CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

Faculty of Tropical AgriSciences

Post-harvesting Processing and Final Quality of the Coffee

BACHELOR'S THESIS

Prague 2023/2024

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Declaration

I hereby declare that I have done this thesis entitled, “Post-harvesting Processing and Final Quality of the Coffee”, independently, all texts in this thesis are original, and all the sources have been quoted and acknowledged by means of complete references and according to the Citation rules of the FTA.

In Prague date

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Anna Markova

Acknowledgements

Coffee is one of my favourite beverages, not because it can be warm, smell, and taste very nice, but also and mainly because it showed me a world full of different people, who love it as I do. Interesting people from all over the world who can help each other in need, and at the same time share a cup of coffee, a very simple beverage with so many layers, as many as we can count. But the biggest thanks belong to Verena and Henry, they invited me to their farm several years ago, and it changed my heart forever, they also helped me with my crazy ideas, and my experiments, because they are great people who share the love for coffee as I do. To my partner, who is the most supportive person I have ever met and was able to help me make measurements in very early mornings. To my family, because they think I am getting crazier as I travel more and more, and to all my colleagues and classmates for being supportive. Coffee is a beautiful commodity, that brings people together, thank you for reading and caring about coffee.

Abstract

The post-harvesting processing of coffee is an important part of quality, including fermentation. This work monitored Brix levels, pH, and temperature of two different processing methods (lavado and honey) during their fermentation in Ecuador, at Finca Maputo, in La Perla, Nanegal. PH and temperature were monitored in three different locations (up, down, middle) to see differences due to the non-controlled environment in the processing facility. The correlation was statistically proved in the pH values and temperature in between the locations, but not between the temperature and pH (Spermank's rank correlation coefficient $p > 0.05$). Sensory quality control of processed samples of lavado and honey proved significant differences (Mann-Whitney test $p > 0.05$) in attributes body and final score, where honey samples received 86.5 SCA points in the final score and lavado 85.91 SCA points. Coffee processing and fermentation methods influence the sensory performance of coffee and creating clear guidelines with thresholds of these main variables can help farmers to navigate within the decision-making.

Keywords: Coffee, Quality, Sensory Properties, Fermentation

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List of the abbreviations used in the thesis

CQI	Coffee Quality Institute
FAO	Food and Agriculture Organization
ICO	International Coffee Organization
ITC	International Trade Center
SCA	Specialty Coffee Association

1. Introduction

Coffee is one of the most consumed non-alcoholic beverages, yet many people do not know the journey behind each cup of coffee they drink every day. As commodity creates a dependency of more than 25 million smallholder farmers around the globe and according to many trading companies, there will be more than 10.88 million bags of traded coffee in 2022 by International Coffee Organization.

Quality is an important part of coffee production, one of the main challenges of research is to generate information that can improve the quality of coffee by changing from spontaneous fermentation to controlled fermentation to reduce variability while improving the consistency of the quality of the coffee for the market (Elhalis et al. 2023). Fermentation of coffee based on the wet method has traditionally been carried out spontaneously, in which a great variety of reactions occur depending on the conditions of the process; therefore, the results also vary (Poltronieri & Rossi 2016).

The research was conducted at Finca Maputo, La Perla, Nanegal, in the Pichincha region in Ecuador. It was focused specifically on monitoring the fermentation of two different processing methods – honey and lavado. Brix levels, pH levels, and the temperature from both methods were closely monitored during the experiments to collect data, which helped us to statistically analyse the correlation between these variables.

The focus of the research is also aimed at providing a clear comparison of these two processing methods from the perspective of sensory performance and identifying the potential value propositions for the farmers and limitations of both processing methods. In the long term, monitoring the fermentation and understanding the thresholds of different variables during all processing methods can help farmers design better quality control processes and achieve specific cup profiles.

2. Literature Review

2.1. The Coffee Plant

2.1.1. Botany

The coffee plant is characterized as a small tree or shrub due to the plant architecture with single or multiple vertical main stems, primary vertical branches at each internode to form secondary horizontal branches, opposite leaves with one leaf blade only, leathery, and thick, nectar-producing flowers, cherries with a sweet pulp containing beans. It takes around 2-3 years to develop from seed germination to first flowering and fruit production. This, of course, is also closely related to the variety that is being planted. The reproduction can also be done via cuttings, which are commonly used in Robusta but lately was also used on Arabica hybrids in Central America. After the cuttings are placed in a suitable environment to reproduce roots and after two or three months transferred to containers in the nurseries. Other methods of reproduction are grafting and in vitro techniques. Propagation via vegetative systems is considered useful mainly for reproducing true genotypes of the varieties, which leads to better physical, biochemical, and sensory quality (Folmer 2017).

The fruit of the tree is known as a cherry; however, it cannot be considered botanically correct as the coffee fruit is a drupe. The beans developed inside the cherry are used as a basic element for producing roast and ground coffee, soluble coffee powders, and coffee liquor. More botanical information on wild and cultivated coffee species is related to their habitats, geographical distribution, and taxonomic characterization. (Wintgens 2004).

Coffee tree production age varies depending on many factors, the raw estimation can be up to 80 years if the plants are well-managed, but in a more economic sense, the quality of coffee production is usually around 30 years (Davis et al. 2006).

Seeds consist of several layers and parts. The main and inner part is an embryo, which is composed of the hypocotyl and two cotyledons. The embryo is followed by endosperm (bean), integument (silverskin), endocarp (parchment), mesocarp (pulp), epicarp (skin), and the top part, which we usually refer as to disk. There is a very interesting correlation between the viability of the seed and moisture content. Variability decreases rapidly after 2 months for Robusta and for Arabica after 6 months when stored at ambient temperature (Wintgens 2004). If there is a need for stored seeds, the preferable way of storing the seeds is in parchment (endocarp) at a lower temperature and with around 12-13% moisture content of the seeds.

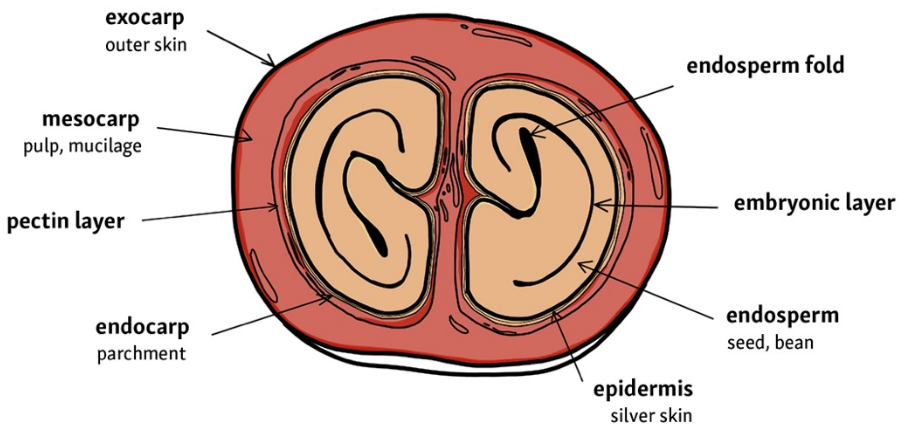

Figure 1: Inner layer of the coffee fruit (Author 2023).

2.1.2. Genetics and Taxonomy

Several documents that can be traced to the 10th century reveal coffee history as a beverage connected within the Arab world of trade and several great empires. At the same time, there are of course few legends about discovering coffee and its effects, for example, the most famous one is about Ethiopian goat shepherd Kaldi, who discovered the impact of coffee cherries due to his goat which ate them and became very active (Folmer 2017).

Currently, in the worldwide spectrum, there are two main commercially grown species: *Coffea arabica* and *Coffea canephora,* which belong to the Rubiaceae family, are from taxonomic classification, and are part of the genus *Coffea*. During the last two centuries the number of species belonging to the genus *Coffea* increased rapidly, on various criteria there were proposed three different groups: geographical origin, architecture, and morphological traits. The major conclusion is that all *Coffea* species share a common base genome (Wintgens 2004).

Most of the coffee species are diploid, meaning they contain 2n=22 chromosomes, however, *C. arabica* is an allotetraploid with 44 chromosomes being the exception within all the species. An interesting fact is that all the species of the genus *Coffea*, except for *C. arabica,* are allogamous, meaning they can be reproduced by cross-fertilization by self-incompatibility (Anthony et al. 2002).

2.2. Geographic Distribution of Coffee

Based on historical and scientific data, *C. arabica* diverged into two genetic bases, which have been described as two distinct botanical varieties Typica and Bourbon. Bourbon-derived cultivars are characterized by a more compact and wide upright growth habit, higher yield, and better cup quality (sensorial quality) than Typica-derived cultivars.

Historical data indicate that the Typica variety originated from a single plant that was taken from Yemen to India. Subsequent generations of this plant were taken to the island of Java in 1690 and then to Amsterdam in 1706 or 1710, where plants were cultivated in the botanical garden. From Amsterdam, coffee was introduced to the Americas when seedlings were taken to Suriname in 1718. From there, an arabica coffee tree was introduced in the West Indies (Martinique) in 1720 or 1723. In 1727, seeds were taken to the state of Pará in northern Brazil, apparently from French Guiana. Seeds from Suriname also became the parent of numerous self-progenies which were further disseminated around the Americas.

The spread of *C. canephora* from Central Africa throughout the world is more recent. It was initially taken to Indonesia in the 20th century as a solution to the coffee leaf rust that was attacking coffee plantations since it had presented resistance. There are many varieties of C. *canephora* in Africa. However, only two have been commercially disseminated throughout the world: *C.canephora* from Guinea and *C.canephora* from Congo.

Currently, coffee is planted in the belt between the two tropics, being widely found in the tropical regions of South America, Asia, Oceania, Africa, Central America, and Mexico.

2.3. Coffee Growing and Production

The main three categories can be considered as affecting the cup coffee quality could be considered: genetics, agriculture and farmers' practices, and environmental factors, which are of course dependent on the position where the plantation and coffee are grown. There is none more important than others, but their interaction is critical for good production.

2.3.1. Current Distribution and Native Range

The homeland of coffee and the greatest diversity can be found in tropical Africa, southwestern Ethiopia, and the Boma Plateau (South Sudan). Currently, coffee is mainly found in tropical and subtropical regions of South and Central America, the Caribbean, Africa, and Asia, this accounts for more than 50 countries that are nowadays producing coffee in the intertropical belt.

2.3.2. Climatic Conditions in Cultivation Areas

The elevation range for growing regions is sea level up to 2500 meters at higher altitudes. For both species, there are more suitable altitudes and climatic conditions as each species prefers and produces better in a different environment. In general, the best conditions for *C. arabica* and *C. canephora* are high continuous air humidity, most of the annual rainfall during the period when beans are developed, and the duration of the dry season, which can affect potentially the yield of both species. The optimum average annual temperatures for the species fluctuate between 22°C and 26°C (DaMatta & Ramalho 2006). In most cases, climate-stressed plants rapidly reduce their growth and start losing leaves. Considering that the beverage quality is correlated to a larger leaf area-to-fruit ratio (Vasst et al. 2006), there will be a certain correlation between the physiological stress of the plants and the negative influence of the cup quality.

2.3.3. Growth and Development of Fruit

Most of the trees start having first fruits at about 2 years old if they are grown exposed to the sun, but plants in the shade of for example agroforestry systems can take one more year to bear the cherries. Understanding more about the quality of the final cup is also very important to the anatomy and chemistry of the fruit before harvesting.

The coffee fruit and seed are developed by cell division and differentiations which start after the flowering phase and continue until full maturity. Once pollination is done, the embryo is formed by the fusion of the male gamete with an egg cell, at the same time another male gamete fuses with the polar nuclei to form the endosperm. After this double fertilization, a transitory perisperm tissue is formed by the rapid multiplication of the integument cells. From this process, the fruit increases in the side, and the two seeds acquire their characteristic form (Borém 2014).

2.3.4. Sustainable Coffee Growing Practices versus Intensified Practices

One of the main differences between intensified and sustainable coffee growing practices is the usage of modern technology and intensive technical practices, which leads to higher production due to the higher density of the plants but also a lack of shade, therefore it can be referred to as sun coffee. To meet the higher production one of the other intensified practices is also the use of a big volume of fertilizers, herbicides, fungicides, and nematicides for rapid growth. While you can consider the system highly productive, at the same time it leads to soil erosion, and reduce biodiversity or contamination.

On the opposite side, sustainable coffee production is focusing on long-term environmental sustainability with a focus on benefits not just in the environmental spectrum, but also on the economic and social side of the coffee growers. One of the examples of more sustainable practices can be shade management or intercropping with species that are not just creating shade but can also be food crops for farmers or basically provide any additional income. Another advantage of shade-giving canopy with a combination of organic production can be the recycling of nutrients by promotion of nitrogen-fixing plants, preserving wildlife habitat and biodiversity, reducing crop damages by unexpected events such as wind, rain and creating deeper root systems, which leads to better preservation of nutrients and water.

To get a better context of these two approaches in the conclusion is important to say that sustainable coffee production requires more labour for disease control, mulching, weeding or even hand-picking, but in contrast, intensive and conventional coffee production needs higher chemical inputs. Therefore, the cost of production due to the cost of the chemical inputs does not have to be necessarily lower than in the case of sustainable coffee production.

2.4. Harvesting and Processing

For coffee growers, the harvest represents one of the most important parts of the year. Depending on the region and environmental conditions which can affect flowering and the development of the fruit, can be focused on three to four months period or even longer. Usually, when the coffee matures unevenly it leads to selective picking to obtain the maximum of the cherries and potential of the harvest.

On the other hand, the harvesting period is also one of the most difficult parts of the year for the owners of the coffee farms, as it is very labour-demanding. Therefore, very costly, and usually the pickers receive the payments immediately after delivering cherries, however in most parts of the coffee supply chain, farmers receive the payments once the coffee is in the port and prepared for shipments.

2.4.1. Different methods of harvesting

Harvesting can be separated into main three groups: mechanical, manual selective picking, and manual strip picking. What method of harvesting are farmers performed depends usually on several factors such as the location of the farm and area, where the cherries are picked, environmental conditions, part of the harvesting season, or even the available labour force in the region. Of course, some of the producing countries have a long history within harvesting of cherries and perform the same practices over centuries.

Manual selective harvesting focuses mainly on fully ripe cherries, pickers are most of the time trained to pick the best maturity depending on the variety, and quality of the season. For the collection they use different types of baskets, cherries are then transferred to plastic bags and then forwarded to the processing facilities, where they weigh and check the quality picked. The downside of manual selective harvesting is that pickers need to pick the coffee at some lots several times because the ripping does not have to be the same on every coffee plant. This method of harvesting is used mainly in specialty coffee, but also in very difficult parts of the Andes, where there is no access or investment for any mechanization in the harvesting.

Once the maturation of the cherries is more uniform and pickers do not have to selectively pick and go back several times to the same lots, this is the time when strip picking is performed. It can be done by hand but also mechanically by prolonged hands with vibrating fingers. The common practice is to place sheets of nylon or other available material under the trees to reduce any contamination and collect all the stripped cherries. Harvesting is faster and more economical, and farmers need less workforce, but at the same time, this method leads to breaking branches on the trees and different maturation stages of harvested cherries.

Mechanical harvesting is very common in flat areas, where harvesters have access. This can be also considered strip harvesting but the coffee cherries are removed by the usage of hand-held harvesters which have vibrating rods that knock the coffee off the branch. This method can also lead to a higher difference in the stages of maturity but also a higher content of foreign material such as leaves, branches, and others. Also, the land and plants need to be in the required shape to use the maximal protentional of the harvesters. On the other hand, big advantages are lower operational costs, shorter harvesting periods, more balanced flow of cherries from the field to the processing facilities, on the opposite side selective picking depends a lot on environmental conditions and when are the cherries ready to harvest.

2.4.2. Harvesting: Problems and Impact of Quality

Farmers can never obtain the same maturity stage for all cherries at one time; however, it is a crucial indicator to retain the quality in the final cup. For example, if the cherries are unripe, and green it can lead to a hard green and very sour cup profile, which can result in being very difficult to roast. On the opposite side if the pickers are picking over-ripe cherries these can bring alcoholic, unpleasant fruity notes to the final cup due to over-fermentation which occurs in the over-ripe cherries. The cherries need to be processed immediately after picking, to prevent any undesirable fermentation, as once the cherry is removed from the branches, the fermentation process is accelerated. In any critical situations, when the cherries need to be stored, is recommended to place them in the water to slow done the microbial activity and protect the raw material before any further fermentation.

Therefore, it is very important for farmers to know the quality of the harvest, to be able to distinguish which processing method can be suitable to obtain the highest possible quality in the final cup, and at the same time to act quickly during the harvesting period, especially in the warmer environment, where the microbial activity can be higher and to lead unfavourable flavour profiles.

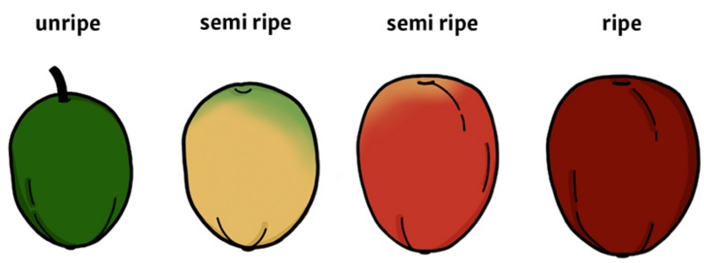

Figure 2: Maturity of the cherries (Author 2023).

