Implementation of Accelerated Cold Brew into Fully Automatic Espresso Machines

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Dedication

This thesis is dedicated to my parents.

For their endless love, support, and encouragement.

Acknowledgments

Foremost, I would like to express my sincere gratitude to my supervisor Prof. Lucia Rosa Elena Rampino for the continuous support of my research, for her patience, motivation, enthusiasm, and immense knowledge that encouraged me to do this research.

Besides my supervisor, I would like to express my deepest appreciation to my Philips colleague Nicola Puliafico for his guidance. Without his persistent help and great opportunity offer in Philips, this dissertation would not have been possible. This work would not be materialized without support of Philips. I would like to thank all other Philips colleagues for their kind support, technical information, and permission to use their laboratories in experiments.

Abstract

Cold brewing made by traditional methods takes an extended period of time. Although the popularity of cold brewing has increased, home consumption has not become widespread due to the long-brewing time and the equipment requirements. Research has shown that the brewing time can be reduced with a variety of effects. This study aims to reduce the brewing time by investigating coffee extraction with using a fully automatic espresso machine which contributes to cold brewing at home. Based on a review of the literature an online survey was distributed to coffee consumers and fully automatic machine owners, coffee consumers were interviewed, an experiment performed with fully automatic espresso machine and results were tested according to sensory attributes. Analysis of the experiments demonstrated that cold brewing time was reduced to 3 minutes with new brewing parameters of fully automatic espresso machines and the sensory test showed the perceived sensory difference between traditional cold brew and accelerated cold brew is small. The research indicates that cold brew time can be reduced by changing the extraction parameters of a fully automatic espresso machine while keeping the temperature at ambient. Further research is needed for understanding the chemical difference between resulting coffees with compound-specific analysis and investigating consumer acceptability with a quantitative sensory evaluation with consumers.

Keywords: coffee extraction, accelerated cold brew, espresso machines

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Introduction

Cold brew? From many hours to few minutes?

I have done 6 months of internship at Philips Innovations SpA in Italy which manufactures automatic espresso machines. During the period, I worked on cold brew subject for my thesis which became popular recently and many companies try to offer cold coffee feature with their product.

Figure 1. Philips and Saeco logo.

Cold brew is one of the brewing methods of coffee which is made most typically at room temperature or at 8 °C while producing a different chemical profile from conventional brewing methods which results less acidic and sweeter in cup than hot brewing (Kwok et al., 2020; Angeloni et al., 2018). It is a growing trend especially among millennials and people's interest in drinking cold beverages and cold brew coffee is increasing (Grant, 2020).

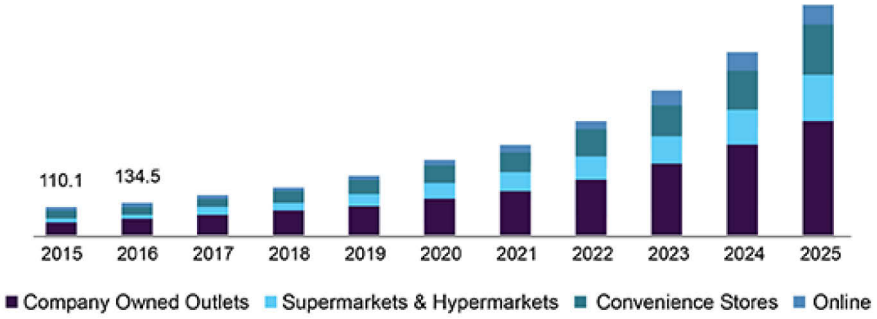

Figure 2. U.S. Cold Brew market size and future estimation.

USD Million, Grand view research

Historical data: 2015 – 2017, Base year for estimate: 2018, Published date: Jun 2019

Cold brew coffee is available as ready-to-drink in coffee chains or supermarkets, although the preparation time at home with traditional methods takes 2-12 hours in room temperature which is considered essential (Schwarz et al., 2020; Heffernan, 2019). There are products in the market trying to reduce the brewing time by using different technologies such as spinning, vibrating, vacuuming; no one has focused specially producing cold brew coffee with fully automatic espresso machines in a short time.

Are traditional cold brewing results achievable with an automatic espresso machine at short notice, if so, how sensory difference will be perceived by coffee experts? To answer the research question, the main objectives of the thesis defined as collecting data from traditional cold brewing methods to cognize the target, defining, and estimating brewing parameters of the fully automatic espresso machine to get target values, changing brewing parameters, and running the design of the experiment to define optimized response. At the end, performing sensory test to clarify the sensory difference between fully automatic espresso machine cold brew and traditional cold brew.

Figure 3. Philips fully automatic espresso machine.

Philips, 3200 Series EP3221/44

Two different traditional cold brewing methods are used during the research which are full immersion and cold dripping methods. Dripster 2 in 1 product is used for traditional cold brewing which offers both methods. Philips 3200 Series EP3221/44 fully automatic espresso machine is used in the experiments of Philips cold brew.

Extraction of the coffee is one of the most important parameters in coffee brewing which refers to extracting desirable compounds from coffee. It depends on many parameters such as coffee type, grinding, dosage, water, turbulence, brewing time, and brewing temperature (Kwok et al., 2020).

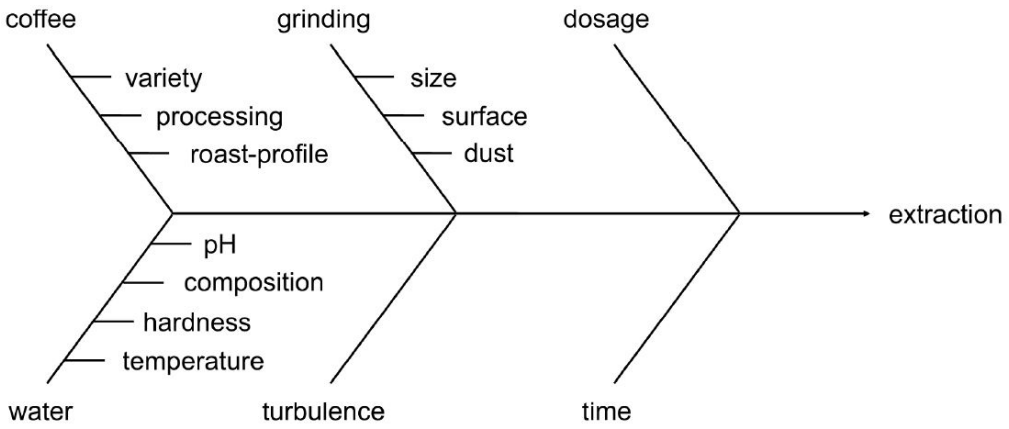

Figure 4. Casual influences regarding cold brew coffee extraction.

Kwok et al., 2020

Extraction is the percentage of coffee grounds dissolved during brewing to total coffee grounds and has significant role on the aroma of the coffee. To keep the coffee aroma consistent, extraction parameters should be well-balanced to avoid underdeveloped or over extracted coffee. Water temperature affects the extraction directly proportional, for example recommended brewing water temperature for espresso is 93 ± 3 °C (SCAA, 2015). Cold brewing, as the name suggests, does not use hot water in the process, and it is one of the main reasons cause longer brewing time. In the research, experiments are made by changing extraction parameters to provide the consistent extraction with low brewing temperatures in a short time with fully automatic espresso machine. Cold brew

coffee obtained by traditional methods is compared with the cold brew coffee obtained by Philips from the point of sensory.

The goal of this chapter is to introduce the topic and give the reader information about context and aim of the study. Chapter 1 will start by briefly introducing the basics of coffee which contains information about coffee culture containing history and three waves of coffee. In Chapter 2, coffee market and demand for coffee are explained and especially focused on cold coffee. Afterward, in Chapter 3 coffee types and differences are explained in three categories which are black coffee, milk-based coffee, and cold coffee. Chapter 4 provides information about how coffee comes from seed to cup which starts with planting and ending up with brewed coffee in our cup. In Chapter 5, different kinds of brewing methods and their tools are explained by emphasizing differentiation between hot and cold brewing. It is explained how brewing occurs, what are the techniques, and what should be considered during brewing the coffee. Afterward, in Chapter 6, information is provided about coffee machines which include espresso machines. Fully automatic espresso machines are introduced with working principles, how are they named by their automation. Properties of coffee such as strength and extraction yield are explained in Chapter 7 by providing information about their importance in coffee brewing by scoping their standardization and effect on the aroma. Finally, in Chapter 8, existing accelerated cold brew coffee machines are introduced while explaining the technologies. In the followed chapters, data and method and results are discussed for consumer research, experiments and sensory test.

Chapter I.

COFFEE CULTURE

Coffee is a type of beverage obtained from the fruits of the tree named coffea by separating the seeds and brewing them. The brewing methods may differ from region to region according to people's preferences. Coffee has managed to enter the lives of many communities, contributed to the economy of many people, and is also one of the most consumed beverages in the world which is consumed by most of the adult population (Samuel, 2021).

1.1 History

It is not known exactly how and when coffee was discovered. The word ‘coffee’ is derived from Arabic word ‘quahweh’ and transferred very similar to the other languages (Smith, 1985). Coffee cultivation and trade started in the Arabian Peninsula in the 15th century. In the 16th century, coffee, was known in countries Iran, Egypt, Syria, and Turkey.

Figure 1-1. Coffee houses.

Seher, 2019

The establishment of a coffeehouse culture in some countries and people's preference of coffeehouses for social activities led to the increase the popularity of coffee. Coffeehouses, which had an important place in the society, became places

where other activities such as music, art, backgammon, and chess were performed (Ellis, 2008). It was called "schools of the sages".

In the 17th century, coffee began to become popular in Europe. Coffeehouses started to become social activity and communication centers in the major cities of England, Austria, France, Germany, and Holland. First coffee house in Europe opened in Italy in 1645 which is followed by England, Paris, Berlin (Meyers, 2005). Coffee came to New York in the mid-17th century by the British. U.S. coffee consumption was low in 1783. By the 1830s, North Americans started preferring coffee instead of coffee which started increasement of U.S. coffee market (Topik, 2009).

As the demand for coffee increased, coffee started to be grown outside of Arabia. Coffee seeds were moved day after day to the new lands and coffee trees were planted all over the world. It has planted in tropical forests, rugged mountain areas. At the end of the 18th century, coffee exports were increased. Coffee became one of the most important agricultural commodities and the second most valuable commodity exported by developing countries (Pendergrast, 2009).

Figure 1-2. Turkish coffee in a cup.

Yucar FotoGrafik, İnegöl, Turkey

Every nation continues to live its own coffee culture, some cultures are known by the whole world. For instance, Turkish coffee is cooked in a coffee pot and served with its grounds. The process of filtering after brewing, which is common in other coffee cultures, does not exist in Turkish coffee. Coffee has an

important place in Turkish culture and traditions. It is used to be served to house guests and is also used in ceremonies to ask for a marriage (Ayvazoğlu, 2011). Coffee culture in Italy has been on the rise with espresso (Morris, 2013). Most of the coffees consumed today are espresso-based and fed from the Italian coffee culture. Filter coffee is a type of coffee which is identified with the French culture. It is obtained by filtering the coffee brewed by infusion after the brewing is over.

1.2 Three Waves of Coffee

People's ways of making and consuming coffee have changed, new methods began to be used in coffee making, and different coffee cultures are created. Over time, changes have occurred in the coffee culture due to economic and social developments. Fast preparation of coffee is an important factor for the first wave. Today, the quality, social interaction, and artistic pleasure of coffee are determinative (Güler et al., 2020).

1.2.1 First Wave

The first wave started in the 1800s when coffee consumption began to increase. The highlight of this wave is that coffee is common which can be found in households.

Figure 1-3. First wave coffee.

Taha

Convenience and accessibility are the most important features of this wave in this wave where instant coffee and vacuum packs are used which allows quick preparation. Coffee is obtained by mixing water and soluble coffee. However, factors such as the origin and flavor of coffee are not the priority.

1.2.2 Second Wave

The second wave coffee is still spreading all over the world. It began in the 1970s with the growth of some chain markets in the coffee industry. This wave started with the consumer seeking information about the quality and origin of coffee. Besides, coffee places became social meeting centers. People started drinking different coffee-based beverages that coffee meets other flavors such as milk, sugar which are mostly prepared by espresso-based coffees.

Figure 1-4. Second wave coffee.

Hansel

1.2.3 Third Wave

The term third coffee wave was first used by in 2003 (Skeie, 2003). People attach great importance to the origin, processes, and brewing ways of coffee. It is

considered the turning point for qualified coffee. During this period, respect for baristas increased and their knowledge became interesting.

1.3 Health Benefits

Cold and hot coffee has many health benefits. The caffeine in coffee increases the number of calories burned and fat burning. While coffee has positive effects on mood, it has been shown in some studies, it also reduces the risk of depression. It has positive effects on increasing brain function. Drinking coffee regularly is beneficial for heart health, but people with high blood pressure should limit caffeine or avoid caffeine intake. Regular coffee consumption helps to keep blood sugar stable and reduces the risk of type 2 diabetes. Cold coffee compounds can protect the brain from age-related diseases. Cold brewed coffee is less acidic than hot coffee. Therefore, it causes less unpleasant digestive and acid reflux symptoms. Coffees contain antioxidants. Although cold brewed coffee contains less total antioxidant than hot brewed coffee, it contains compounds with high antioxidant activity (Panoff, 2019).

Chapter II.

COFFEE IN THE MARKET

2.1 Worldwide Market Share

There is a large coffee market in Europe, and it is the largest coffee market in the world, accounting for about one-third of global consumption. In 2019, it covered 34% of the total consumption with 3356 thousand tons (ICO, 2020). Asia and Oceania follow Europe with 22% market share. Latin America and North America have a market share of 19%.

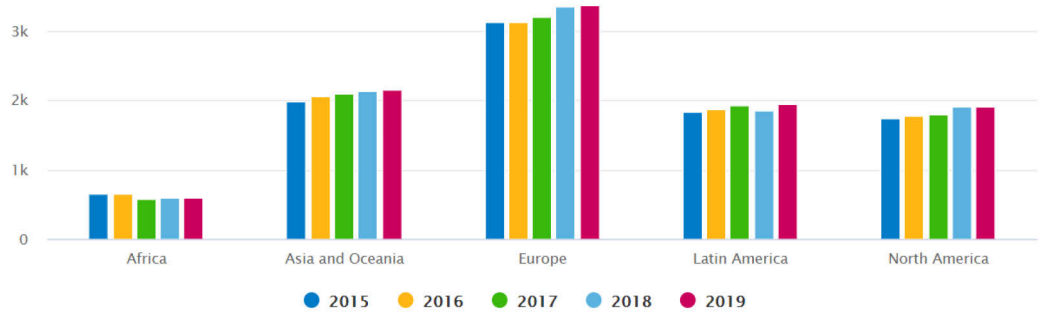

Figure 2-1. Global coffee consumption per region in 1.000 tons.

ICO, 2020

2.2 Importing and Production

Europe is the largest importer of green coffee. An average increase of 2.3% was observed between 2015 and 2019. The green coffee imports in 2018 are covered by one-third Robusta and two-third Arabica (CBI, 2020).

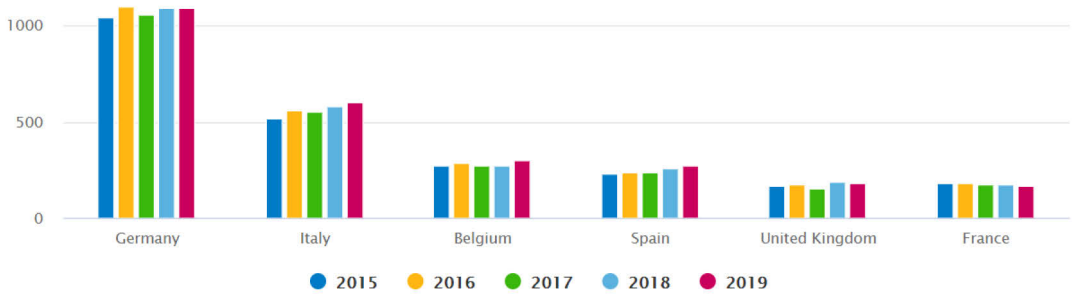

Figure 2-2. European importer countries of green coffee in 1.000 tons.

Eurostat, 2020

Most of the coffee imported to EU comes from Brazil and Vietnam.

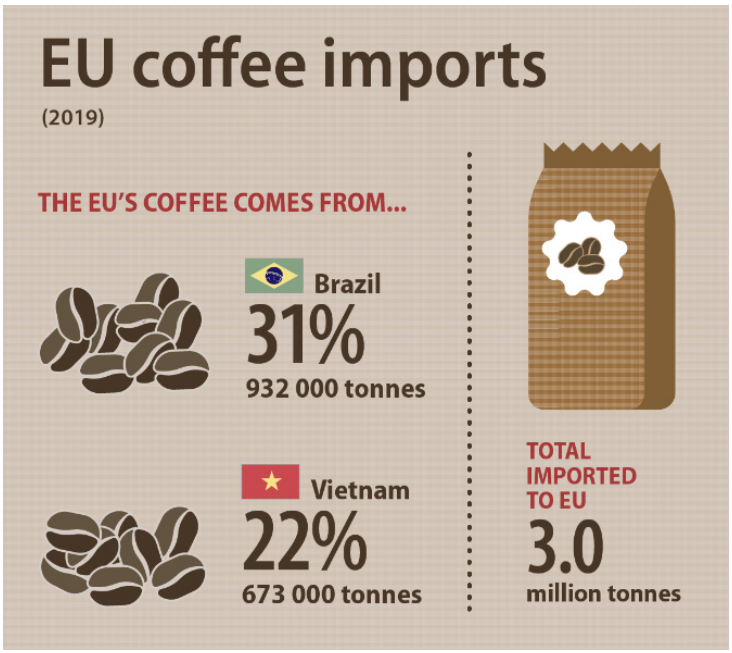

Figure 2-3. EU's coffee comes from.

Eurostat, 2019

Germany, Italy, Spain, Netherlands, France and Sweeden are procuded %86 of the total EU production of roasted coffee. Germany is leading with 31% of the total EU production.

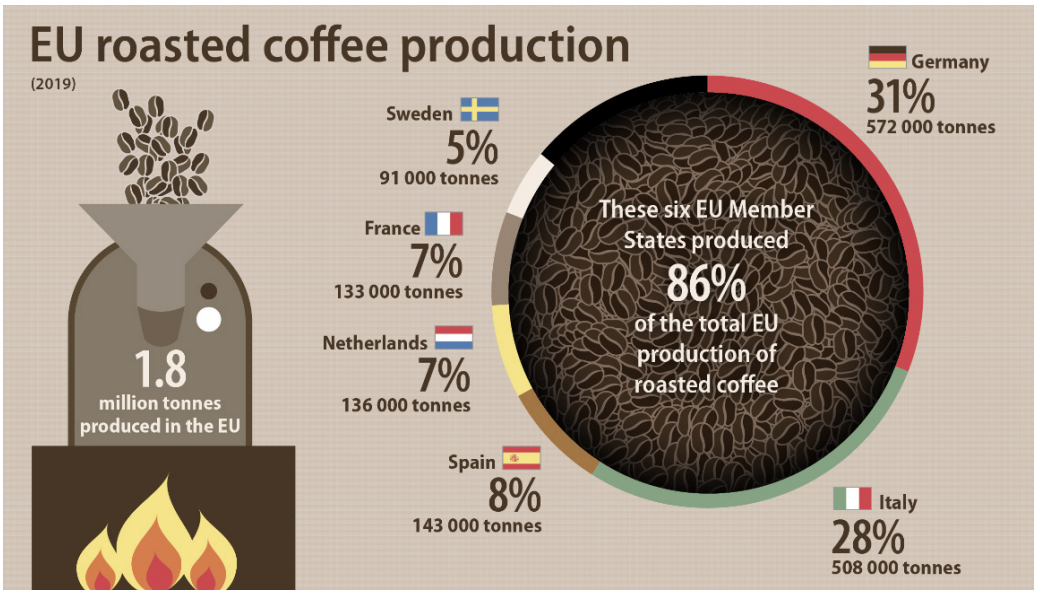

Figure 2-4. EU roasted coffee production.

Eurostat, 2019

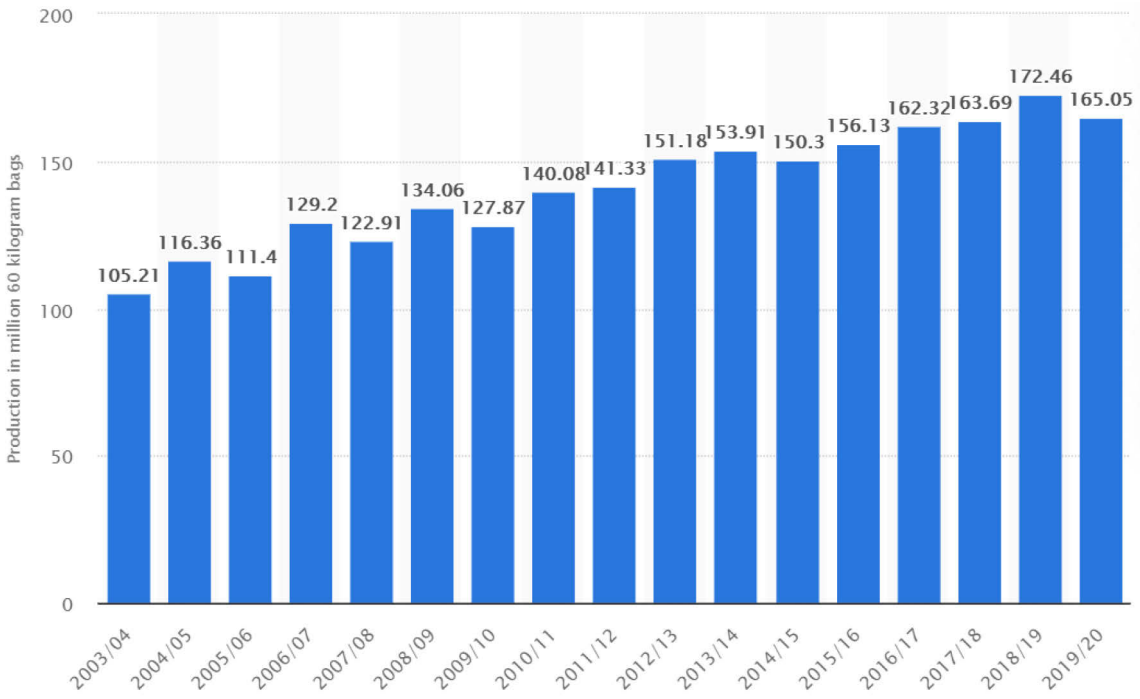

Figure 2-5. From 2003/04 to 2019/20 production.

In million 60-kilogram bags, Statista, 2021

2.3 Consumption

Europe has the highest per capita coffee consumption in the world. In the European Union, over 5 kg of coffee is consumed per person per year. In Finland, there is a consumption of 12 kg of coffee per person per year. Annual consumption is also very high in other Scandinavian countries (Bernard, 2020).

Coffee is the most preferred iced drink flavor in Spain, England, Germany, and Nordic countries. While cold brew has been popular in the US for over 10 years, it has also started to become popular in Germany. It is found in approximately 40% of the outlets (Kerry, 2019).

Coffee is one of the most popular drinks in the United States. Americans consume an average of two cups of coffee a day. While the young generation consumes about 1 cup of coffee a day, Americans aged 70 and over consume more than three cups of coffee a day. The most popular brewing method is the drip coffee maker (Shahbandeh, 2021).

Rank	Country	Coffee Consumption (kg per person per year)
1	Finland	12,00
2	Norway	9,90
3	Iceland	9,00
4	Denmark	8,70
5	Netherlands	8,40
6	Sweden	8,16
7	Switzerland	7,90
8	Belgium	6,80
9	Luxembourg	6,50
10	Canada	6,50

Table 2-1. Top 10 coffee consuming nations.

(Bernard, 2020)

2.4 Cold Brew Growing Trend

The cold brewed coffee market size has been increasing in recent years. The global cold brew coffee market size was valued at $ 339,7 million in 2018.

Figure 2-6. Cold brew tools in Starbucks Reserve Roastery Milano.

Coffee chains like Starbucks started to sell and advertise the cold brew accompanied with iced coffee recipes in coffee shops (GVR, 2018). Besides, there are products that they sell on the market for cold brewing at home. There is an increasing interest in cold coffee on millennials side who play key role in the popularity grow (Berry, 2016). The interest in the RTD beverage category also contributes to the growth of cold brew coffee and global market (Wright, 2016). The growing interest in iced coffee contributes to the popularization of cold brewing (Schwaner-Albright, 2007).

According to the study conducted in 2018, North America is the largest market for cold brewed coffee and accounts for 70% of the total share which is followed by European market.

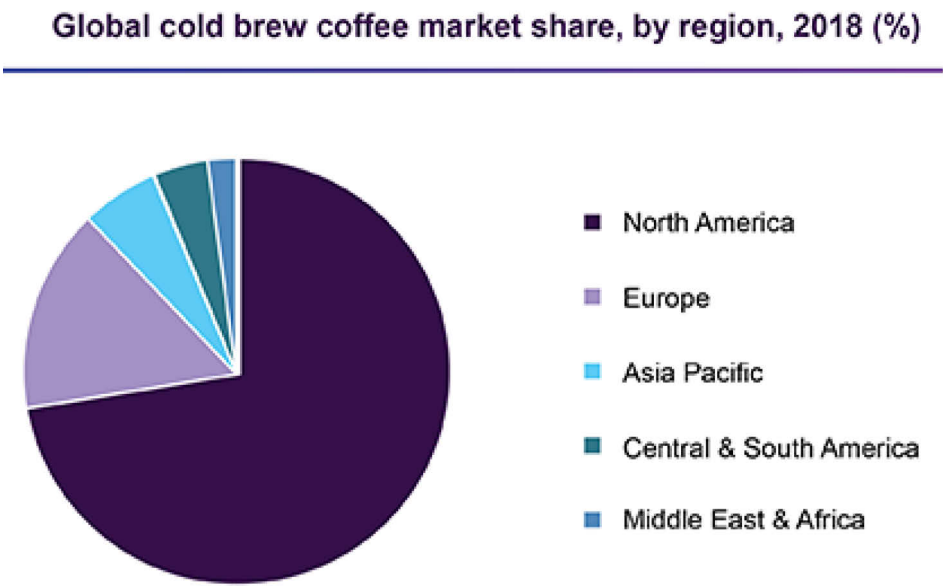

Figure 2-7. Cold brew coffee market share.

Grandviewresearch, 2019

Chapter III.

TYPES OF COFFEE

3.1 Black Coffee

Black coffee is a brewed coffee without the addition additives such as sugar, milk, cream, ice cream or added flavors.

Figure 3-1. Black coffee.

Bean Box

- Espresso is Italian creamy head coffee made by forcing pressurized water through coffee grounds. It is the base for many coffee types.
- Ristretto is made like espresso differently half amount of water used, more concentrated compared to espresso.
- Americano is diluted espresso which hot water is poured over to espresso.
- Long black is made of two shots of espresso/ristretto, and small amount of water compared to Americano which makes it stronger.
- Doppio is double espresso shot.
- Instant coffee is coffee powder and mixed with hot water to make a coffee, used for simplicity.

3.2 Milk Based Coffee

Milk coffee is a category which coffee-based drinks are made with milk.

Figure 3.2 Milk based coffee.

Roasty Coffee

- Flat white consists of espresso, steamed milk with low amount of foam.
- Cappuccino consists of espresso, steamed milk, and foam equally.
- Latte consists of espresso, steamed milk, and foam. Steamed milk quantity is more compared to Cappuccino and Flat white.
- Caffe Breve consist of espresso and steamed half-and-half (milk and cream) and milk foam.
- Piccolo Latte is made by ristretto shot and warm milk.
- Macchiato is an espresso shot with just a bit of milk.
- Latte Macchiato is made by pouring espresso over milk. It is usually served in tall glass and the layers of foam, espresso, milk respectively can be seen.
- Cortado is a drink which is popular in Spain, Portugal, and Latin America. It is served with small amount of froth and a 1:1 espresso to milk ratio.
- Gibraltar is a variation of Cortado coffee, difference is Gibraltar has thicker froth. It is served with its special glass.
- Mochaccino is consisting of a double espresso shot, milk foam and additional flavor such as chocolate, cocoa, or chocolate syrup. Whipped cream can be used as well (Azoury, 2019).

Figure 3-3. Coffee types.

Freepik

3.2.1 Creating Milk Foam

There are 2 ways of creating foam which are frothing the milk and steaming the milk. Both are quite different from each other, while having different properties of the foam.

Figure 3-4. Handheld milk frother.

Amazon

Frothed milk is aerated milk which adds tiny air bubbles to achieve creamy, airy mouthfeel. There are 3 types that are manual, handheld electric and automatic. Manual milk frothers consist mesh plunger in a cylinder which can be pushed downwards and upwards. Foam is created by pressing the pump repeatedly. Its appearance looks like French Press. Handheld milk frothers are battery powered operated by hand. It has a wand part with a whisk at the end which froths milk by spinning at very high speed (Klets, 2021). Automatic frothers run hands free operation. They include power base, carafe, and frother disk. Some of the automatic frothers provide cold, and hot froth.

Figure 3-5. Automatic cold and hot milk frother.

Jura

Steamed milk is different than frothed milk. It produces hot and finer foam which is called micro foam by introducing air and heating milk. Steam comes out of the holes, when the steam tip is on the milk surface, it acts like a steam whisk and injects air by breaking the milk surface (MacDonnell, 2021).

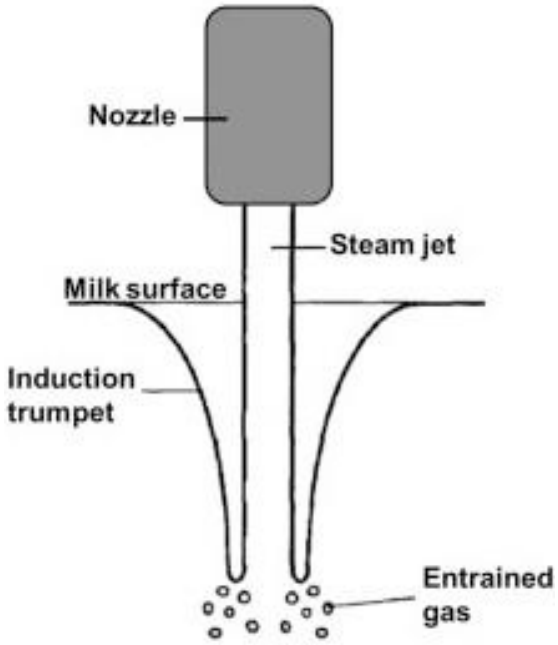

Figure 3-6. Steam jet working principle.

Clive Coffee

3.3 Cold Coffee

Cold coffee is a type of coffee which is brewed cold or brewed hot and served cooled. Cold brew does not need extra process to make beverage colder; coffee can be consumed directly as brewed or with ice. However, hot brewed coffee needs to be cooled down to consume with adding ice or cooled milk to reach the desired cold temperature for the coffee. Cold brew recipes require ground coffee to be extracted 2 to 24 hours. Some studies are concluded near 400 minutes of brewing time is adequate to extract most of available caffeine and 3-CGA (Fuller and Rao, 2017). It can be served over ice or with added water or milk. There is difference in sensory between cold brew and hot brewed coffee (McCain-Keefer, 2020). Sweeteners or syrups can be used in cold coffees. Pre-packaged cold coffees which are called ready-to-drink (RTD) are also available in grocery stores. In hot brews, components to be dissolved such as sugar better added before it cooled down to help dissolving process.

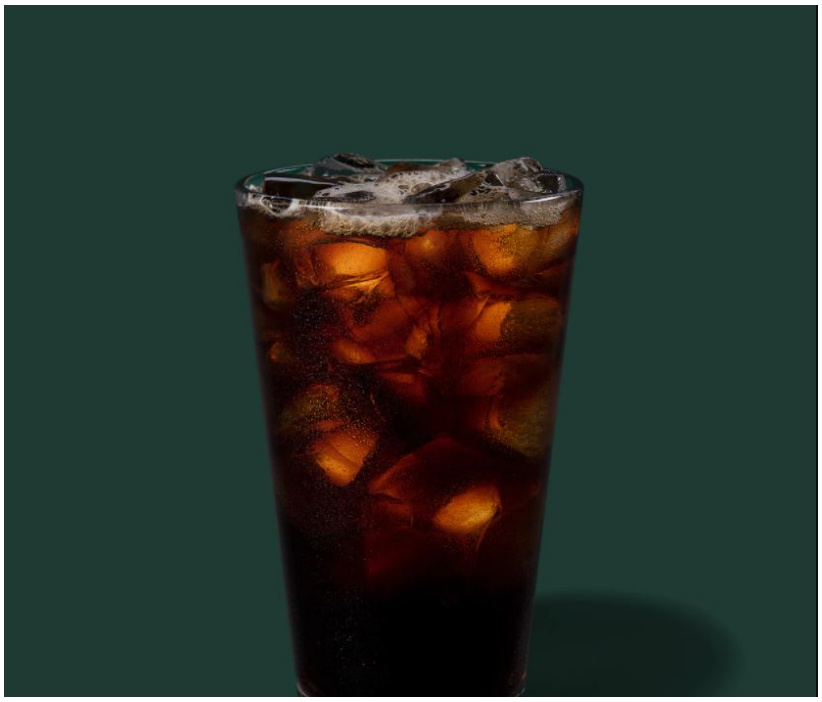

Figure 3-7. Cold brew coffee.

Starbucks

There are differences between hot and cold brewing. Hot brew tends to extract more non-deprotonated acids than cold brew, it results in less acidic cup meanwhile it could affect the antioxidant activity in hot brew coffee (Rao and Fuller, 2018).

3.3.1 Variations by Countries

As the popularity of cold coffee has increased, variations have emerged in the countries. Here are some examples of cold coffees all over the world. Iced coffee in Australia is made using milk and sugar. It is served with ice cream and whipped cream in cafes. In addition, it may contain syrup, cream, cocoa powder, or coffee beans. It can be made using instant coffee or espresso (Coates, 2015). Ice coffee in Chile is called café helado. Ice cream, vanilla, cinnamon or dulce de leche can be added to this coffee made with espresso or coffee powder. In Chile, people invite friend or family to have tea or coffee and as part of the culture, coffee can be cold (Castillo-Feliú, 2000). Cold coffee is called Eiskaffee in Germany. Milk,

vanilla ice cream, whipped cream, and chocolate sprinkles are used together with cold coffee (Cate, n.d.). Frappé is cold coffee that is famous in Greece and prepared with instant coffee. Instant coffee is poured into the glass and after that water is poured over it, optionally, milk and sugar are added, and the combination is mixed with a mixer. Foam is created at top of the drink (Rossi, 2019). Also, in India, iced coffee is prepared using instant coffee. Vanilla ice cream or sugar can be added optionally. It is made by mixing instant coffee and cold milk (Palani, 2015). It is known as "Caffè in ghiaccio" in Italy. It is made by adding sugar to brewed espresso and served with ice in whiskey glasses. Affogato is a dessert made with coffee, by pouring espresso over vanilla ice cream. "Caffè shakerato" is another cold coffee drink known in Italy which is made by mixing double espresso and sugar and ice cubes in a shaker (Gritzer, 2020). Cold tea is popular in Japan, therefore cold coffee is also popular and common in the country. It is served with gum syrup and milk, known as Dutch coffee, and can be found as canned coffee as well. Slovenian version is called "ledena kava" which is made using double espresso, vanilla ice cream, whipped cream, almond or chocolate chips. Waffles can be used on top. Iced coffee is also available in supermarkets in Slovenia as in many countries.

Figure 3-8. Slovenian iced coffee.

Midva Kuhava, 2019

Unlike other countries, brandy can be added to cold coffee made in Sri Lanka. Thai iced coffee made in Thailand is known as Oliang which is made by mixture of Robusta coffee, grains and seeds, brown sugar, cardamom, corn, soybeans, rice, and sesame seeds. It has a different aroma due to the use of various grains and seeds. There are several variations of Oliang, for instance iced black coffee, black coffee with condensed milk, iced black coffee with fresh milk. Cold coffee has been popular in the US for a long time (Schwaner-Albright, 2007). It is prepared in two ways as cold and hot brew which can also be found on supermarket shelves as Frappuccino. It is consumed with or without milk, almond or oat milk are among the options. Vietnamese iced coffee is brewed by Phin filter or French press and served with condensed milk on ice.

Nitrogen infusion is a feature used with cold brewing. Nitro cold brew (NCB) is a cold-brewed coffee that is charged with nitrogen. Unlike normal cold brew, it has a rich and creamy head. The purpose of using nitrogen infusion in cold brewing is to get a foamy texture on the top of the coffee and to achieve a smooth mouthfeel (Calderone, 2015). We are also familiar with the infusion method from beers. Carbon dioxide is used instead of nitrogen in beers. Nitro cold brew coffee has a sweeter taste than regular coffees, so it can reduce people's calorie intake and prevent many health problems (Link, 2018).

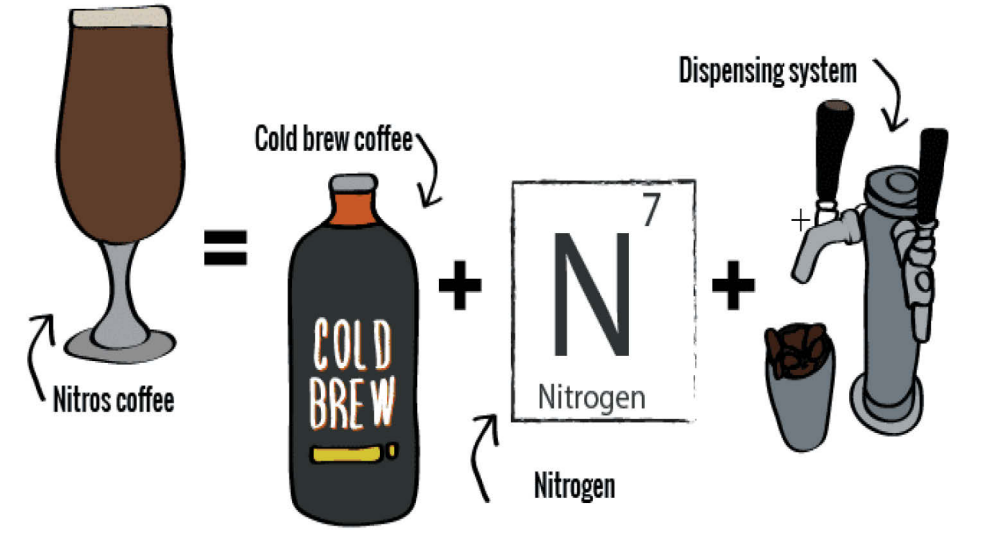

Figure 3-9. Nitro cold brew coffee.

Home Grounds

Chapter IV.

FROM SEED TO CUP

4.1 Planting

The coffee bean is a seed. It is used for brewing after drying, roasting, and grinding processes. The planted areas are generally shady which facilitates the watering and planting of seedlings. The planting period is before the rainy season (Reddy, 2019). There are many impacts of climate in different time periods. For instance, in the growing season, low rainfall and cool temperatures have a risk of small beans. In the harvest season, high rainfall and low temperatures have a risk of coffee bean defects. Periodic adaptations can be provided according to the period to minimize these problems (Kath et al., 2021).

Coffee trees are cut short to get a good harvest, they exceed 9 meters in height (Regalado, 2018). Coffee cherries grow in a cycle. Flowers, green fruits, and ripe fruits can be seen at the same time in a single tree. One year takes cherry to mature and plants that live up to 100 years are most productive between 7 and 20 years old (Meister, 2012). Rich soil, mild temperatures, frequent rain, and shady-sunny spots are the most suitable environments for tree farming.

Ideal conditions for the growth of coffee trees are in the equatorial region which has tropical climates. This region is called the Bean belt. Many factors such as soil, weather, amount of rain, sunlight, altitude affect the quality and aroma of the coffee. Although coffee trees can tolerate cold, they are not frost tolerant (Petek et al., 2005). It is convenient to keep the plant indoors or greenhouse during the freezing seasons. When the subsequent processes are included, the coffees grown between the regions differ considerably from each other. South America is the continent where the most coffee is produced in the world. Coffee is grown in more than fifty countries around the world. North America (Hawaii, Mexico, Puerto Rico), Central America (Guatemala, Costa Rica), South America (Colombia, Brazil), East Africa (Ethiopia, Kenya), West Africa (Ivory Coast), Arabian Peninsula

(Yemen), Asia (Indonesia and Vietnam) are some of the places where coffee is produced. Countries such as Guatemala, Costa Rica, Brazil, Colombia, Mexico cover most of the production. Only Brazil has 30% of the coffee production all over the world which is world largest producer and exporter (Volsi et al., 2019). The African continent also has a large share in coffee production.

Figure 4-1. Arabica coffee plantlets.

Bertrand, 2013

There are many types of coffee beans, the most popular types are: Arabica and Robusta. Coffea Arabica comes from the coffee trees in Ethiopia. In year statistics ending with April 2020, exports of Arabica were 81,3 million bags, 0,55 bags more than last year; on the other hand, 47,65 million bags Robusta exported which is 2,02 million bags more than last year's value (ICO, 2021). A fine, soft, and aromatic coffee is produced with Arabica which differs from Robusta in appearance of the kernel, which is flatter and longer than Robusta, as well as has a lower caffeine ratio. Arabica coffee is grown at a high altitude nearly 600-1900 meters above sea level (Daggett, 2015), and its cost is higher due to its grown slopes and

altitudes. Amount of precipitation and having mild climatic conditions are important factors for growing Arabica. Robusta mostly grows in Central and West Africa, in some regions of South East Asia and in Brazil. Robusta tree is easier and cheaper to grow through its durability. It is grown in low altitudes and able to withstand hot climatic conditions. Dominant flavor changes depending on altitude for both Arabica and Robusta. Dominant tastes are subtle, soft, bland, earthy, simple, and mild in lower altitude; low acidity, smooth and sweet in medium altitude; citrus, vanilla, chocolate, and nuts in high altitude; fruit, floral, spice, berry, and wine in very high altitude.

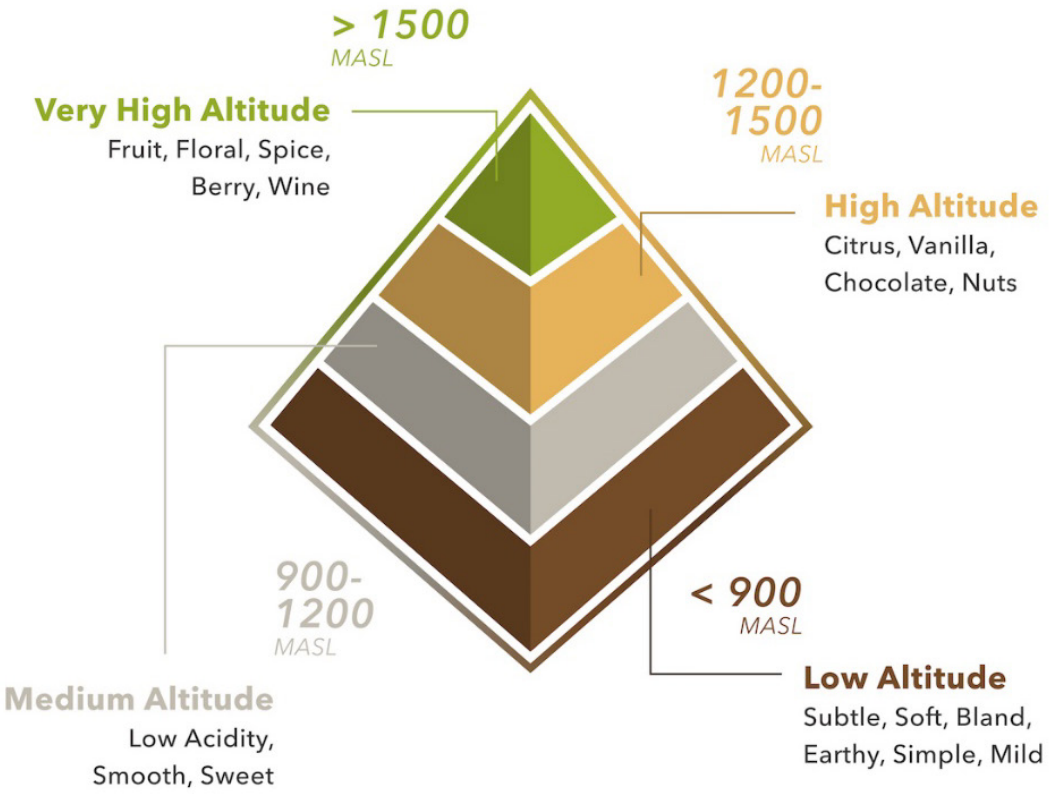

Figure 4-2. Coffee flavor by altitude.

Indonesia International Trading, 2020

4.2 Harvesting and Processing Cherries

Coffee is harvested after it turns into a cherry color which is bright and dark red. It is harvested once a year, in most countries it is collected by hand which

makes it nontrivial (Scott, 2015). The use of the harvesting machine is also seen in places where have many fields, and flat ground. There are two methods of picking cherries: harvesting all the cherries or harvesting only ripe cherries. If only ripe cherries are harvested, a mechanized system is not used, and the cherries are picked by hand. Therefore, the second method is costly due to involving high labor in the process.

Processing begins after the coffee has been collected. It can be processed in 2 ways: dry method or wet method. In the wet method, the pulp is extracted from the coffee cherry and dried together with the parchment skin. It is processed in the machine to separate the seeds and pulp from the beans. After that, the seeds are sent to the water channels and the larger ones are transported to the fermentation tanks to be kept there for a while. When the fermentation is over, the beans are rinsed and dried. In the dry method, cherries are laid on the ground to be dried under the sun. The aim is to reduce the moisture content of the cherries below a certain level. The beans processed by the wet method must be dried before storing. Coffee beans in the endocarp can be sun-dried or dried in the machines.

Figure 4-3. Coffee harvesting.

Essence Coffee

4.3 Milling Beans and Tasting

Parchment coffee is processed before it is exported. The endocarp is removed by peeling machines, additionally polishing can be applied. Seeds are examined for defects and classified according to their size and weight. Some defective beans are eliminated, and their export is prevented. Ready to be exported ground beans are called green coffee. Coffee is tested before roasting in terms of taste and quality. Both the properties and flaws of the coffee are determined. It is also important to mix different beans and understand their proper roasting properties before roasting the coffee.

Decaffeinated coffee is used by some people to get coffee taste and social connection. There is additional process to remove caffeine from coffee. The beans are dipped in liquid to dissolve the caffeine. There are many ways to remove caffeine, most of them use water (Ramalakshmi and Raghavan, 1999). a mixture of water and solvents can be used as a liquid. Although decaffeination removes most of the caffeine, there is very little left caffeine in decaf coffee which is up to 7 mg in 180 mL. (Goodson, 2018). Caffeine, which is consumed up to 400 mg a day, seems to be safe for healthy adults (Mayoclinic, 2020).

Figure 4-4. Dry milling.

West Rock Coffee

4.4 Roasting Coffee

Roasting is the process in which green coffee turns into fragrant, aromatic brown beans. Roasting the green beans adds aroma and flavor to the coffee. Coffee is kept green during the storage, and it should be roasted before being brewed. During the roasting process heat is applied, and with different temperatures allow to procure varieties of roasted beans in light to dark colors. To prevent beans from burning, beans are moved. Time is another important parameter to avoid undesirable tastes may occur if it strings out. Roasted beans are lighter than green beans due to substance of moisture. The beans are cooled down after it is completed. There are 4 categories according to their colors: light, medium, medium-dark, and dark.

Roast type	Temperature range
Light roasts	180 – 205 °C
Medium roasts	210 – 220 °C
Medium-dark roasts	225 – 230 °C
Dark roasts	240 – 250 °C

Table 4-1. Roasting temperatures.
Lokker, 2013

Figure 4-5. Green, light, medium, medium-dark, dark beans in order.
Caffeinesolution

Light roasted beans are light brown, and it does not have any oil on the surface of the beans which retains more the raw plant characteristics compared to ones roasted in higher temperatures (Schultz 2020). The oil content on the surface increases as roasting time increases. It contains more acidity, citrus, fruity and floral flavors. Medium roasts are medium brown, and balanced flavor with having combination of inherent nuanced flavors and chocolate, caramel-like flavor. Dark roast coffee offers lower acidity since the acidity gets lower due to increased temperature and time of roasting and it can reach deeper levels of sugars (Bilge, 2020; Moon et al., 2009). Also, a research shows that the difference between cold and hot brew coffee is increased as the degree of the roast increased (Rao, 2020).

Figure 4-6. Common tasting notes by roast level.

MISTOBOX, 2020

4.5 Grinding Coffee

One of the last stages that beans go through before reaches the consumer is the grinding of the coffee. To increase the flavor of the coffee, different grinding sizes are selected according to the brewing method.

The finer grinding results in shorter preparation time of the coffee due to increasing surface area and filtration of the coffee is also important to define proper brewing method. For instance, fine grind size is not used with French press to avoid a lot of sediment in the glass after filtration. Coffee should be grinded before brewing to keep its aroma and freshness.

Method	Grinding size
Turkish coffee	Extra fine
Espresso	Fine
AeroPress	Medium-fine
Pour-over	Medium
Home coffee maker	Medium-coarse
French press	Coarse
Cold brew	Extra Coarse

Table 4-2. Grind table for different coffees.

Pavlovich, 2020

Figure 4-7. Grind sizes.

Coarse – medium coarse – medium – medium fine – fine – extra fine, Coffee Dorks

4.6 Brewing Coffee

Last process which coffee reaches out to the cup by pouring hot or cold water on ground coffee and waiting water to dissolve coffee and extracts its compounds into the cup. There are many different brewing methods that applies different rules to brew the coffee. Although there are many options, considering personal preferences, appropriate tastes can be obtained by trying various combinations.

Some factors affect the quality and aroma of the coffee, for instance, origin of country, bean type, roast type, grind size. Using newly roasted coffee and grinding before brewing are important that increases the quality of the coffee for preserving the aroma and the flavor (Ross et al., 2006). The grind size is determined depending on a brewing method and tools are used and they are both important factors which affect physicochemical parameters, number of total phenols, caffeine, and antioxidants (Derossi et al., 2017). Evaluating many factors such as temperature, grinding size and brewing time which water interacts with coffee grounds, the extraction of the coffee can be bitter or under-developed in the brewing process. Leaving aside different brewing methods such as cold brewing, the ideal water temperature for optimum extraction is near 93 °C (Batali et al., 2021). Too hot water disrupts the taste of the coffee by causing the extraction of undesired components. Therefore, after the brewing water reaches its boiling temperature, it should be cooled down to 93 °C to not extract undesired components in the cup. Based on the material of the cup what is made of influence beverage temperature. For instance, paper cups' insulation performance is significance to keep drinks hot (Kuang et al., 2015).

The water used is very important for the quality of the brewed coffee and some coffee machines use water filters to improve the water quality (Navarini and Rivetti, 2009). Amount of water and its ratio with coffee is determined according to different brewing methods and personal preferences. It should be kept in mind that in some brewing methods the water evaporates and there is less amount of water when the brewing is completed.

Chapter V.

BREWING METHODS AND TOOLS

5.1 Hot Brewing

The hot brewing methods can be divided into 4 groups according to the preparation and systems are used. These four methods are called boiling, pressure-based, gravity brewing and steeping. Each brewing method has its specific parameters. Temperature of the brewing water, pressure, grinding size, and extraction time are some of the important parameters to be considered during the brewing. The cleanliness of the equipment used in coffee making is important. In each brewing method, it should be rinsed with water and dried after each use, otherwise the accumulated coffee oil may negatively affect the next cups' taste.

5.1.1 Boiling

Although it is referred to coffee boiling technique, the coffee grounds are not boiled. It is one of the simplest methods of brewing coffee which can be done by placing the coffee grounds in a bowl with hot water. The coffee is served while the coffee grounds subside and filtering process is not applied.

Figure 5-1. Cowboy coffee.

The Roasterie, 2020

Cowboy coffee is made by using coffee grounds and hot water. Coarse grind size is used, and the extraction is not fully completed in this method. Coarse grinding has a longer storage life than finely ground coffee which is the reason for preference (De'Longhi, 2020). Finer grinding accelerates the oxidation in the coffee, causing it to become stale faster. This method, which does not require the use of much equipment, is suitable for camping.

Turkish coffee uses a narrow pot known as "cezve" or "pitcher" for brewing with the finest coffee grounds. After the Turkish coffee and water are placed in the coffee pot, it is placed on the stove. Removing the coffee pot from the heat when the mixture reaches boiling temperature is important to avoid over-extraction. The grounds sink to the bottom after the coffee is poured into the cup.

Figure 5-2. Turkish coffee.

Oraio

5.1.2 Pressure Based Methods

Espresso is one of the most popular consumed coffee which is strong and dense. Finely ground coffee is used for brewing and the system works with pressure. It is concentrated coffee which offers 64 mg caffeine in 30 mL cup with crema (Mayo Clinic, 2020). Espresso is obtained by forcing 93 ± 3 °C water

through ground coffee with 9 atmospheric pressure (SCAA, 2015). However, it is reported brewed espresso in lower temperatures are not distinguished by tasting panel and can be lowered down to 86 °C (Klotz et al., 2020). 5 mL of espresso and 9 bar of pressure setting is convenient to achieve quality espresso with very strong aroma intensity (Caprioli et al., 2012). Also, another study shows that in the espresso brewing, 7–9 bar pressure is needed most efficient extraction of some bioactive compounds such as caffeine, trigonelline, and nicotinic acid (Caprioli, 2014). The grinding is coarser compared to Turkish coffee, but it is still one of the finest ground coffees. It is be served as single espresso as 30 mL or double espresso as 60 mL. Espresso is the main component of many coffee varieties used today with added milk or diluted, for example Latte, Cappuccino, Mocha.

Figure 5-3. Espresso.
illy

Moka pot is used with the stove differently from some other equipment. It consists of 3 parts which are lower, middle, and upper parts. It is invented by the Italian engineer Alfonso Bialetti in 1933 (Smith, 2018). The lowest reservoir is the section where water is placed and boiled. The boiling water moves up, first through the coffee grounds, which is in the middle part, with the steam pressure, and then it is transported to the upper part, where the brewed coffee is collected and being

served. The pressure that is 1 bar in the moka pot is low compared to an espresso machine and the water temperature is higher (Bodnariuc, 2019). Essential technical parameters are defined to make a Certified Italian Espresso (Italian Espresso National Institute, 1995).

Parameters	Values
Necessary portion of ground coffee	7 g ± 0,5
Exit temperature of water from the unit	88°C ± 2°C
Temperature of the drink in the cup	67°C ± 3°C
Entry water pressure	9 bar ± 1
Percolation time	25 seconds ± 5 seconds
Viscosity at 45°C	> 2 mg/ml
Caffeine	< 100 mg/cup
Milliliters in the cup (including froth)	25 ml ± 2,5

Table 5-1. Espresso technical parameters.

Italian Espresso National Institute

Figure 5-4. Moka pot.

Shutterstock

Vacuum coffee maker also known as syphon coffee maker consists of two parts, the vacuum pot and the bowl that sits on top of the pot. Water is added to the lower part while coffee grounds are placed on the upper part. The device's working principle is based on expansion and contraction of water vapor. The bottom globe is heats up and creates the water vapor. The vapor pushes the water up the tube and through filter to the upper globe. After the heater is removed, the vapor in lower chamber cools down and contracts which creates vacuum, and the suction pulls the brewed coffee back down to the bottom globe.

Figure 5-5. Vacuum coffee brewer.

Flickr, Moren

AeroPress is a coffee maker which allows to brew coffee and invented by Alan Adler (Kumstova, 2018). It is easy to use and clean; therefore, mostly used by travelers and campers. The recommended coffee to water ratio for AeroPress is 1:17 for regular coffee and 1:11 for strong coffee (Robinson, 2018). Manpower is used in this method. First, plunger is pushed out of the chamber and paper filter is placed. After twisting filter cap, coffee is added into the chamber. After water is added, coffee and water are mixed for 10 seconds. Plunger is inserted and pressed until coffee grounds resist the force (Adler, n.d.).

5.1.3 Gravity Brewing Methods

Drip coffee brewing is also called drip brewing. In this method, coffee grounds are placed in the filter basket. The recommended coffee to water ratio for drip is 1:17 for regular coffee and 1:15 for strong coffee (Robinson, 2018). The heated or cold-water drips where the coffee grounds are, then the coffee is filtered to drink.

Figure 5-6. Drip brewer.

Hario Peru

Percolating is the brewing of coffee using both pressure and gravity methods. Electric percolator was the widespread method for home usage. In this equipment, water is placed in the lower chamber, and the coffee grounds are placed in the filter basket which is in the upper chamber. Water moves to the upper chamber with the pressure when it reaches its boiling temperature. Water starts dripping into the coffee grounds basket and be collected in the lower chamber after filtration. This process repeats for a length of time.

Figure 5-7. Electric percolator.

Euro Cuisine, Amazon

Pour over coffee brewing is brewing method for a single cup of coffee. It provides a good infusion for small portion of coffees. The recommended coffee to water ratio for pour over is 1:17 for regular coffee and 1:15 for strong coffee (Robinson, 2018). Pour over coffee brewer, V60, is a brewing equipment with cup appearance which has hole at the bottom. It is placed usually on a cup or carafe. Paper filter is placed in V60 and prewet before brewing to remove paper-like flavor. The water is boiled on the stove and first a small amount of water is poured over the coffee grounds to pre-brew. The brew is completed by pouring the rest of the water slowly and brewed coffee is collected in the lower chamber.

Figure 5-8. Pour over brewing (V60).

Craig

There is another equipment called Chemex for pour over coffee brewing. It was invented by Peter Schlumbohm and started to be used in 1941 (Odabaşı, 2020). It has 3 different types: automatic, wooden handle and glass handle. Although the methods are similar compared to V60, there are some differences that grind size, paper thickness, amount of coffee used and brewing time.

Figure 5-9. Pour over brewing (Chemex).

Kahvecom

5.1.4 Steeping

French press is also known as press pot which is one of the most used equipment to make coffee. It is practical and easy to clean which increases its acceptance by people. It has a manually controlled piston with a mesh filter and the coffee is prepared with ground coffee and water. First, coffee is added to the French press, then boiled water poured and it is left to brew. After waiting 4 minutes, the coffee seeds are held downside by pressing the plunger and it is served to the cup (Boesch, 2019).

After the coffee grounds are placed in the pot, hot water is added into it. The coffee grounds are steeped with hot water. The plunger is pushed downwards when the brewing is completed to allow brewed coffee to remain separate from the coffee grounds. The recommended coffee to water ratio for French press is 1:17 for regular coffee and 1:11 for strong coffee (Robinson, 2018).

Figure 5-10. French press.

Taft Coffee

5.2 Cold Brewing

There are multiple ways to brew cold coffee, and different methods differ in terms of taste and preparation. The recommended coffee to water ratio for cold brew is 1:8 for regular coffee and 1:5 for strong coffee which is higher coffee input than other brewing methods (Robinson, 2018).

Figure 5-11. Cold brew coffee to water ratio.

Little Coffee Place

Time and effort factors should be considered to choose cold brewing method to use. Brewing can be done with simple equipment or special equipment. There are 2 main methods which can be applied in traditional way of making cold brew.

5.2.1 Cold Drip Brewing

Cold drip brewing is also called Kyoto cold drip or Dutch cold drip. In drip brewing, the water drips slowly onto the coffee grounds. The drip rate is set by the user which influences the brewing time. It is more complex than the immersion method and may require extra equipment. It usually consists of three compartments. Water is placed in the upper chamber; the valve is opened at a rate which allows dripping, and the water is dropped into the middle chamber where the coffee is located. There is a filter at the bottom of the middle chamber and after water passing through the coffee is filtered and brewed coffee collected in the lower chamber.

Figure 5-12. Cold drip tools.

Hario Shiziku, Bruer, Dripster, Yama

Dripster offers cold brew coffee in 2-6 hours with using cold drip method which is used in further experiments. The steps are explained to prepare in Figure 5-13.

Figure 5-13. Step by step cold drip method with Dripster 2 in 1.

Dripster

5.2.2 Immersion Brewing

Immersion brewing is a method which ground coffee is combined with water left to brew for hours. After brewing is completed, the coffee is filtered and becomes ready to drink. Products such as Toddy, Dripster, Hario in the market offers immersion method cold brew. Some of the products have 2 chambers. Brewing occurs in the upper chamber where grounds coffee and water are combined. The lower chamber is the section where the brewed coffee is collected after filtering the coffee grounds.

Figure 5-14. Immersion cold brew tools.

Hario cold brew – Brew jar – Dripster – Toddy cold brew

Dripster offers cold brew coffee in 18-24 hours with using full immersion method which is used in experiments in this research. The methods steps are explained.

Figure 5-15. Step by step full immersion method with Dripster 2 in 1.

Dripster

The two methods used in the preparation of cold coffee are compared. Between the two methods, it is found that the physical parameters, chemical components, and sensory profiles are different from each other. Immersion method is resulted with more sweet taste than cold drip because of contents of caffeine and chlorogenic compounds which has effect on intensity of sweet taste. The temperature affects increasing intensity which is observed coffees extracted at 22 °C were more intense than those extracted at 5 °C (Angeloni et al., 2018).

Cold brew can be prepared with immersion method by using only a large container and strainer at home (Christensen, 2016).

Figure 5-16. Immersion brewing at home without any tools.

Christensen, Simplyrecipes, 2016

Here are the basic steps of cold brew preparation.

1. Beans are coarsely ground.
2. Water and coffee are placed in the same container and gently mixed to distribute the ground coffee and water.
3. It steep for 6-24 hours.
4. Coffee is strained.
5. Cold brew is ready.

Chapter VI.

COFFEE MACHINES

There are many coffee machines on the market today. The most common households can be divided into 4 groups, these are filter coffee machines, capsule or pod coffee machines, ground coffee machines, and bean-to-cup machines (Marcus, 2021).

6.1 Type of Machines

6.1.1 Filter Coffee Machines

Filter coffee machines are simple to use. Coffee is produced when the water slowly drips onto the ground coffee and passes into the jug. The volume of coffee that can be made in one go is high (Bowen, 2019). It is advantageous for an office environment and large families. Ground coffee is used in coffee making and can only produce black coffee. The brewing time is longer and less intense than espresso.

Figure 6-1. Filter coffee machine.

Beko

6.1.2 Capsule or Pod Coffee Machines

Capsule or pod coffee makers are suitable for drinking various types of coffee. In these machines that can prepare coffee quickly and have simple use and maintenance, a capsule or pod is placed in the machine and the start button is pressed to make coffee. Coffee beans or pre-ground coffee cannot be used in these machines. The capsules are in different shapes and sizes which should be compatible with the device although each machine has its own from the manufacturer. Pods and capsules are both standardized and prepacked with measured dose of coffee (Spori, 2014).

Figure 6-2. Capsule coffee machine.

Philips

6.1.3 Ground Coffee Machines

They make espresso using pre-ground coffee and any ground coffee with provided grinding size can be used. Their prices are cheaper than bean-to-cup machines because there is no grinder. It gives more control to the user like arranging strength and volume of the drink which allows personalization of the coffee (Marcus, 2021).

Figure 6-3. Ground coffee machine.

Krups

6.1.4 Bean-to-cup Machines

Bean-to-cup machines make coffee from beans to cups. These machines contain a grinder to grind the coffee by itself. The coffee beans are ground just before consumption and the espresso maintains its freshness. There are models with milk frother. In this way, milk-based espressos such as cappuccino and latte can be prepared. It is easy to use due to the low manual process. It provides the user with customization such as coffee strength, temperature, volume. Pre-ground coffee can also be used but is expensive compared to other machines. It can take up more space in terms of volume and grinding is an audible operation.

A comparison was made in 2021 with using different coffee machines. If 2 cups of espresso are consumed every day for 5 years, the cost has been

calculated over time plus upfront cost. Ground-coffee machine is found the cheapest option among the machines (Marcus, 2021).

Figure 6-4. