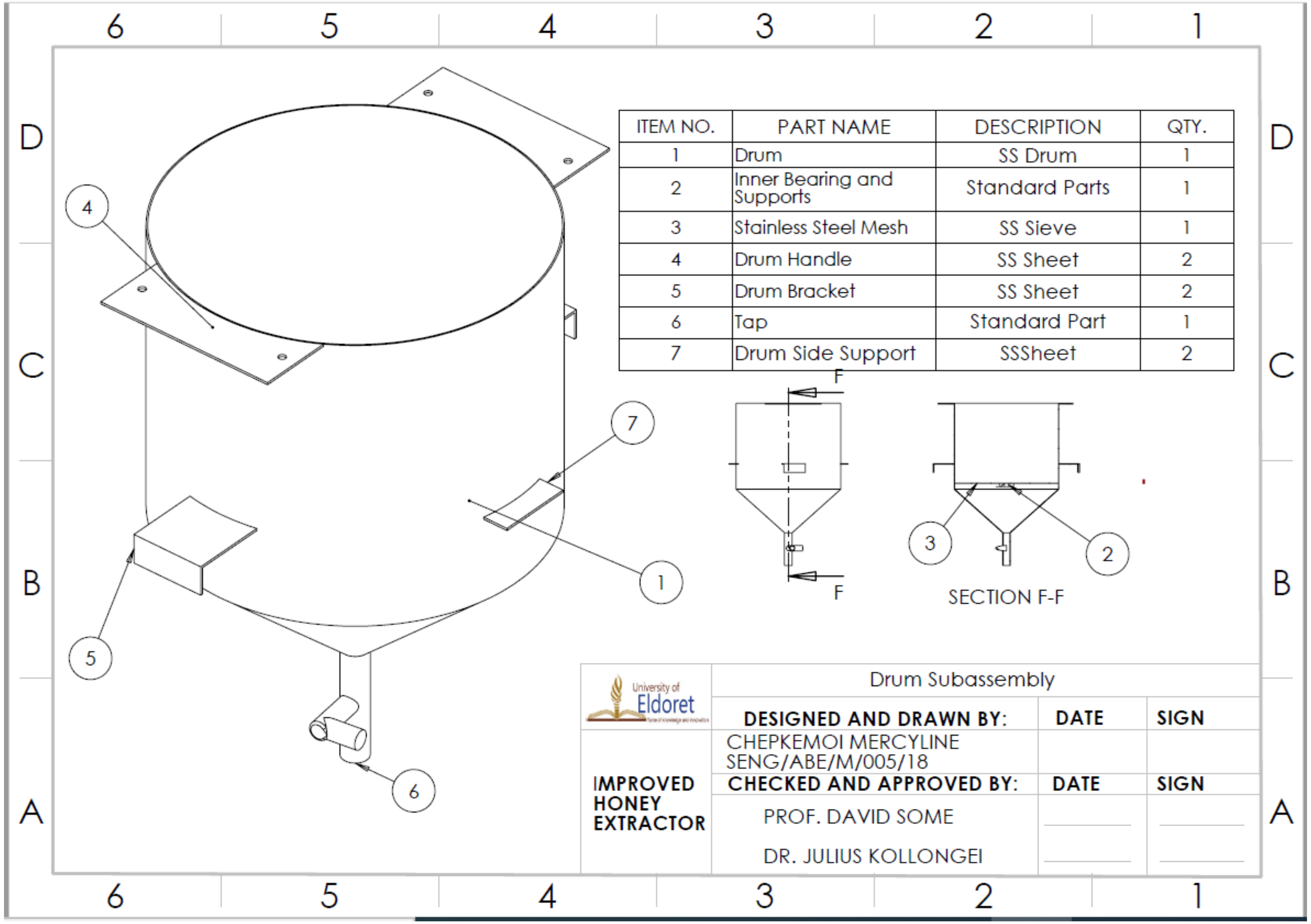


Figure 7.6: Parts of drum sub-assembly

(Source: Author, 2021)

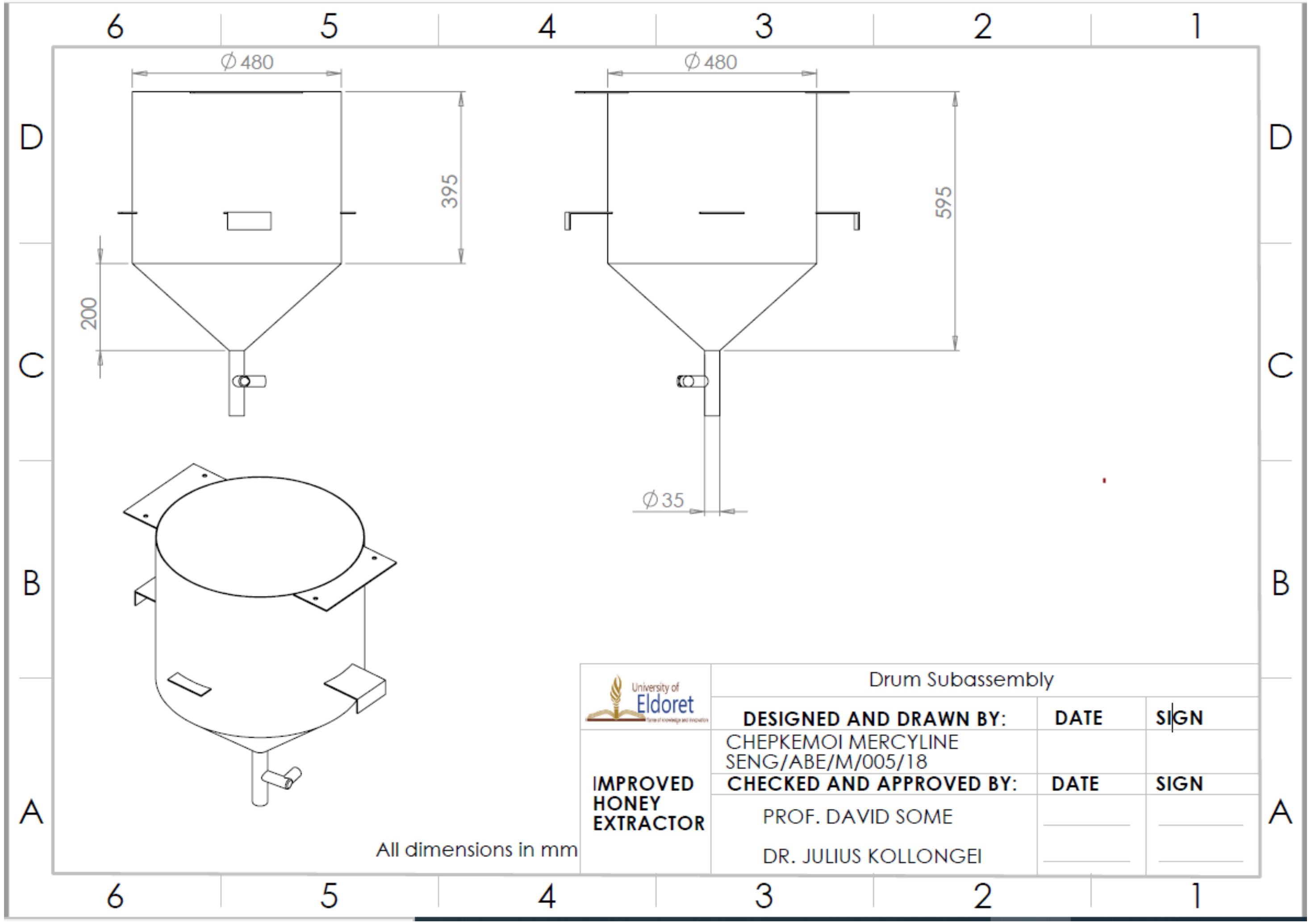


Figure 7.7: Dimensions of the drum sub-assembly (side views)

(Source: Author, 2021)

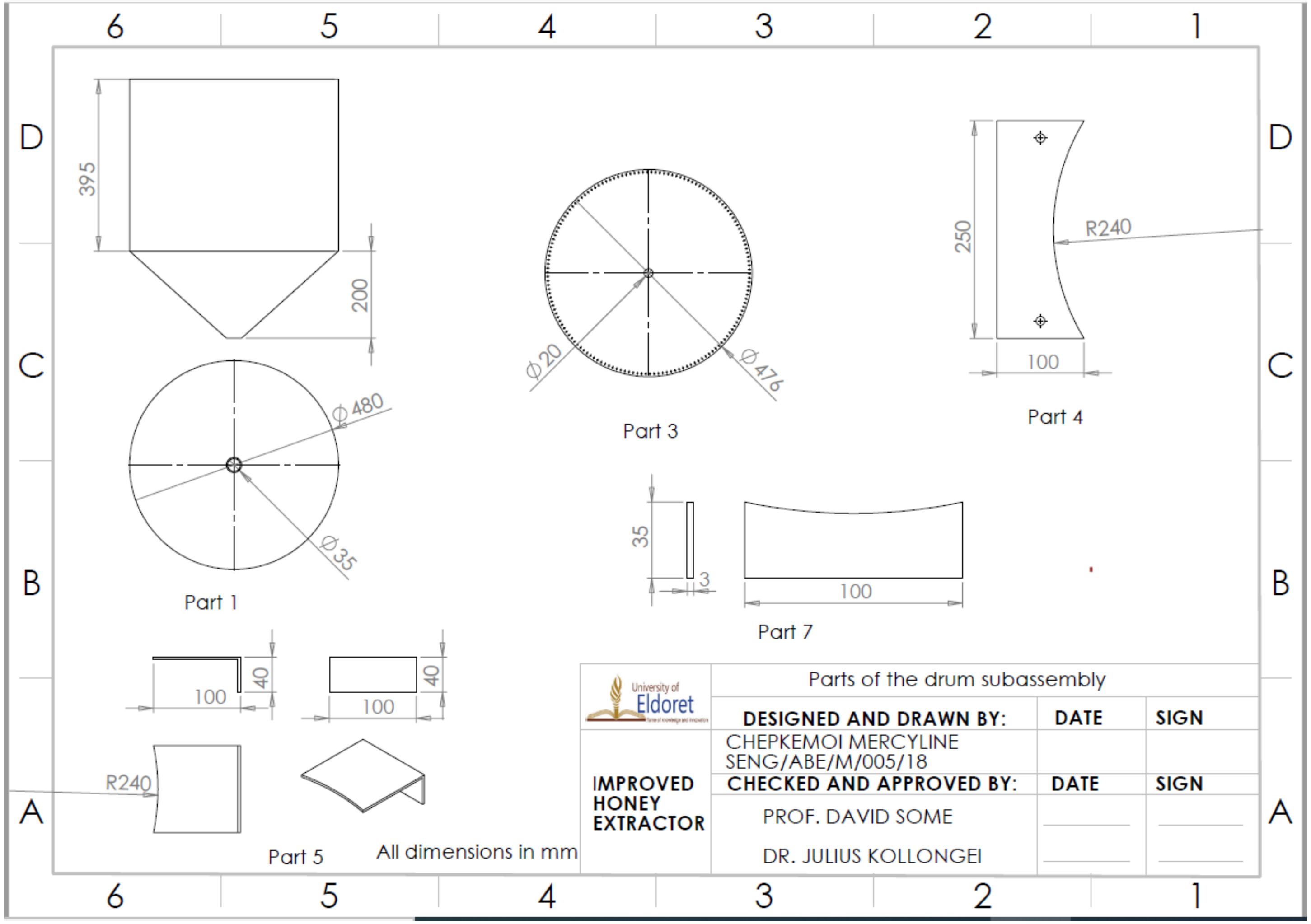


Figure 7.8: Dimensions of the parts of drum sub-assembly

(Source: Author, 2021)

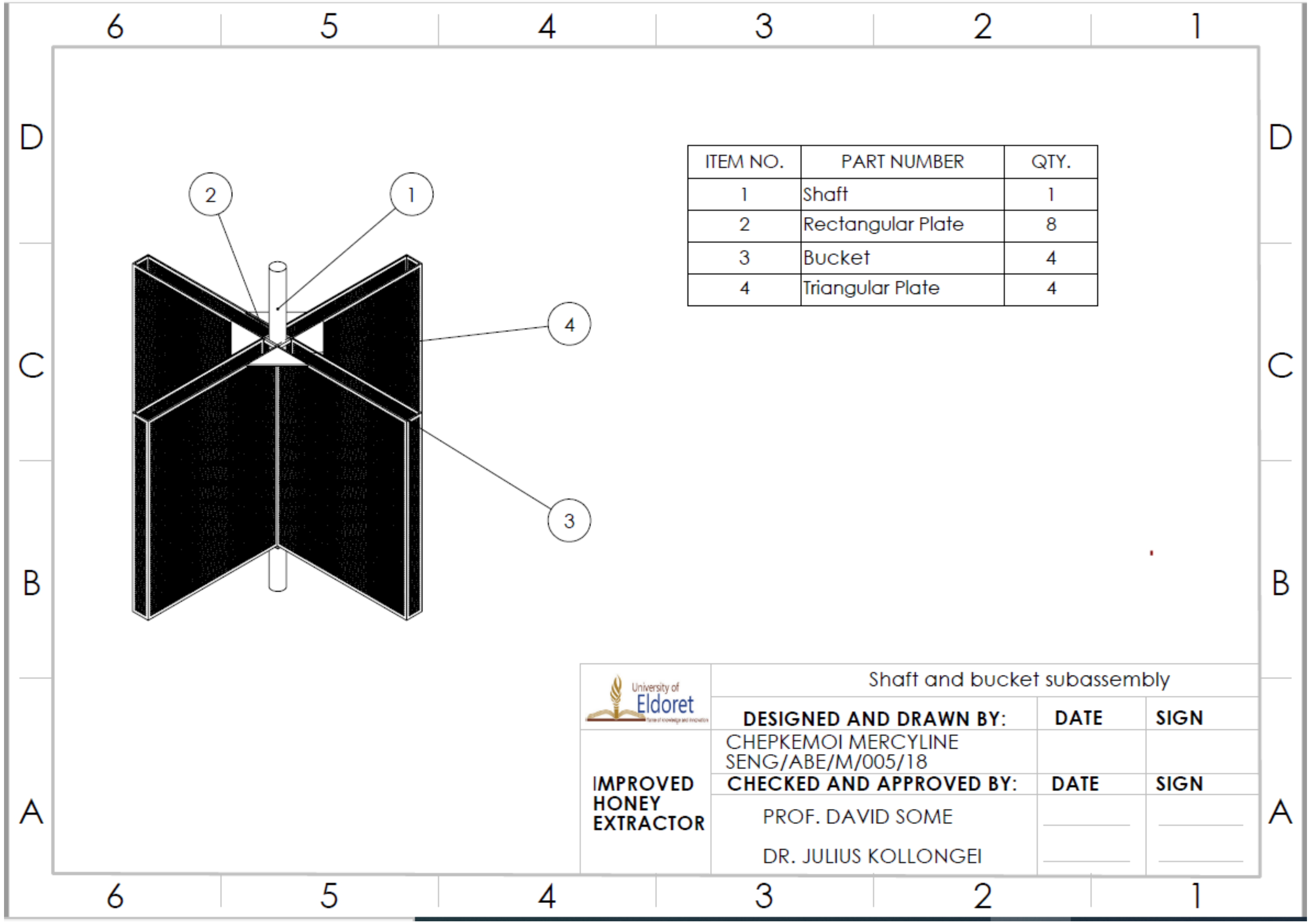


Figure 7.9: Parts of the shaft and honeycomb net buckets sub-assembly

(Source: Author, 2021)

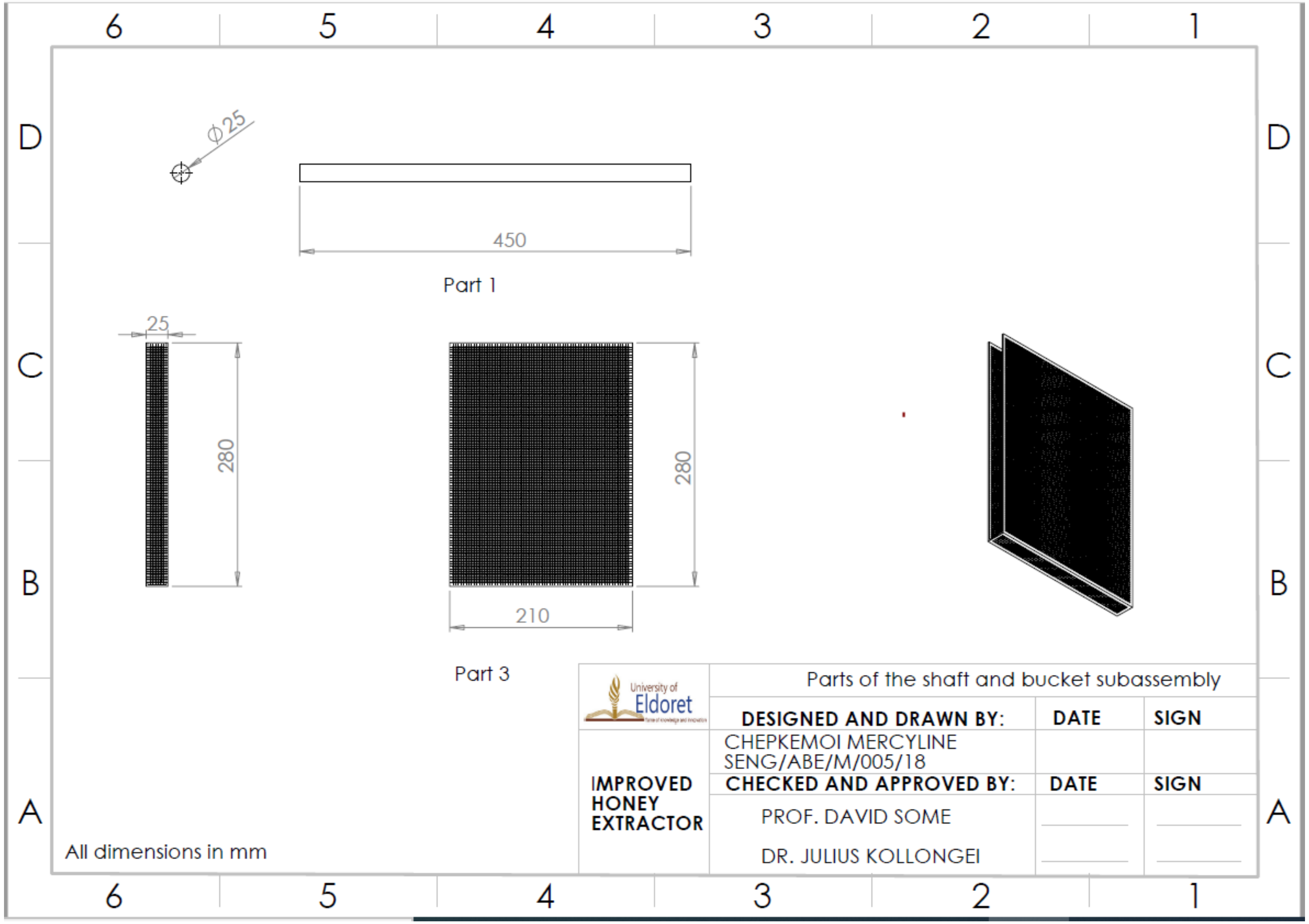
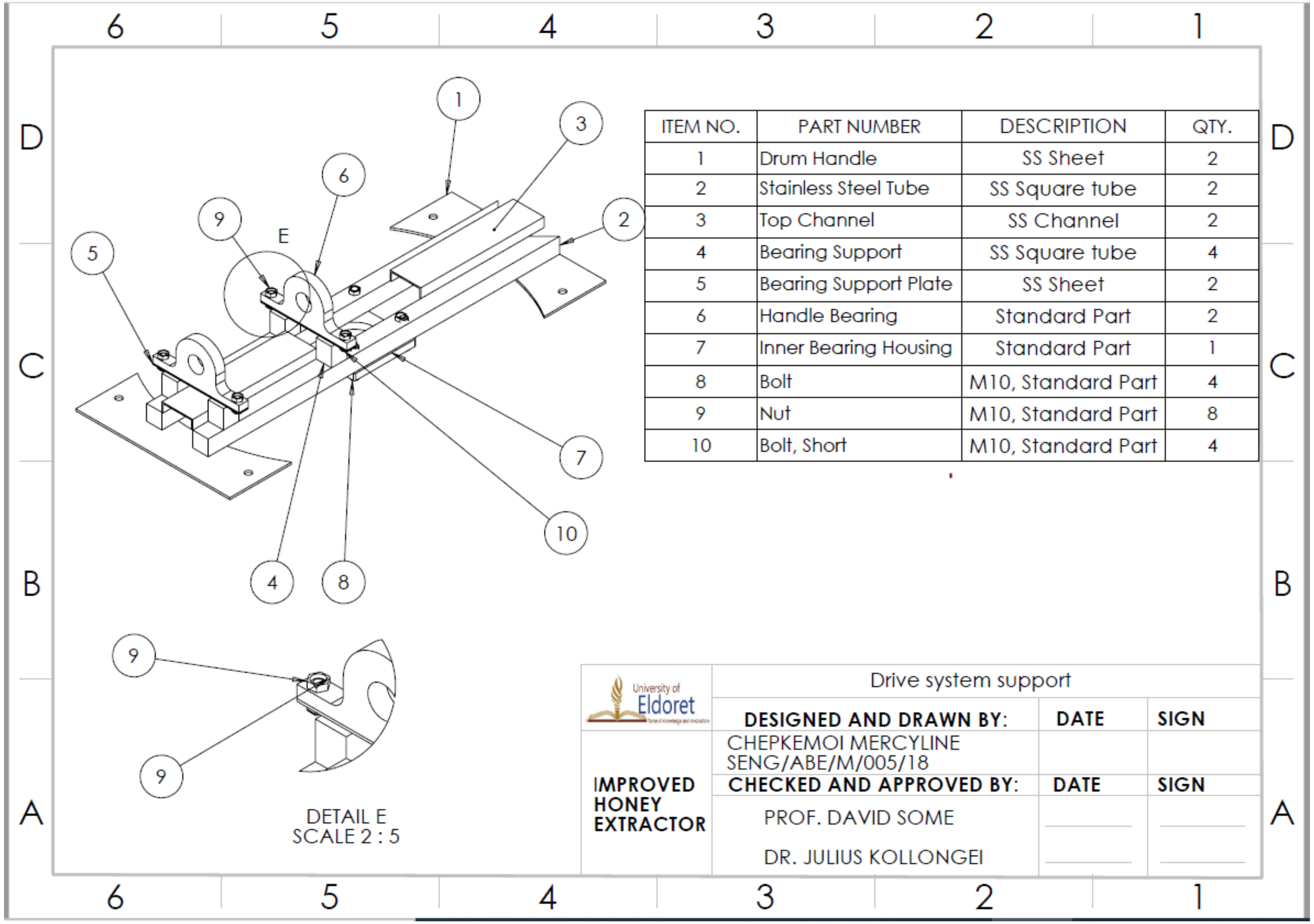


Figure 7.10: Dimensions of the parts of shaft and honeycomb net buckets

(Source: Author, 2021)



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Drum Handle	SS Sheet	2
2	Stainless Steel Tube	SS Square tube	2
3	Top Channel	SS Channel	2
4	Bearing Support	SS Square tube	4
5	Bearing Support Plate	SS Sheet	2
6	Handle Bearing	Standard Part	2
7	Inner Bearing Housing	Standard Part	1
8	Bolt	M10, Standard Part	4
9	Nut	M10, Standard Part	8
10	Bolt, Short	M10, Standard Part	4

Figure 7.11: Parts of the drive system support

(Source: Author, 2021)

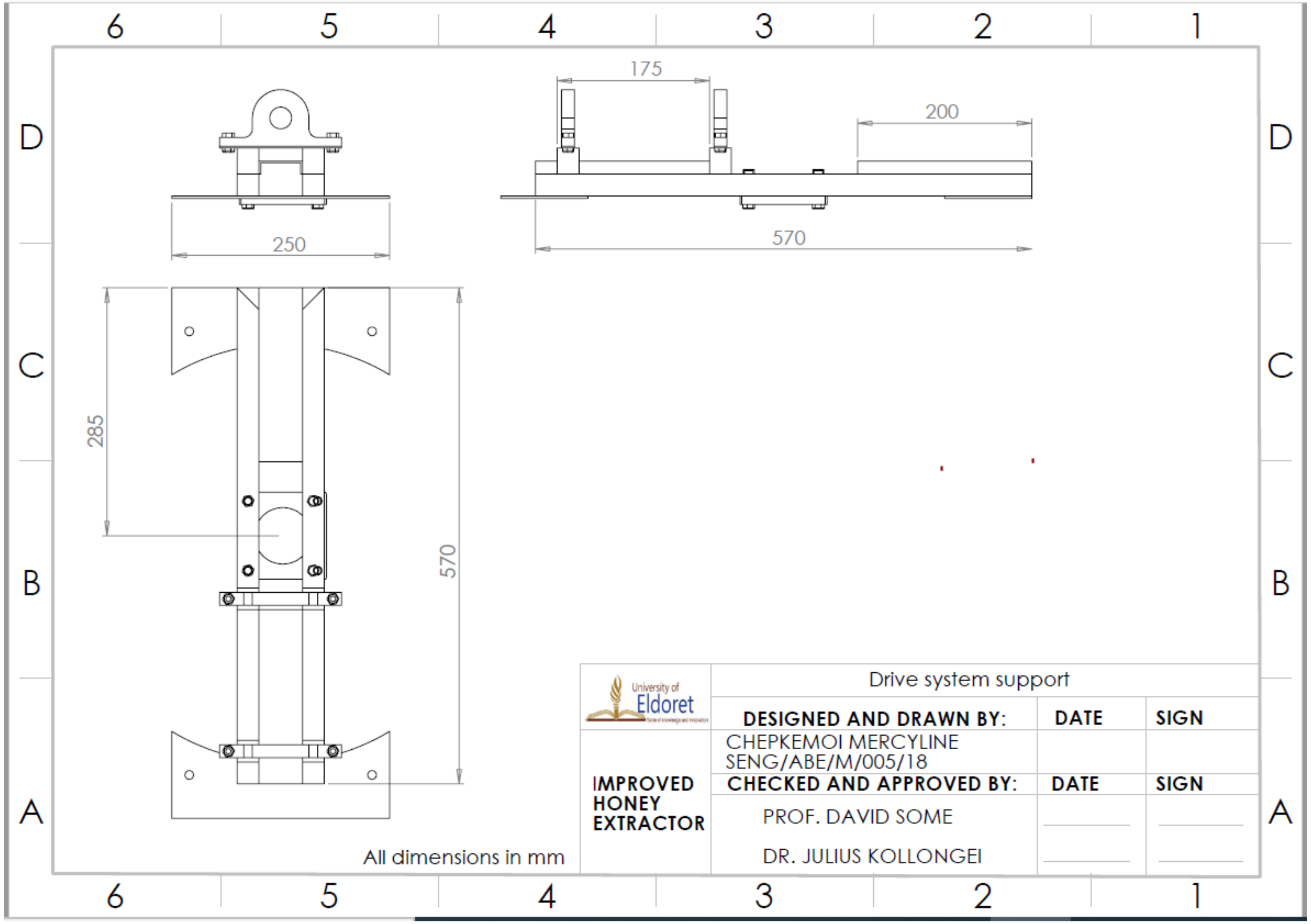


Figure 7.12: Dimensions of the drive system support (top and side views)

(Source: Author, 2021)

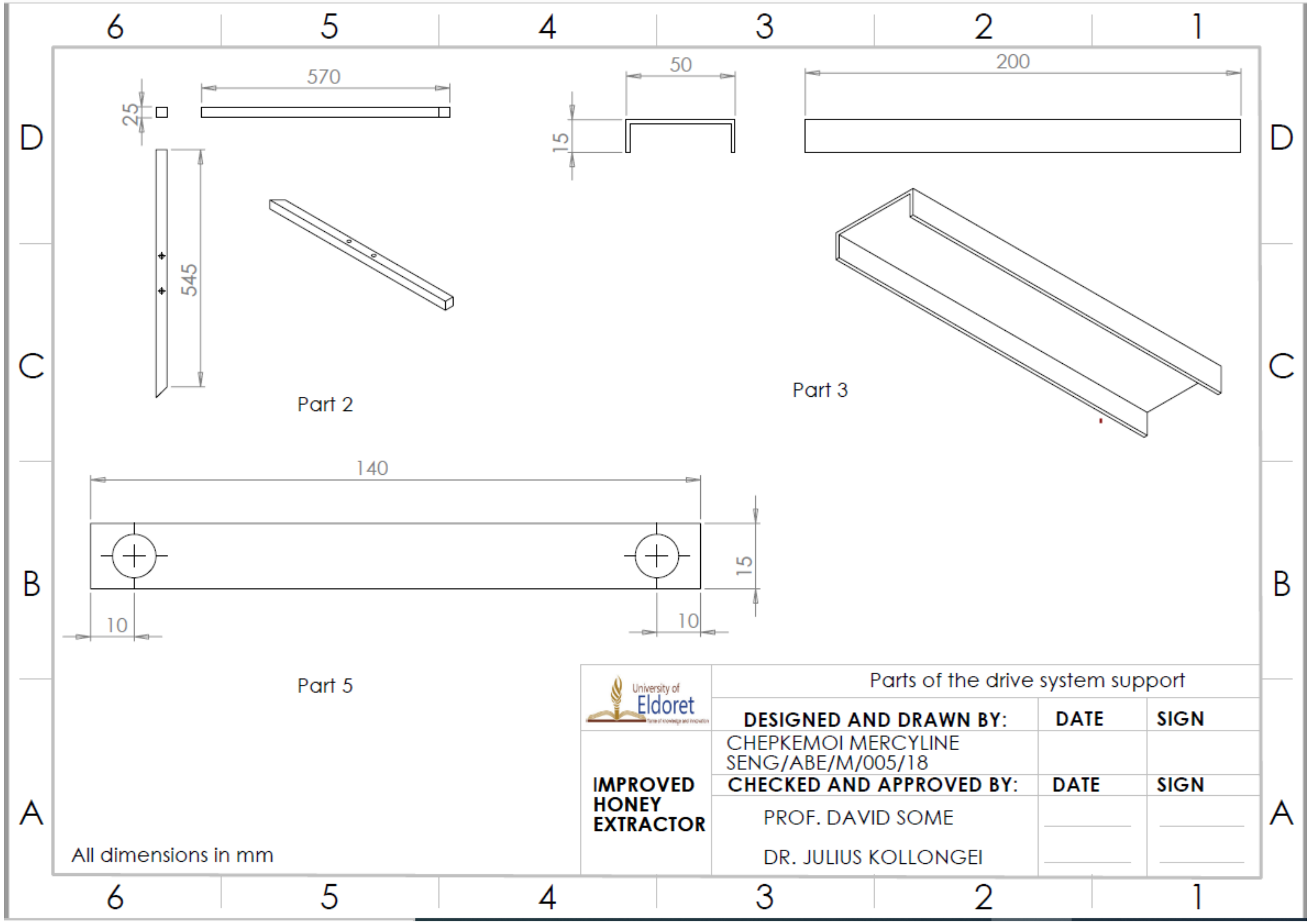


Figure 7.13: Dimensions of the parts of drive system support

(Source: Author, 2021)

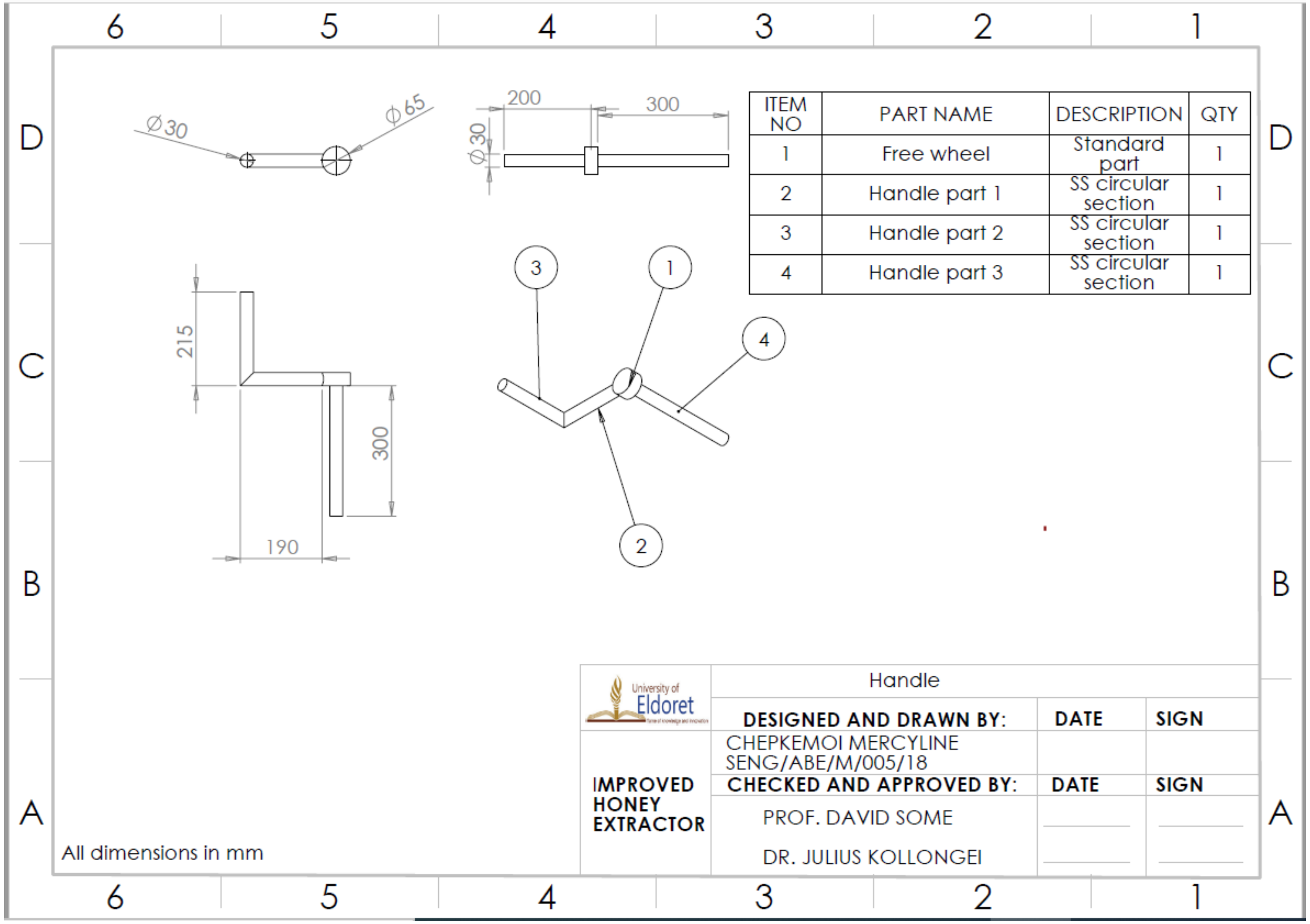


Figure 7.14: Parts and dimensions of the handle

(Source: Author, 2021)

Appendix II: Bill of quantities

Item	Description	Quantity	Unit Cost (KES)	Total Cost (KES)
Honeycomb net buckets	Stainless-steel wire mesh	1 roll	5,000	5,000
Filtering mesh	Stainless-steel wire mesh	1 roll	3,000	3,000
Cylindrical drum	1.2 mm stainless-steel plate	1 piece	14,500	14,500
Pillow bearings	Nylon bearings	2 pieces	1,500	3,000
Flange bearings	Number 205	2 pieces	750	1,500
Centre bearing	For supporting the vertical central shaft	1 piece	400	400
Bevel gears	18 teeth for driver gear and 10 teeth for driven gear	2 pieces	1,500	3,000
Central and horizontal shaft	Stainless-steel shafts	I piece	3,500	3,500
Support stand	Mild steel	2 pieces	3,000	6,000
Gate valve	Stainless-steel valve	1 piece	1,700	1,700
Handle	Stainless-steel	1 inch piece	1,500	1,500
Labour costs	Fabrication		10,000	10,000
Total cost				**53,100**

(Source: Author, 2021)

Appendix III: Worldwide honey production (2017)

Country	**Honey production in metric tonnes**
China	543,000
Turkey	114,471
Iran	69,699
United States	66,968
Ukraine	66,231
Russia	65,678
India	64,981
Total	**1,860,712**

Source: (Faostat, 2016)

Appendix IV: References for design calculations

Table 7.1: AISI 304 stainless steel properties and values

AISI 304				
Chemical composition: C=0.08%max, Mn=2%max, Cr=19%, Ni=9.5%				
Property	**Value in metric unit**		**Value in US unit**	
Density	7.9 *10^3	kg/m³	493	lb/ft³
Modulus of elasticity	193	GPa	28000	ksi
Thermal expansion (20 ºC)	17.2*10^{-6}	ºC^{-1}	9.5*10^{-6}	in/(in* ºF)
Specific heat capacity	502	J/(kg*K)	0.12	BTU/(lb*ºF)
Thermal conductivity	16.2	W/(m*K)	112	BTU*in/(hr*ft²*ºF)
Electric resistivity	7.2*10^{-7}	Ohm*m	7.2*10^{-5}	Ohm*cm
Tensile strength (annealed)	586	MPa	85000	psi
Yield strength (annealed)	241	MPa	35000	psi
Elongation (annealed)	55	%	55	%
Hardness (annealed)	80	RB	80	RB
Tensile strength (1/2 hard)	1100	MPa	160000	psi
Yield strength (1/2 hard)	760	MPa	110000	psi
Elongation (1/2 hard)	10	%	10	%
Hardness (1/2 hard)	35	RC	35	RC

Source: (Wikipedia, 2020)

Table 7.2: Minimum number of teeth on the pinion to avoid interference

S. No.	*Systems of gear teeth*	*Minimum number of teeth on the pinion*
1.	$14\frac{1}{2}°$ Composite	12
2.	$14\frac{1}{2}°$ Full depth involute	32
3.	20° Full depth involute	18
4.	20° Stub involute	14

Source: (Khurmi and Gupta, 2005)

Table 7.3: Values of allowable static stress

Material	*Allowable static stress (σ_o) MPa or N/mm²*
Cast iron, ordinary	56
Cast iron, medium grade	70
Cast iron, highest grade	105
Cast steel, untreated	140
Cast steel, heat treated	196
Forged carbon steel-case hardened	126
Forged carbon steel-untreated	140 to 210
Forged carbon steel-heat treated	210 to 245
Alloy steel-case hardened	350
Alloy steel-heat treated	455 to 472
Phosphor bronze	84
Non-metallic materials	
Rawhide, fabroil	42
Bakellite, Micarta, Celoron	56

Source: (Khurmi and Gupta, 2005)

Appendix V: Bearing design and selection

Table 7.4: Principal dimensions for radial ball bearings

Bearing No.	*Bore (mm)*	*Outside diameter*	*Width (mm)*
200 300	10	30 35	9 11
201 301	12	32 37	10 12
202 302	15	35 42	11 13
203 303 403	17	40 47 62	12 14 17
204 304 404	20	47 52 72	14 14 19
205 305 405	25	52 62 80	15 17 21
206 306 406	30	62 72 90	16 19 23
207 307 407	35	72 80 100	17 21 25

Source: (Khurmi and Gupta, 2005)

Table 7.5: Basic static and dynamic capacities of various types of radial ball bearings

Bearing No.	Basic capacities in kN							
	Single row deep groove ball bearing		Single row angular contact ball bearing		Double row angular contact ball bearing		Self-aligning ball bearing	
	Static (C_0)	Dynamic (C)	Static (C_0)	Dynamic (C)	Static (C_0)	Dynamic (C)	Static (C_0)	Dynamic (C)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
200	2.24	4	—	—	4.55	7.35	1.80	5.70
300	3.60	6.3	—	—	—	—	—	—
201	3	5.4	—	—	5.6	8.3	2.0	5.85
301	4.3	7.65	—	—	—	—	3.0	9.15
202	3.55	6.10	3.75	6.30	5.6	8.3	2.16	6
302	5.20	8.80	—	—	9.3	14	3.35	9.3
203	4.4	7.5	4.75	7.8	8.15	11.6	2.8	7.65
303	6.3	10.6	7.2	11.6	12.9	19.3	4.15	11.2
403	11	18	—	—	—	—	—	—
204	6.55	10	6.55	10.4	11	16	3.9	9.8
304	7.65	12.5	8.3	13.7	14	19.3	5.5	14
404	15.6	24	—	—	—	—	—	—
205	7.1	11	7.8	11.6	13.7	17.3	4.25	9.8
305	10.4	16.6	12.5	19.3	20	26.5	7.65	19
405	19	28	—	—	—	—	—	—

Source: (Khurmi and Gupta, 2005)

Table 7.6: Values of X and Y for dynamically loaded bearings

Type of bearing	*Specifications*	$\frac{W_A}{W_R} \leq e$		$\frac{W_A}{W_R} > e$		*e*
		X	*Y*	*X*	*Y*	
Deep groove ball bearing	$\frac{W_A}{C_0} = 0.025$				2.0	0.22
	= 0.04				1.8	0.24
	= 0.07				1.6	0.27
	= 0.13	1	0	0.56	1.4	0.31
	= 0.25				1.2	0.37
	= 0.50				1.0	0.44
Angular contact ball bearings	Single row		0	0.35	0.57	1.14
	Two rows in tandem		0	0.35	0.57	1.14
	Two rows back to back	1	0.55	0.57	0.93	1.14
	Double row		0.73	0.62	1.17	0.86
Self-aligning bearings	Light series : for bores					
	10 – 20 mm		1.3		2.0	0.50
	25 – 35	1	1.7	6.5	2.6	0.37
	40 – 45		2.0		3.1	0.31
	50 – 65		2.3		3.5	0.28
	70 – 100		2.4		3.8	0.26
	105 – 110		2.3		3.5	0.28
	Medium series : for bores					
	12 mm		1.0	0.65	1.6	0.63
	15 – 20		1.2		1.9	0.52
	25 – 50		1.5		2.3	0.43
	55 – 90		1.6		2.5	0.39
Spherical roller bearings	For bores :					
	25 – 35 mm		2.1		3.1	0.32
	40 – 45	1	2.5	0.67	3.7	0.27
	50 – 100		2.9		4.4	0.23
	100 – 200		2.6		3.9	0.26
Taper roller bearings	For bores :					
	30 – 40 mm				1.60	0.37
	45 – 110	1	0	0.4	1.45	0.44
	120 – 150				1.35	0.41

Source: (Khurmi and Gupta, 2005)

Table 7.7: Values of service factor (Ks)

S.No.	*Type of service*	*Service factor (K_S) for radial ball bearings*
1.	Uniform and steady load	1.0
2.	Light shock load	1.5
3.	Moderate shock load	2.0
4.	Heavy shock load	2.5
5.	Extreme shock load	3.0

Source: (Khurmi and Gupta, 2005)

Appendix VI: KEBS Test Results

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Laboratory Test Report

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Page 1 of 1

REPORT UID: 20201020204230-V1
KEBS Sample Ref. No: BS202036287
Date : 15 October, 2020

1. Description of Sample: HONEY

2. Sample Submitted by: UNIVERSITY OF ELDORET

3. Customer Contact: MERCYLINE CHEPKEMOI
4. Customers Ref No: PRIVATE

5. Customer's Address: P.O BOX 1125-30100 ELDORET,

6. Lab Ref: KEBS/TES/FOO-LAR/F/20

7. Date of Receipt: 9 October, 2020
8. Date Analysis Started: 12 October, 2020
9. Sample Submission Form No: 227633

10. Additional Information provided by the customer:
MAOI-A1

11. Acceptance criteria-title and number of specification against which it is tested:
EAS 36:2000 EAST AFRICAN STANDARD Honey - Specification

12. Parameters tested and Method(s) of test: as listed in the report below:

LABORATORY TEST REPORT

No.	Parameters		Results	Requirements	Test Method No.	LOD
1.	Moisture Content	% by mass	18.4	22Max	EAS 36	
2.	pH		4.0		TES/ING/TM/46	
3.	Relative Density	g/mL	1.4129	Not Specified	TES/F & A /TM/43	
4.	Total Water Insoluble Solids Content	% m/m	0.14	0.5Max	KS 05-344	

COMMENTS/REMARKS:
The sample performed as shown

Millicent Owuor - Laboratory Analyst
FOR: MANAGING DIRECTOR

15 October, 2020
Date of Issue

Figure 7.15: Maoi A1 test results

(Source: KEBS, 2020)

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Laboratory Test Report

Page 1 of 1

REPORT UID: 20201020201723-V1
KEBS Sample Ref. No: BS202036288
Date : 15 October, 2020

1. Description of Sample: HONEY

2. Sample Submitted by: UNIVERSITY OF ELDORET

3. Customer Contact: MERCYLINE CHEPKEMOI
4. Customers Ref No: PRIVATE

5. Customer's Address: P.O BOX 1125-30100 ELDORET,

6. Lab Ref: KEBS/TES/FOO-LAR/F/20

7. Date of Receipt: 9 October, 2020
8. Date Analysis Started: 12 October, 2020
9. Sample Submission Form No: 227633

10. Additional Information provided by the customer:
MAOI-A2

11. Acceptance criteria-title and number of specification against which it is tested:
EAS 36:2000 EAST AFRICAN STANDARD Honey - Specification

12. Parameters tested and Method(s) of test: as listed in the report below:

LABORATORY TEST REPORT

No.	Parameters		Results	Requirements	Test Method No.	LOD
1.	Moisture Content	% by mass	18.6	22Max	EAS 36	
2.	pH		4.2		TES/ING/TM/46	
3.	Relative Density	g/mL	1.4123	Not Specified	TES/F & A /TM/43	
4.	Total Water Insoluble Solids Content	% m/m	0.30	0.5Max	KS 05-344	

COMMENTS/REMARKS:
The sample performed as shown

Millicent Owuor - Laboratory Analyst
FOR: MANAGING DIRECTOR

15 October, 2020
Date of Issue

Figure 7.16: Maoi A2 test results

(Source: KEBS, 2020)

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Laboratory Test Report

Page 1 of 1

REPORT UID: 20201020190721-V1
KEBS Sample Ref. No: BS202036289
Date : 15 October, 2020

1. Description of Sample: HONEY

2. Sample Submitted by: UNIVERSITY OF ELDORET

6. Lab Ref: KEBS/TES/FOO-LAR/F/20

3. Customer Contact: MERCYLINE CHEPKEMOI
4. Customers Ref No: PRIVATE

7. Date of Receipt: 9 October, 2020
8. Date Analysis Started: 12 October, 2020
9. Sample Submission Form No: 227633

5. Customer's Address: P.O BOX 1125-30100 ELDORET,

10. Additional Information provided by the customer:
MAOI-A3

11. Acceptance criteria-title and number of specification against which it is tested:
EAS 36:2000 EAST AFRICAN STANDARD Honey - Specification

12. Parameters tested and Method(s) of test: as listed in the report below:

LABORATORY TEST REPORT

No.	Parameters		Results	Requirements	Test Method No.	LOD
1.	Moisture Content	% by mass	18.4	22Max	EAS 36	
2.	pH		4.1		TES/ING/TM/46	
3.	Relative Density	g/mL	1.4126	Not Specified	TES/F & A /TM/43	
4.	Total Water Insoluble Solids Content	% m/m	0.37	0.5Max	KS 05-344	

COMMENTS/REMARKS:
The sample performed as shown

Millicent Owuor - Laboratory Analyst
FOR: MANAGING DIRECTOR

15 October, 2020
Date of Issue

The results contained herein apply only to the particular sample(s) tested whose sample submission form serial number is herein quoted, and to the specific tests carried out, as detailed in this Test Report. No extract, abridgement or abstraction from a Test Report may be published or used to advertise a product without the written consent of the Managing Director, KENYA BUREAU OF STANDARDS. If undelivered, please return to the address written above.

Figure 7.17: Maoi A3 test results

(Source: KEBS, 2020)

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Laboratory Test Report

Page 1 of 1

PRIVATE SAMPLE

REPORT UID: 20201020190718-V1
KEBS Sample Ref. No: BS202036284
Date : 15 October, 2020

1. Description of Sample: HONEY

2. Sample Submitted by: UNIVERSITY OF ELDORET

3. Customer Contact: MERCYLINE CHEPKEMOI
4. Customers Ref No: PRIVATE

5. Customer's Address: P.O BOX 1125-30100 ELDORET,

6. Lab Ref: KEBS/TES/FOO-LAR/F/20

7. Date of Receipt: 9 October, 2020
8. Date Analysis Started: 12 October, 2020
9. Sample Submission Form No: 227633

10. Additional Information provided by the customer:
LOPOI JUNCTION-B1

11. Acceptance criteria-title and number of specification against which it is tested:
EAS 36:2000 EAST AFRICAN STANDARD Honey - Specification

12. Parameters tested and Method(s) of test: as listed in the report below:

LABORATORY TEST REPORT

No.	Parameters		Results	Requirements	Test Method No.	LOD
1.	Moisture Content	% by mass	15.0	22Max	EAS 36	
2.	pH		3.3		TES/ING/TM/46	
3.	Relative Density	g/mL	1.4343	Not Specified	TES/F & A /TM/43	
4.	Total Water Insoluble Solids Content	% m/m	0.07	0.5Max	KS 05-344	

COMMENTS/REMARKS:
The sample performed as shown

Millicent Owuor - Laboratory Analyst
FOR: MANAGING DIRECTOR

15 October, 2020
Date of Issue

Figure 7.18: Lopoi Junction B1 test results

(Source: KEBS, 2020)

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REPORT UID: 20201020190719-V1
KEBS Sample Ref. No: BS202036285
Date : 15 October, 2020

1. Description of Sample: HONEY

2. Sample Submitted by: UNIVERSITY OF ELDORET

6. Lab Ref: KEBS/TES/FOO-LAR/F/20

3. Customer Contact: MERCYLINE CHEPKEMOI

4. Customers Ref No: PRIVATE

7. Date of Receipt: 9 October, 2020

8. Date Analysis Started: 12 October, 2020

9. Sample Submission Form No: 241365

5. Customer's Address: P.O BOX 1125-30100 ELDORET,

10. Additional Information provided by the customer:
LOPOI JUNCTION-B2

11. Acceptance criteria-title and number of specification against which it is tested:
EAS 36:2000 EAST AFRICAN STANDARD Honey - Specification

12. Parameters tested and Method(s) of test: as listed in the report below:

LABORATORY TEST REPORT

No.	Parameters		Results	Requirements	Test Method No.	LOD
1.	Moisture Content	% by mass	18.1	22Max	EAS 36	
2.	pH		3.9		TES/ING/TM/46	
3.	Relative Density	g/mL	1.4154	Not Specified	TES/F & A /TM/43	
4.	Total Water Insoluble Solids Content	% m/m	0.11	0.5Max	KS 05-344	

COMMENTS/REMARKS:
The sample performed as shown

Millicent Owuor - Laboratory Analyst
FOR: MANAGING DIRECTOR

15 October, 2020
Date of Issue

Figure 7.19: Lopoi Junction B2 Test results

(Source: KEBS, 2020)

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REPORT UID: 20201020191820-V1
KEBS Sample Ref. No: BS202036286
Date : 15 October, 2020

1. Description of Sample: HONEY

2. Sample Submitted by: UNIVERSITY OF ELDORET

3. Customer Contact: MERCYLINE CHEPKEMOI
4. Customers Ref No: PRIVATE

5. Customer's Address: P.O BOX 1125-30100 ELDORET,

6. Lab Ref: KEBS/TES/FOO-LAR/F/20

7. Date of Receipt: 9 October, 2020
8. Date Analysis Started: 12 October, 2020
9. Sample Submission Form No: 227633

10. Additional Information provided by the customer:
LOPOI JUNCTION-B3

11. Acceptance criteria-title and number of specification against which it is tested:
EAS 36:2000 EAST AFRICAN STANDARD Honey - Specification

12. Parameters tested and Method(s) of test: as listed in the report below:

LABORATORY TEST REPORT

No.	Parameters		Results	Requirements	Test Method No.	LOD
1.	Moisture Content	% by mass	17.1	22Max	EAS 36	
2.	pH		4.0		TES/ING/TM/46	
3.	Relative Density	g/mL	1.4192	Not Specified	TES/F & A /TM/43	
4.	Total Water Insoluble Solids Content	% m/m	0.19	0.5Max	KS 05-344	

COMMENTS/REMARKS:
The sample performed as shown

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FOR: MANAGING DIRECTOR

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Figure 7.20: Lopoi Junction B3 test results

(Source: KEBS, 2020)

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PRIVATE SAMPLE

REPORT UID: 20201020204228-V1
KEBS Sample Ref. No: BS202036281
Date : 15 October, 2020

1. Description of Sample: HONEY

2. Sample Submitted by: UNIVERSITY OF ELDORET

3. Customer Contact: MERCYLINE CHEPKEMOI
4. Customers Ref No: PRIVATE

5. Customer's Address: P.O BOX 1125-30100 ELDORET,

6. Lab Ref: KEBS/TES/FOO-LAR/F/20

7. Date of Receipt: 9 October, 2020
8. Date Analysis Started: 12 October, 2020
9. Sample Submission Form No: 227633

10. Additional Information provided by the customer:
MARIGAT-C1

11. Acceptance criteria-title and number of specification against which it is tested:
EAS 36:2000 EAST AFRICAN STANDARD Honey - Specification

12. Parameters tested and Method(s) of test: as listed in the report below:

LABORATORY TEST REPORT

No.	Parameters		Results	Requirements	Test Method No.	LOD
1.	Moisture Content	% by mass	18.4	22Max	EAS 36	
2.	pH		3.6		TES/ING/TM/46	
3.	Relative Density	g/mL	1.4125	Not Specified	TES/F & A /TM/43	
4.	Total Water Insoluble Solids Content	% m/m	0.10	0.5Max	KS 05-344	

COMMENTS/REMARKS:
The sample performed as shown

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15 October, 2020
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Figure 7.21: Marigat Town C1 test results

(Source: KEBS, 2020)

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PRIVATE SAMPLE

REPORT UID: 20201020201722-V1
KEBS Sample Ref. No: BS202036282
Date : 15 October, 2020

1. Description of Sample: HONEY

2. Sample Submitted by: UNIVERSITY OF ELDORET

3. Customer Contact: MERCYLINE CHEPKEMOI
4. Customers Ref No: PRIVATE

5. Customer's Address: P.O BOX 1125-30100 ELDORET,

6. Lab Ref: KEBS/TES/FOO-LAR/F/20

7. Date of Receipt: 9 October, 2020
8. Date Analysis Started: 12 October, 2020
9. Sample Submission Form No: 227633

10. Additional Information provided by the customer:
MARIGAT-C2

11. Acceptance criteria-title and number of specification against which it is tested:
EAS 36:2000 EAST AFRICAN STANDARD Honey - Specification

12. Parameters tested and Method(s) of test: as listed in the report below:

LABORATORY TEST REPORT

No.	Parameters		Results	Requirements	Test Method No.	LOD
1.	Moisture Content	% by mass	17.8	22Max	EAS 36	
2.	pH		3.8		TES/ING/TM/46	
3.	Relative Density	g/mL	1.4160	Not Specified	TES/F & A /TM/43	
4.	Total Water Insoluble Solids Content	% m/m	0.29	0.5Max	KS 05-344	

COMMENTS/REMARKS:
The sample performed as shown

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Figure 7.22: Marigat Town C2 test results

(Source: KEBS, 2020)

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PRIVATE SAMPLE

REPORT UID: 20201020195035-V1
KEBS Sample Ref. No: BS202036283
Date : 15 October, 2020

1. Description of Sample: HONEY

2. Sample Submitted by: UNIVERSITY OF ELDORET

3. Customer Contact: MERCYLINE CHEPKEMOI
4. Customers Ref No: PRIVATE

5. Customer's Address: P.O BOX 1125-30100 ELDORET,

6. Lab Ref: KEBS/TES/FOO-LAR/F/20

7. Date of Receipt: 9 October, 2020
8. Date Analysis Started: 12 October, 2020
9. Sample Submission Form No: 227633

10. Additional Information provided by the customer:
MARIGAT-C3

11. Acceptance criteria-title and number of specification against which it is tested:
EAS 36:2000 EAST AFRICAN STANDARD Honey - Specification

12. Parameters tested and Method(s) of test: as listed in the report below:

LABORATORY TEST REPORT

No.	Parameters		Results	Requirements	Test Method No.	LOD
1.	Moisture Content	% by mass	18.8	22Max	EAS 36	
2.	pH		3.9		TES/ING/TM/46	
3.	Relative Density	g/mL	1.4103	Not Specified	TES/F & A /TM/43	
4.	Total Water Insoluble Solids Content	% m/m	0.61	0.5Max	KS 05-344	

COMMENTS/REMARKS:
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Figure 7.23: Marigat Town C3 test results

(Source: KEBS, 2020)

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REPORT UID: 20201020203553-V1
KEBS Sample Ref. No: BS202036260
Date : 15 October, 2020

1. Description of Sample: HONEY

2. Sample Submitted by: UNIVERSITY OF ELDORET

3. Customer Contact: MERCYLINE CHEPKEMOI
4. Customers Ref No: PRIVATE

5. Customer's Address: P.O BOX 1125-30100 ELDORET,

6. Lab Ref: KEBS/TES/FOO-LAR/F/20

7. Date of Receipt: 9 October, 2020
8. Date Analysis Started: 12 October, 2020
9. Sample Submission Form No: 227633

10. Additional Information provided by the customer:
KORIEMA-D1

11. Acceptance criteria-title and number of specification against which it is tested:
EAS 36:2000 EAST AFRICAN STANDARD Honey - Specification

12. Parameters tested and Method(s) of test: as listed in the report below:

LABORATORY TEST REPORT

No.	Parameters		Results	Requirements	Test Method No.	LOD
1.	Moisture Content	% by mass	18.4	22Max	EAS 36	
2.	pH		4.0		TES/ING/TM/46	
3.	Relative Density	g/mL	1.4128	Not Specified	TES/F & A /TM/43	
4.	Total Water Insoluble Solids Content	% m/m	0.17	0.5Max	KS 05-344	

COMMENTS/REMARKS:
The sample performed as shown

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Figure 7.24: Koriema Centre D1 test results

(Source: KEBS, 2020)

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PRIVATE SAMPLE

REPORT UID: 20201020203554-V1
KEBS Sample Ref. No: BS202036278
Date : 15 October, 2020

1. Description of Sample: HONEY

2. Sample Submitted by: UNIVERSITY OF ELDORET

3. Customer Contact: MERCYLINE CHEPKEMOI

4. Customers Ref No: PRIVATE

5. Customer's Address: P.O BOX 1125-30100 ELDORET,

6. Lab Ref: KEBS/TES/FOO-LAR/F/20

7. Date of Receipt: 9 October, 2020

8. Date Analysis Started: 12 October, 2020

9. Sample Submission Form No: 227633

10. Additional Information provided by the customer:
KORIEMA-D2

11. Acceptance criteria-title and number of specification against which it is tested:
EAS 36:2000 EAST AFRICAN STANDARD Honey - Specification

12. Parameters tested and Method(s) of test: as listed in the report below:

LABORATORY TEST REPORT

No.	Parameters		Results	Requirements	Test Method No.	LOD
1.	Moisture Content	% by mass	18.0	22Max	EAS 36	
2.	pH		3.9		TES/ING/TM/46	
3.	Relative Density	g/mL	1.4153	Not Specified	TES/F & A /TM/43	
4.	Total Water Insoluble Solids Content	% m/m	0.09	0.5Max	KS 05-344	

COMMENTS/REMARKS:
The sample performed as shown

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Date of Issue

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Figure 7.25: Koriema Centre D2 test results

(Source: KEBS, 2020)

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Laboratory Test Report

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REPORT UID: 20201020190717-V1
KEBS Sample Ref. No: BS202036279
Date : 15 October, 2020

1. Description of Sample: HONEY

2. Sample Submitted by: UNIVERSITY OF ELDORET

3. Customer Contact: MERCYLINE CHEPKEMOI
4. Customers Ref No: PRIVATE

5. Customer's Address: P.O BOX 1125-30100 ELDORET,

6. Lab Ref: KEBS/TES/FOO-LAR/F/20

7. Date of Receipt: 9 October, 2020
8. Date Analysis Started: 12 October, 2020
9. Sample Submission Form No: 227633

10. Additional Information provided by the customer:
KORIEMA-D3

11. Acceptance criteria-title and number of specification against which it is tested:
EAS 36:2000 EAST AFRICAN STANDARD Honey - Specification

12. Parameters tested and Method(s) of test: as listed in the report below:

LABORATORY TEST REPORT

No.	Parameters		Results	Requirements	Test Method No.	LOD
1.	Moisture Content	% by mass	19.6	22Max	EAS 36	
2.	pH		4.0		TES/ING/TM/46	
3.	Relative Density	g/mL	1.4045	Not Specified	TES/F & A /TM/43	
4.	Total Water Insoluble Solids Content	% m/m	0.15	0.5Max	KS 05-344	

COMMENTS/REMARKS:
The sample performed as shown

Millicent Owuor - Laboratory Analyst
FOR: MANAGING DIRECTOR

15 October, 2020
Date of Issue

Figure 7.26: Koriema Centre D3 test results

(Source: KEBS, 2020)

Appendix VII: Similarity report

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