2.4.3. Post-harvesting Processing: Dry Method

In very commercial coffee production, the dry method is used after non-selective harvesting as stripping or fully mechanical harvesting. In the traditional meaning, it is defined as the simplest processing method as it entails drying the entire coffee fruit intact. Commonly used in the producing origin, where the dry season is during the harvest period. As in more wet areas, it is very difficult to dry cherries without exposing them to potential problems of mould due to the high moisture of the cherries. One can also describe this method as drying all cherries immediately after the harvest without any further separation of maturation and coffee quality. In most cases before drying starts, impurities are removed and then fruits flow to the hydraulic separator, where are lots separated due to density according to different moisture levels. The environmental impact of the dry processing method is minimal, and it produces little amount of wastewater and residual liquids or solids.

Several physical changes can be observed while processing natural coffee, the initially red or yellow exocarp is becoming darker while drying the fruits. The outer dried hard layer is called the dry cherry pot. In general, natural process coffees have different sensory characteristics, than semi-dry or wet-processed coffees, as are a more intense dry and wet aroma, lower acidity, and more body.

2.4.4. Post-harvesting Processing: Semi-dry Method

The main objective and purpose of developing the semi-dry processing method were to mechanically remove the outer layer and separate the unripe from the ripe cherries. The semi-dry method is commonly called also pulped natural, or honey, depending on which origin you are and their post-harvesting processing context. For example, pulped-natural is a widely used term in Brazil, and honey for a change in Costa Rica and in other countries from Central America.

In the context of the production of pulped natural coffees, the mucilage that sticks to the seed is maintained and coffee after pulping is sent directly to the drying beds to dry. Due to the elevated moisture and high level of sugar, there is, of course, a bigger risk in terms of non-monitored fermentation which can cause problems in terms of undesirable sensory profiles. Therefore, for the first few days is very important to spread the coffee in thick layers and keep rotating and turning the coffee around to avoid sticking the coffee parchment together and secure faster drying of the left mucilage. Once it is less moist, farmers can keep coffee in higher layers.

2.4.4.1. Pulping

The main purpose of pulping is to remove and separate the pulp from the coffee bean by the friction of a pulping bar and a rotating disk or by a breastplate and rotating drum pulper. On the market, there is available equipment for pulping, which can be suitable for small or large-scale farms. Examples of commonly used pulpers are horizontal drum pulpers, vertical drum pulpers, or disk pulpers.

Pulping operation is based on the idea, that ripe fruit has lower resistance to pressure than unripe fruit. All the models of coffee pulpers on the market perform two basic operations: separation of unripe from ripe and pulping. The order of these two varies by the model (Borém, 2014).

2.4.5. Post-harvesting Processing: Wet Method

The wet method's main point is water use during post-harvesting processing. Directly after pulping coffee is placed in fermentation tanks which can be of different shapes and can be constructed from different materials such as plastic, ceramic, stainless steel, and others. In the fermentation tanks pulped coffee remains for several hours. The period can be defined by variable factors such as the working hours of the workers, the flow of cherries from harvesting, the volume of the fermentation tanks, or already tested trials with very specific sensory results. After reaching the point of the final hour of the fermentation, the rest of the mucilage is cleaned by washing the coffee, to ensure there are no leftovers of mucilage, which could support ongoing fermentation and undesirable fermentation and sensory profile of the coffee.

However, considering recent events of climatic changes and environmental conditions, washed coffees in general are being in the coffee industry in the discussion for the used water to process a kilogram of green coffee. For this, there has been more focus recently on developing more ecological wet milling facilities and different wastewater treatment facilities, which can help reuse and reduce the amount of water for processing.

2.4.6. Physiological and Chemical Aspects Due to Fermentation

The purpose of controlled fermentation is to break down the mucilage through hydrolysis, which facilitates mucilage removal in the final washing stage. The hydrolysis of pectin in the fermentation process is caused by the biochemical action of the pectinase still present in the seed. This reaction can be accelerated by different microorganisms, such as saccharomyces, which also contain pectinolytic properties. The speed of hydrolysis depends on temperature, and it is necessary to adjust fermentation time based on different ambient conditions. Some microorganisms can cause the development of undesirable flavours, especially in prolonged fermentations. For this reason, it is important to avoid the development of fungi, which can lead to the development of acidogenic species. Controlling pH is important to avoid the formation of acids, such as propanoic acid (Borém 2014).

2.4.7. Drying Methods and Impact on Quality

The harvesting of the coffee is performed when the coffee cherries have a very high moisture level between 30 % to 65%, depending on the stage of maturity of the cherries when harvested. While there are several different methods of food preservation as chilling in, a controlled atmosphere, drying remains the most used method for coffee due to several reasons as energy consumption, infrastructure, and costs.

2.4.7.1. Principles of Drying

During the drying, the reduction in moisture content is due to the movement of water from the inside to the outside of the fruit, this movement is caused mainly by the water vapor pressure difference between the product surface and product surroundings. The main factors of chosen methods and devices for drying are location, climate, budget constraints, or even desirable flavour profile.

2.4.7.2. Natural drying

The most traditionally used method of coffee drying is natural often called sun-drying. It involves spreading the cherries or pulped beans out on the patios or raised beds to dry under direct sunlight. The sun-drying is cost-effective since it relies on natural energy sources rather than expensive equipment. However, this can be also a disadvantage depending on the local environmental conditions, as with few hours of sun per day can be very long, and difficult to dry the coffee to the final moisture content. Another disadvantage of natural drying can be the opposite case when in relatively hot areas farmers need to turn their coffees very often not to exceed the temperature of 40 degrees in pulped coffee and 45 degrees in cherries.

2.4.7.3. Mechanical drying

Mechanical drying uses hot air circulation systems to remove the moisture from the beans quickly. In general, mechanical drying is often used in regions where they need to dry bigger volumes of their production faster or farmers are limited by environmental conditions, such as high humidity, and problematic rain patterns. However, sometimes it can also create problems as farmers can overheat these systems, and that affects the bean quality. One of the advantages of mechanical drying is the homogenous quality of the drying for a certain time. New innovative strategies are trying to develop more sustainable types of dryers, which can use a solar panel and dried by-products from the coffee plantation and post-harvesting processing such as dried pulped, parchment, silver skin if the farmers have dry-mills or roasteries, or even dried branches from the field after renovation of the plantations.

2.4.7.4. Hybrid Drying

Many producers employ a hybrid drying approach by initially using sun-dried techniques before completing the process with mechanical means during periods when humidity levels rise or precautions against unpredictable weather conditions. By combining these two methods, farmers can reduce the overall cost and consumption of energy.

2.4.8. Dry Milling and Preparation of Coffee for Export

Dry milling is the process of removing the dry pods, parchment, and silver skin from green coffee beans as well as sorting and grading them to prepare the coffee for export. This process is vital to secure good quality coffee and ensure quality standards of different grades.

In post-harvesting processing, we can distinguish two main categories which are wet-milling and dry-milling, depending on what is the quality of the raw material whether wet or dry we can characterize, which category it belongs. Therefore, in dry milling, we work with dried material. Key steps in dry milling are hulling, polishing, grading, sorting, density separation, defects removal, packing, and storing.

Hulling machines are used to strip off the parchment layers surrounding each bean by using friction, the same as in the pulping, but in the case of hulling this process exposes the green bean encased within a thin membrane called “silver skin”.

Polishing helps to remove residual silver skin on the hulled green beans by abrasive action inside rotating drums.

Beans are sorted according to their size using different hole diameters, larger holes allow bigger beans to pass through while retaining smaller ones above it until further sorting occurs into various grades based on industry standards and origin country.

Density separation is secure by gravity tables, which divide, and separate heavier dense beans from lighter lower-grade less heavy beans. The density is affected by different variables such as altitude or how evenly drying occurred during post-harvesting stages.

After completing all the previous steps, beans are bagged in jute bags or sisal sacks. For perceiving higher quality and preventing spoilage of green coffee, recently there has been a new trend of usage of ecotacts, grain pro, or even vacuum packaging to take out all the present oxygen to slow down the aging process and maintain the bean quality.

2.5. The Markets for Coffee

The structure of coffee traded worldwide can be separated into three main categories: mainstream quality, premium quality, and unique quality. Mainstream quality is widely available, with an acceptable good cup profile. Premium quality can be characterized as good to very interesting and remarkable quality with a limited amount on the market. Unique quality, on the other hand, is a very limited amount of unique taste experience that can be based on specific varieties, processing methods, or related experiments of post-harvesting processing.

Japan, North America, and Western Europe are trading coffee in a very similar way. Coffee is purchased in the exporting countries by traders or dealers, generally sold on free-on-board terms, but this depends on the roasters and traders or coffee growers' relationship. In this supply chain, usually, traders and dealers are the ones, who take responsibility and risk for discharging the coffee from the incoming vessel and all necessary importing arrangements.

Coffee is traded in United States Dollars for several reasons. Coffee as a global commodity is traded daily, and the currencies of many countries are loosely linked to the United States dollar, and they follow the movement of the dollar.

2.6. Trends in Consumers' Behaviour

Every day there are new extraction methods and recipes developed based on several aspects, which baristas can adjust to make the coffee less and more extracted, to meet certain quality and consumer demands. Shift from quick espresso with sugar towards filter methods and pour-overs is now more common in every country. Lately, you can even find cafes of third-wave movement in the coffee origins countries, where instead of finding different beans from all over the world, you can test different varieties from specific regions. Consumers want to know the taste profiles of the coffees, processing methods, the name of the farmer, and varieties.

2.6.1. Coffee Brewing Methods

The preparation of a cup of coffee can be divided into six different methods, based on the type of extraction and the material used to separate coffee after extraction. The main methods are boiled coffee (Turkish coffee), pour-over (filtered coffee), French press, Espresso, Moka pot, and Cold brew.

Turkish coffee is prepared by boiling the coffee in water, traditionally by use of hot sand and several spicy. Coffee is ground on a very fine setting, then added to the traditional device called a cezve, along with water, sugar, or spices. Everything all together is boiled and then served.

Preparation of filter coffee has a regularly coarser setting than for espresso or Turkish coffee. Water is then allowed to pass through the coffee and then separated by a metal or paper filter. On the market are various filters available of different shapes, and sizes and from different materials, this allows baristas to control and change the degree of filtration and extraction.

French press coffee grounds are even coarser than the filter preparation. Hot water is mixed with grounded particles and remains for a certain amount of time, then the metal filter is pressed down, and the coffee is separated. This method can be also called immersion brew, as during the extraction coffee is fully immersed in water. An alternative immersion brew is called Aero Press, which starts as an immersion brew. At the end, pressure is added by a piston to extract more from the coffee bed, and the final brew is filtered through paper giving it elements of both immersion and drip filter methods (Folmer 2017).

Espresso has its tradition in Italy, where there are very precise parameters for making it. Classic Italian espresso has parameters as follows: 7g of finely grounded coffee, temperature of water 94 °C, and a pressure of 9 bar to obtain the final size of espresso roughly about 25 ml. However, with the third wave coffee movement coffee shops are preparing and dialing the coffee according to the specific taste profiles to highlight the best attributes of origin, processing methods, or simply the characteristics of varieties, which are grown in certain origins.

Moka-pot could be considered one of the most famous brewing methods kept at home in Italy, this unique device with a three-chambered design is also dependent on the pressure which is as steam pressed thought the chamber with coffee, and then in final chamber coffee is separated. Of course, the pressure is not as high as in the espresso machines, but thanks to the filter, and very fine grinding setting, coffee is characterized with heavy body and longer aftertaste as in espresso.

One of the last methods, which is becoming recently very popular especially in the warm days is cold brew. Method based on the extraction of coffee by using cold or room temperature water. There are many techniques and recipes how to set and prepare nice and extracted cold brews, usually by use of longer time period as we are missing the force of heat.

Key factors affecting coffee brewing quality are grinding setting and device, quality, and chemical composition of water, age of the coffee since roasting, brewing equipment, and pressure, filters, and others.

2.6.2. Storing, Roasting, and Packing Coffee

Coffee as a commodity is very complex, from the chemical perspective as well as for being ready for consumption it needs to go through several processes before being ready for consumption.

Storing coffee is as crucial as any previous steps because the moisture level of dried coffee is still about 11% in the ideal situation, this means that the quality of coffee can be still compromised by several factors as the relative humidity of ambient air, temperature, amount of light and type of storage. The recommended general guidelines for storing dried coffee or green beans are the following: 60% of the relative humidity and a temperature below 20°degrees Celsius. Of course, is also very important to store the coffee in a darker environment and without the access of animals and pests to the area, where the coffee is stored to eliminate any contamination (Selmar et al. 2008).

The roasting process can be divided into three main stages, which follow a distinctive pattern. Understanding those patterns can help roasters to master the quality and process of roasting. The initial stage of the roasting process is drying, where green beans lose water and moisture content through the heat of the roaster, the stage can be differentiated from other stages by the temperature of 150°C when most of the water is eliminated from the beans. The drying stage is followed by the first initial roasting stage where most of the types of sugars present in the coffee beans will undergo thermal degradation. Basically, the faster the temperature rises the higher the caramelization temperature is. At this stage, beans are getting darker, from initial slight green colour. The final stage of colouring continues as the temperature increases (Baggenstoss et al. 2008). An important part of this stage is also the so-called first crack, which is marking the expansion of the bean through the various gases, water, and other organic volatile elements. The first crack usually helps to the roasters distinguish a few indicators of their roast in the roasting profiles such as development after the first crack (Yeretzina et al. 2002).

On the market, there are several types of roasters that have different setups and can allow roasters to create unique roasting profiles. The most common ones are drum roasters or fluid bed roasters. Of course, in the more conventional and industrial roaster the process is fully automized and pre-set to make more uniform quality and roasting.

Packing materials and options to preserve the quality of roasted coffee developed over the years and shifted from cardboard bags to air packing, vacuum packing, inter-gas packing, and pressurization. The most common use is air packing, which easily protects the coffee from humidity, external light, and off-flavours from the environment. However, air packing means you simply hermetically seal the bag, therefore the oxygen present inside of the sealed bag can lead to a shortening of the shelf-life of the coffee. Vacuum packing does not allow a high level of oxygen to enter the packing, is more costly, and discussed issue is an expansion of the oxygen once the bag is open and the chemical reaction of the coffee after opening. The inert gas packing principle is based on replacing of oxygen by different gases which can be used for the function of perceiving specific shelf-life of coffee.

2.6.3. Sustainability and Certifications in Coffee Industry

In the coffee industry, a very frequent topic of discussion is the sustainability of coffee production and consumption. The core definition of the coffee industry can be meeting the needs of the current generation without compromising the future generation's needs. This tackle environmental, economic but also social factors of coffee production. Sustainability itself does not need the guarantee of any certification and verification of any set indicators. Very often the coffee growers are already using good agricultural and management practices. Nevertheless, consumers generally wish to be able to place a certain trust in claims such as environmentally friendly or socially responsible products.

Certification through a specific certificate secure that coffee growers are meeting standards, rules, and regulations toward environmental, social, or economic requirements. Roasters on the other side of the spectrum, are sourcing certified coffee beans and benefiting from the certificate and can use the logo and related information for their retail.

The most common certifications in the coffee industry are UTZ Certification, Fairtrade, and Rainforest Alliance. Each of these labels focuses on a different angle of sustainability. The Fairtrade initiative aims to enable organizations of smallholder producers of coffee and other commodities, to improve their conditions of trade to receive more stable and equitable prices. Important to mention that Fairtrade does not operate with the traditional marketing cycle and works on the basis that there is a place for each, provided all accept the Fairtrade goal of selling the largest possible volume of smallholder coffee at a fair price: fair for growers and consumers alike (The Coffee Export Guide 2021).

Rainforest Alliance and UTZ joined forces in 2018 together, mainly because of similarities in the scope of certifications and areas of operations. Both focus on sustainable farming practices while meeting the quality of the production and conservation of nature and the environment.

2.7. Sensory Analysis of Roasted Coffee

In the coffee, industry quality plays a very important and significant role, which also helps coffee growers, traders, and roasters decide about the potential of the coffee, how they should market it, or whenever the coffee is valued enough, not because of the niche product, but how people respected the roasted beans and the quality itself. But every coffee has a home and market, and to find the market and sell the coffee is important to be able to analyse the quality.

2.7.1. Quality Control of Coffee: Cupping

Cupping is a standardized method of evaluating coffee. Professional cuppers are trained panelists with years of experience in coffee and tasting. However, their ability and capacity for evaluation and tasting are also depending on their genetics, life experiences, and health. Coffee cupping stands for the complex olfactory and gustatory evaluation of different qualities of coffee such as fragrance, aroma, body, acidity, flavour, aftertaste, balance, sweetness, uniformity, overall, and balance.

The difference between professional cuppers is their objectivity while tasting coffee, they have their routines where key elements as the same sample roaster, resting of the coffee for the same period, and similar cupping protocols, which they try to fill up methodically to avoid nonuniformity in their results.

Several coffee organizations developed very systematic cupping protocols, with clear guidelines, standard methods, and rules. One of the most used ones is developed by the Speciality Coffee Association or by Cup of Excellence.

3. Aims of the Thesis

This thesis aims to investigate the post-harvesting processing of coffee, mainly focused on the fermentation and sensory properties.

3.1. Specific Objectives

Specific objectives were to analyse the pH values and temperature of the fermentation of two different processing methods and evaluate their impact on sensory performance, which can finally give a better understanding of value potential for farmers.

4. Methods and material

4.1. Study Area

This study was conducted at Finca Maputo in La Perla, Nanegal, region Pichincha, Ecuador, more specifically on Hakuna Matata, where the processing facility is located. Finca Maputo contains four different farms: Rancho Tio Emilio, Hakuna Matata, Maputo 1, and Maputo 2. On the farms, you can find several different varieties: Sidra, Typica, Caturra, SL28, Bourbon, Kaffa and several more hybrids, which were shared by a local experimental coffee lab from Nestlé, which runs their operations focused mainly on genetics there. The harvesting was done at the same location. The altitude of the area is relatively low, between 1250-1350 meters. The main harvest is from May to August, but lately, due to the different climate patterns, it changed a lot.

Figure 3: Location of the study area (Author 2023)

4.2. Sampling and sample processing

4.2.1. Harvest and pulping

Coffee cherries of a variety of Typica were picked on the 29th of June 2022 from 8 am until 3 pm, the picking was done by a group of trained pickers who had worked with Finca Maputo for several years now, and at the same time the quality was controlled by a full-time employee José Bravo. The uniformity and ripeness of cherries were checked upon receiving the cherries at the processing facility at Hakuna Matata after 3 pm. The pickers handed over the cherries for visual inspection, if there was any quality issue, cherries were placed on the drying beds, and sorted, the semi-ripe or unripe cherries were processed separately with floaters and carried on the drying beds and dried separately from the first class.

After controlling the quality of the cherries, coffee was weighed on an industrial scale (Jontex), to track the volume each picker delivered. Then cherries were placed in a plastic tank with clean fresh water, which separates impurities and floaters from good-density cherries, this is crucial for quality-driven processing facilities and farms, as floaters are cherries which are having different densities and maturity, which is linked to the final quality of the product.

High-density cherries were separated from the water and were pulped by the horizontal pulper (ECOLINE, EL 800, Penagos, CO). This model also had an integrated screening module, which helped to sort any non-pulped, semi-pulped coffee, to secure the flow of cherries through the pulper, it is needed to insert water to reduce the risk of damaging the beans and pulped coffee parchment. The pulping process took about 45 minutes up to 1 hour depending on the volume, which was harvested that day also as they needed to feed the pulper with a smaller volume of cherries to secure equally removed mucilage from the coffee beans.

4.2.2. Fermentation

All experiment samples were conducted from one cherry delivery on the 29th of June 2022. Three repetitions were performed for lavado processing and honey processing of coffee beans. In Table 1 and Table 2, individual amounts of samples for every repetition are presented. Coffee was pulped (removing the mucilage) after floating the cherries and then weighed.

Table 1: Indication of the weight of lavado processing methods samples

Processing method: Lavado Samples ID:	**Weight (kg)**
Lavado 1	5.46
Lavado 2	5.33
Lavado 3	5.40

Table 2: Indication of the weight of samples of the honey processing method

Processing method: Honey Samples ID:	**Weight (kg)**
Honey 1	40
Honey 2	40.20
Honey 3	40.30

For the lavado processing method, samples were placed in plastic fermentation tanks of size 20l and afterward, the water was added to the top of the tank. For the honey processing method, pulped coffee was placed directly after pulping in a fermentation tank of 80l without any additional water.

During the fermentation of both processing methods, the following conditions were monitored in total 19 times: relative air humidity and ambient temperature (instrumentation see Table 3). Within the fermentation tank, Brix levels, pH levels, and temperatures (instrumentation see in Table 3) were monitored in 3 different positions of the tanks: upper level (pH1, t1), middle level (pH1, t2), and bottom level (pH3, t3). Brix levels were monitored in one position for every tank. Each of these measurements was taken 3 times for accuracy and preciseness. The fermentation of honey samples was monitored for 24 hours and the fermentation of lavado samples was monitored for 64 hours. Measurements were taken for the honey processing method 12 times during the 24 hours of fermentation from each position in the tank (up, middle, down). For the lavado were taken 19 measurements during 64 hours of fermentation from each position in the tank (up, middle, down).

Table 3: List of equipment used during monitoring and measuring of the experiments.

Equipment	Manufacturer and model	Units
Industrial scale	Jontex, up to 300kg, Ecuador	Kilograms (Kg)
Ph meter	GIB Industries, PH PRO, Germany	-
Temperature meters	Combisteel, COM-7521.0020, Netherlands	Celsius (°C)
Digital refractometer for sugar analysis	Milwaukee, MA871, Romania	Degree brix (°Bx)
Hygrometer	Garden Highpro, HYGROTHERMO PRO, Spain	Percentage (%) Celsius (°C)

Figure 4: Measurement of pH levels taken from honey samples (Author 2022).

4.2.3. Drying, Storage, and Roasting

After the fermentation, all samples were dried in the drying room located at farm Maputo 1 on raised drying beds. Honey samples were placed on the beds on the 30th of June after washing, and then dried for 16 days with the frequent turning of the parchment and monitoring of the moisture level by the moisture meter (miniGAC, DICKEY-john, US). The same was done for lavado samples, however, they were placed on the drying beds on the 2nd of July and dried for 13 days in total.

Once the parchment was dried for 11% moisture, samples were placed separately in GrainPro hermetic plastic bags (GrainPro, US) in parchment for storage and homogenization for 2 months and then milled to achieve green beans and kept in clean hermetic plastic bags and ready for export.

All samples were dispatched from Ecuador on the 4th of January 2023 by FedEx. The weight of each sample was 350g of green beans.

The samples were roasted on the 2nd of February 24 hours before cupping on the roasting machine (ROEST L100, Roest, NO). Each roast was done from 100g of green coffee with a time length between 8 to 8:27 minutes, and the outcomes of the roasted samples were between 86 to 89g of roasted samples, the difference can be based on slight differences in density, water activity, and moisture connected within the quality of the green coffee, as well as the roasting profile and usage of the gas, airflow during the roasting.

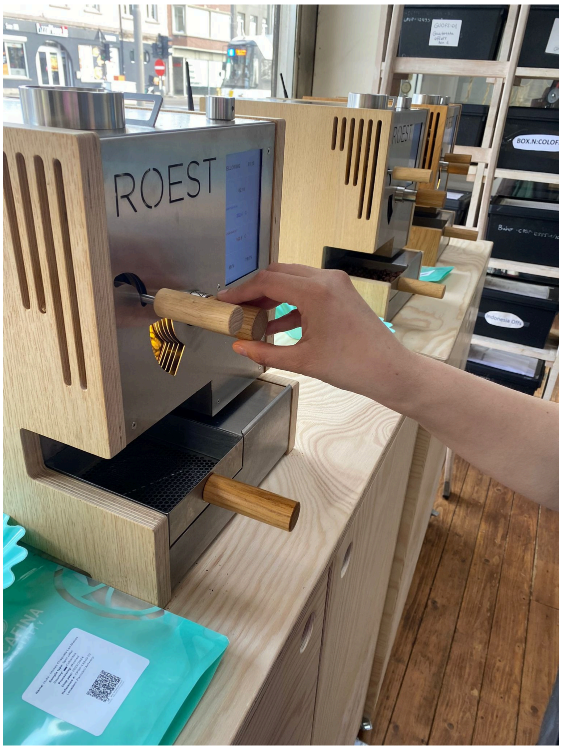

Figure 5: Roasting samples on Roest sample roaster (Author 2024)

4.2.4. Sensory Analyses

Sensory analyses were done in the quality control lab of Sucafina Specialty in Antwerp, Belgium on the 3rd of February 2023. During the cupping session, 3 skilled cuppers with more than 8 years of experience in coffee quality control participated. Two of them are also holders of Q Grader certifications, which are for specialized professionals in the sensory evaluation of green coffee developed by the Coffee Quality Institute (CQI 2020).

All samples were coded by 3-digit codes to keep the cupping session objective as much as possible. Coffee was weighed in cupping glasses of volume 220ml (scale Brewista Smart Scale V2, Brewista, US) and ground by a grinder (EK43, Mählkonig, DE). Each final roasted sample from the lavado processing method for repetition Lavado 1, Lavado 2, Lavado 3 and from honey processing method Honey 1, Honey 2, and Honey 3 was represented by 5 cups per individual sample, and the final score was based on these 5 cups tested by 3 cuppers. Thus, each sample was tested 15 times, and each processing method was represented by 15 cups.

Cupping was conducted based on SCA cupping standards and protocols (, which are as follows: optimum ratio 8.25g of coffee per 150 g; water used for poring is clean, without any odours, and with ideal temperature: 93 ºC (SCA 2003).

The cupping form developed by the Specialty Coffee Association (SCA) was used for evaluations of the following attributes and parameters: roast level of the sample, fragrance/aroma, flavour, aftertaste, acidity, body, uniformity, balance, clean cup, sweetness, overall, and scoring for any defects.

4.3. Data Analysis

For the monitoring of the measurements on the farm level within the experiment setting Google Sheets were used. The spreadsheet application was developed by Google and helped to monitor all the samples on separate sheets and to keep the data complete. Afterwards, for cleaning and arranging of the collected data we used Microsoft Excel Office 365. Finally, IBM SPSS Statistics software version 23.0 (IBM, US) was used for data management and advanced analytics.

First, the collected data for its normal distribution by the Shapiro-Wilk test were tested. Due to most of the variables being non-normally distributed (except values of pH, p-value < 0.05) -non- parametric tests for the statistical analyses were used.

Spearman´s rank correlation coefficient was used to test the correlation between pH and temperature, first for honey and lavado samples separately. Mann-Whitney U test was used to test the differences between the pH and temperature of both samples.

All the sensory attributes were tested by the Kruskal-Wallis test for all the honey and lavado samples separately. The comparison of honey and lavado samples was done by the Mann-Whitney test.

5. Results and discussion

5.1. Fermentation performance

As for the relative humidity during the fermentation period, it is displayed in Fig 6, where is indicated that the measurements varied from 78-99%.

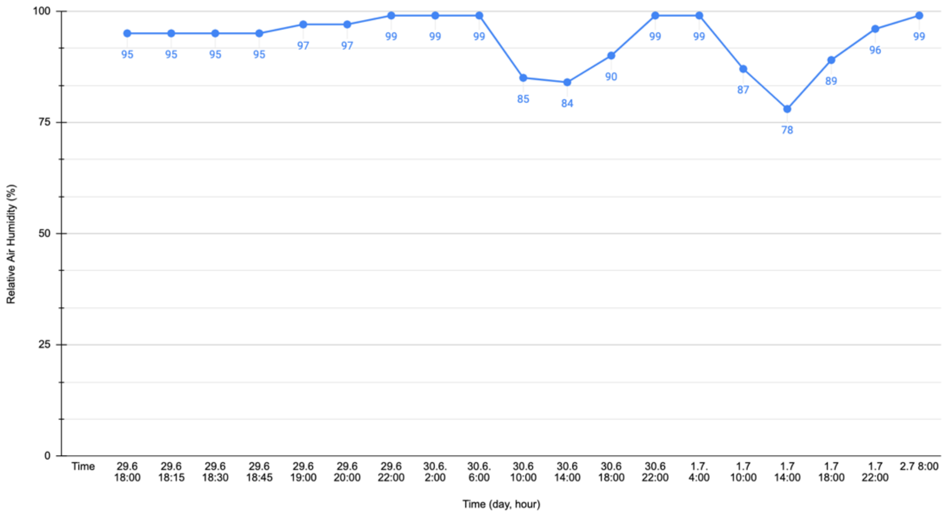

Figure 6: Relative air humidity in the study area during fermentation

During the fermentation time of all treatments, the average ambient temperature varied from 16.8°C up to 23.4°C as can be seen in Figure 7.

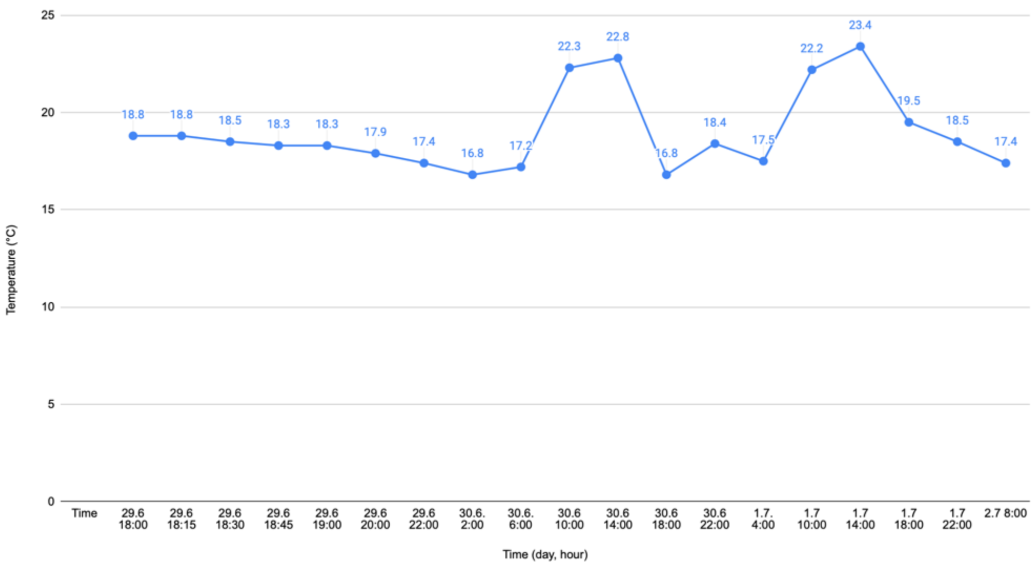

Figure 7: Ambient temperature measured during the fermentation

The values for Brix levels during the fermentation time are seen in Figure 8a for honey samples and in Figure 8b for lavado samples. All treatments exhibited a decreasing trend from the initial average value of 16.7°Bx, this finding is in line with the study of Rocha et al. (2024), who monitored natural coffee and pulped coffee and its fermentation for over 72 hours.

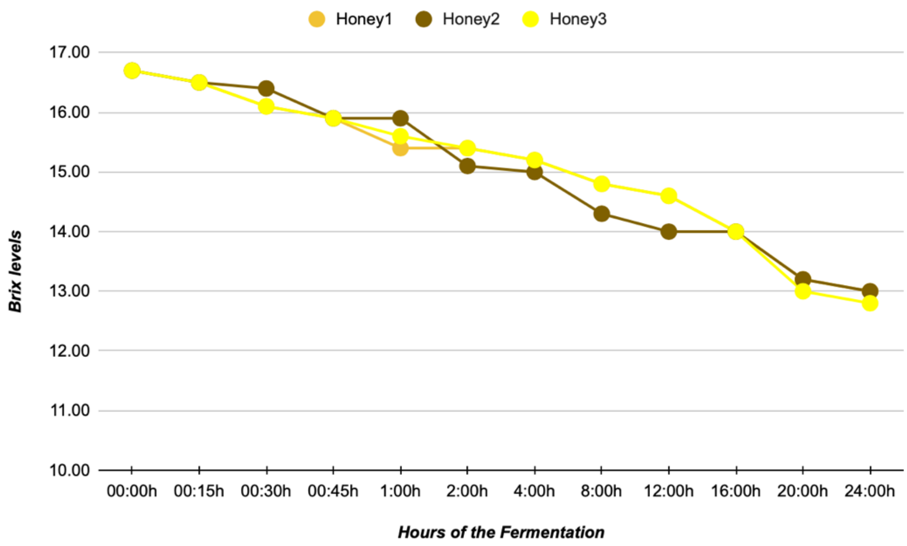

Figure 8a: Brix levels of the honey samples during fermentation time

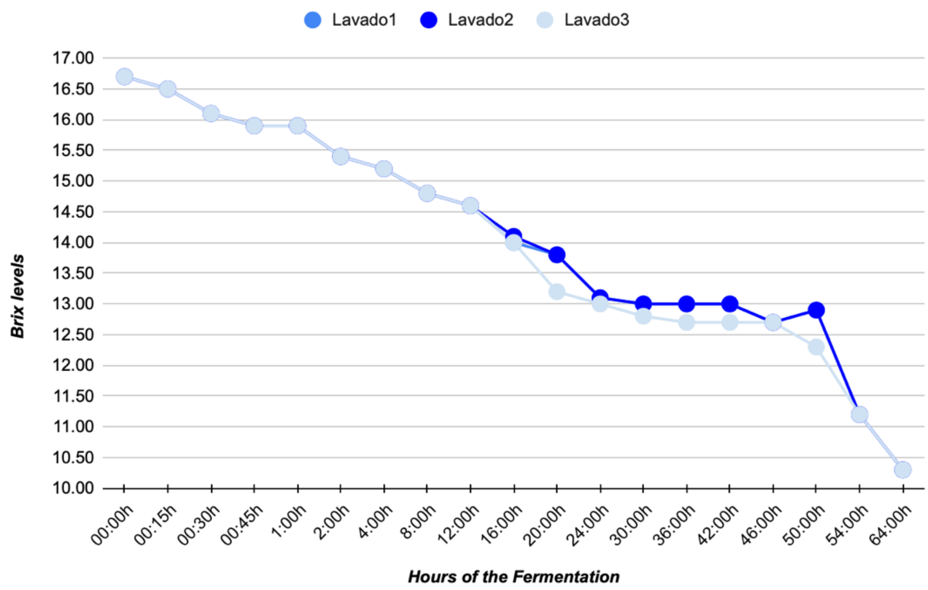

Figure 8b: Brix levels of lavado samples during fermentation time

All repetitions of processing Honey and Lavado in all positions (up, middle, bottom) exhibited a decreasing trend of pH values during the time of the fermentation (see Figure 9a and Table 9b). This finding is supported by the fact that most of the yeast species exhibited after 24 hours when the water is reduced, and the pH decreases because of acid production by the bacteria population Vilela et. al (2022).

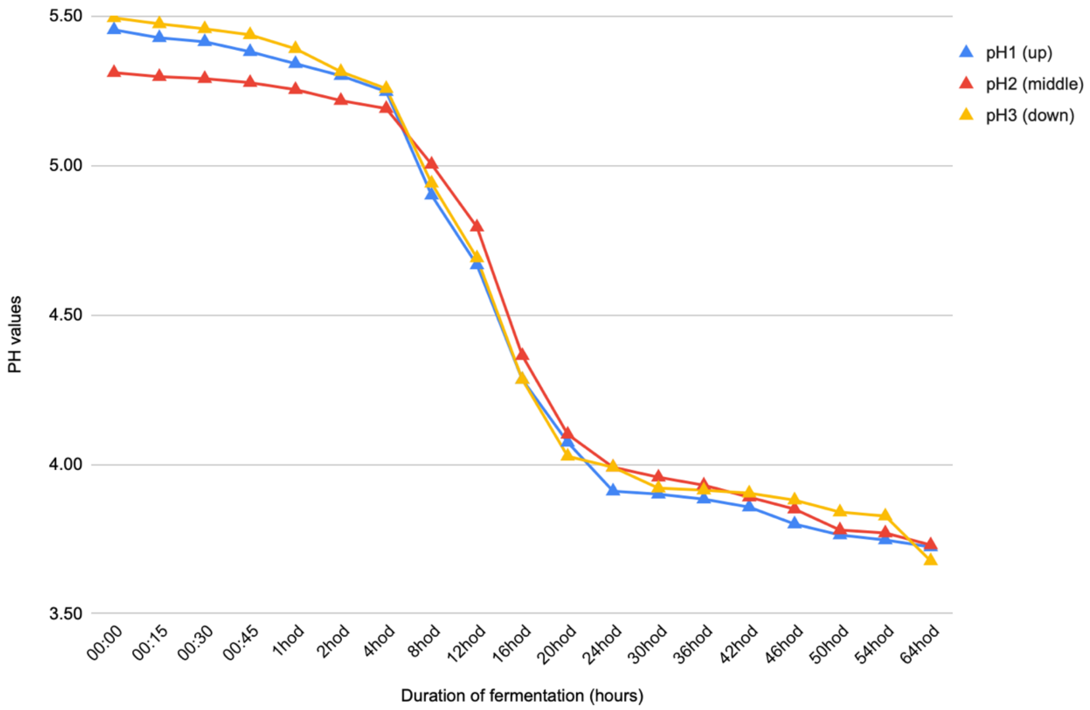

Figure 9a: Means of measurement of pH values for pH1, pH2, and pH3 for lavado samples (Author 2024)

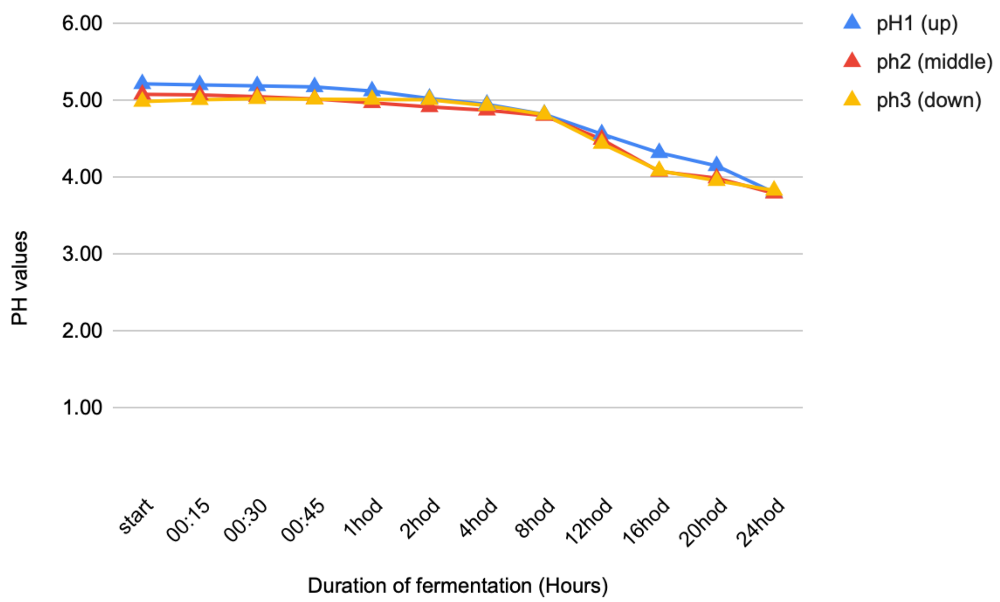

Figure 9b: Means of measurement of pH values for pH1, pH2, and pH3 for honey samples (Author 2024)

Results of monitoring temperature during the fermentation process of Honey and Lavado in all positions (up, middle, bottom) see in the Figure 10 and Figure 11.

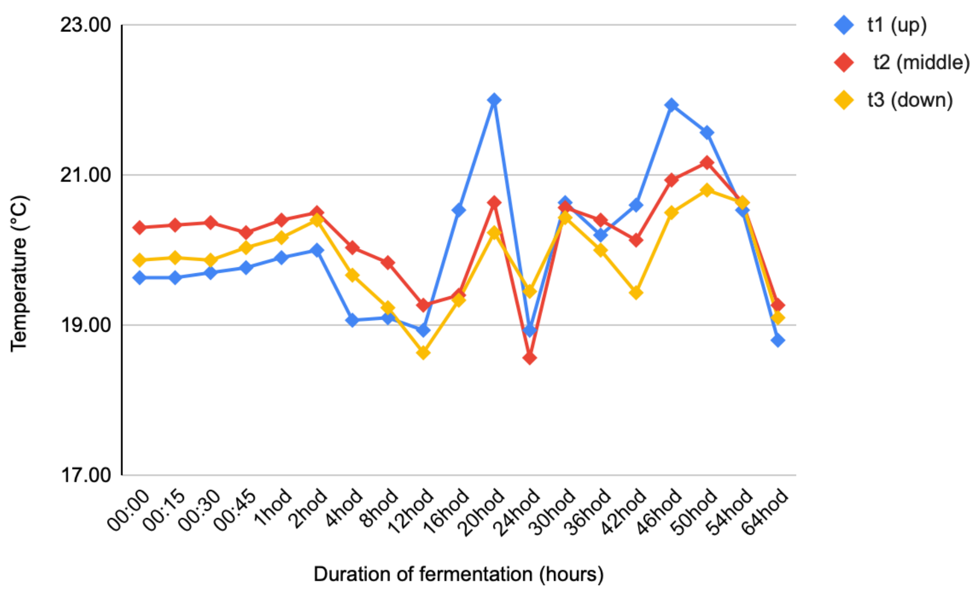

Figure 10: Measurements of temperature value for t1, t2, and t3 lavado samples (Author 2024)

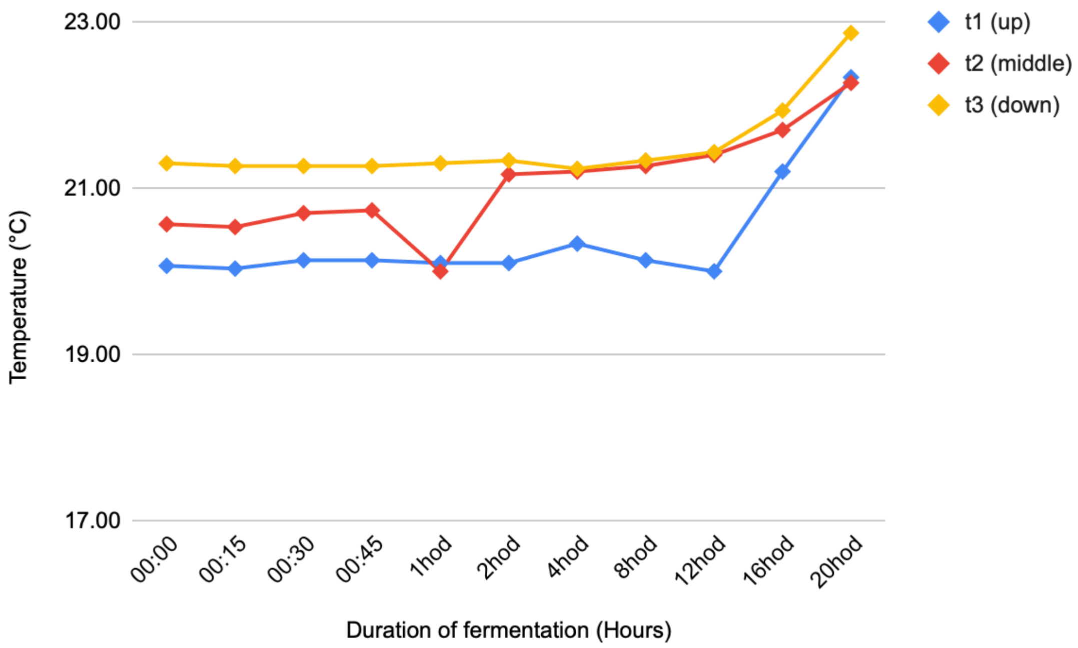

Figure 11:Measurements of temperature value for t1, t2, and t3 for honey samples (Author 2024)

Temperatures of Honey t2 ($p < 0.001$) and t3 ($p < 0.001$) are significantly higher than in Lavado samples (according to the Mann-Whitney test). However, the mean value of t1 is non-significant.

Comparison of all pH locations from a statistical point was non-significant. However, the mean values of Honey samples are much higher than those of lavado samples ($p > 0.05$, according to the Mann-Whitney test).

There is a strong correlation (Table4a) between pH1, pH2, and pH3 in Honey samples ($p > 0.05$, according to Spearman's rank correlation coefficient. Temperature t1, t2 and t3 correlate non-significantly.

Table 4a: Spearman's rank correlation coefficient for the honey processing method

				Honey			
		pH1 (up)	pH2 (middle)	pH3 (down)	t1 (up)	t2 (middle)	t3 (down)
pH1 (up)	Correlation Coefficient	1.000	1.000**	.832**	-0.487	-0.466	-0.410
	p-value			0.001	0.108	0.127	0.186
pH2 (middle)	Correlation Coefficient	1.000**	1.000	.832**	-0.487	-0.466	-0.410
	p-value			0.001	0.108	0.127	0.186

pH3 (down)	Correlation Coefficient	.832**	.832**	1.000	-0.312	-0.543	-0.378
	p-value	0.001	0.001		0.324	0.068	0.225
t1 (up)	Correlation Coefficient	-0.487	-0.487	-0.312	1.000	.828**	.795**
	p-value	0.108	0.108	0.324		0.001	0.002
t2 (middle)	Correlation Coefficient	-0.466	-0.466	-0.543	.828**	1.000	.796**
	p-value	0.127	0.127	0.068	0.001		0.002
t3 (down)	Correlation Coefficient	-0.410	-0.410	-0.378	.795**	.796**	1.000
	p-value	0.186	0.186	0.225	0.002	0.002	

There is a strong correlation (Table 4b) between pH1, pH2, and pH3 in Lavado samples ($p > 0.05$, according to Spearman's rank correlation coefficient. T1, t2, and t3 correlate non-significantly. All locations data points +1, which indicates a perfect association, these samples were conducted with water, which homogenized the mass of pulped coffee.

Table 4b: Spearman's rank correlation coefficient for the lavado processing method

				Lavado			
		pH1 (up)	pH2 (middle)	pH3 (down)	t1 (up)	t2 (middle)	t3 (down)
pH1 (up)	Correlation Coefficient	1.000	1.000**	1.000**	-0.404	-0.117	-0.182
	p-value				0.087	0.634	0.455
pH2 (middle)	Correlation Coefficient	1.000**	1.000	1.000**	-0.404	-0.117	-0.182
	p-value				0.087	0.634	0.455
pH3 (down)	Correlation Coefficient	1.000**	1.000**	1.000	-0.404	-0.117	-0.182
	p-value				0.087	0.634	0.455
t1(up)	Correlation Coefficient	-0.404	-0.404	-0.404	1.000	.792**	.782**
	p-value	0.087	0.087	0.087		0.000	0.000
t2 (middle)	Correlation Coefficient	-0.117	-0.117	-0.117	.792**	1.000	.950**
	p-value	0.634	0.634	0.634	0.000		0.000
t3 (down)	Correlation Coefficient	-0.182	-0.182	-0.182	.782**	.950**	1.000
	p-value	0.455	0.455	0.455	0.000	0.000	

5.2. Sensory analysis

The results of the sensory panel are shown in Table 5. No significant differences were observed in the sensory evaluation of the following attributes: aroma, flavour, aftertaste, acidity, balance, cleanliness, sweetness, and uniformity, overall ($p > 0.05$, according to the Mann-Whitney test). However, statistically significant differences were obtained in the attributes body ($p < 0.027$) and final score ($p < 0.001$) with the mean value of 86.5 SCA points for Honey and 85.91 points for Lavado. These findings regarding statistical differences in the sensory performance of honey and lavado processing methods support evidence from Pereira et al. (2020) about their experiment above 1033 meters in Colombia with submerged fermentation (underwater) and they were able to receive a final score of 85.33 points.

Table 5: Results of sensory evaluation Honey and Lavado samples by Mann-Whitney test

Processing methods	*Honey*		*Lavado*		*Mann-Whitney test*
Attributes	***Mean***	***SD***	***Mean***	***SD***	
Aroma	8.08	0.121	8.03	0.088	0.573
Flavour	8.10	0.129	8.00	0.000	0.173
Aftertaste	7.95	0.158	7.84	0.129	0.203
Acidity	8.10	0.175	8.06	0.116	0.573
Body	8.18	0.121	8.00	0.134	**0.027***
Balance	8.00	0.000	7.94	0.177	0.408
Cleanliness	10.00	0.000	10.00	0.000	1
Sweetness	10.00	0.000	10.00	0.000	1
Uniformity	10.00	0.000	10.00	0.000	1
Overall	8.10	0.129	8.06	0.116	0.633
Final score	86.50	0.264	85.91	0.326	**0.001***

The type of fermentation and processing method, which is used in coffee post-harvesting processes is influenced by the availability of oxygen, the natural microbiota present, and the metabolites produced, and so is the sensory performance of the final product, in addition to the type of fermentation, the variation in the other process conditions, such as the use of natural or pulped fruit, altitude, coffee variety, starter culture strain, environmental conditions (Pereira et al. 2022), all these variables can be influencing the processing method.

6. Conclusions

This thesis helped analyse variables of coffee fermentation such as pH and temperature in 3 different locations of the fermentation tank in two different processing methods: honey and lavado. In both processing methods, all pH measurements in all locations significantly correlated with each other, in the lavado the correlation coefficient was for all locations data points +1, which indicates a perfect association, these samples were conducted with water, which homogenized the mass of pulped coffee.

At the same time, the findings have contributed to the understanding of the influences of two different processing methods lavado and honey on sensory performance and cup quality based on the SCA cupping protocol and scoring system.

Samples of both methods cupped clean, and treatments of honey had received 86.50 SCA points in the final score with a 0.58 difference in comparison with the lavado samples. From sensory attributes, the attribute body was statically significant along the final score.

The main limitation of the research was the environmental conditions, mainly the relative humidity was very high, therefore it was not possible to focus on specific processing methods with raw cherries to avoid any undesirable cup profiles and defects. The processing facility at Hakuna Matata was a limitation due to the volume of cherries, that can be processed and the space for the experiments.

As a recommendation for the following experiments, it is suggested to monitor the fermentation in the controlled environment with more externally connected measuring devices to obtain constant data points; focus on the analyses of the local microbiome, to understand better microorganisms present and dominant during the fermentation. In the future, this can give more understanding of how to influence fermentation tanks to obtain specific microorganisms present and therefore potential specific cup profiles. And to focus more on analysing green coffee and its chemical composition to link the chemical composition to sensory performance.

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Appendices: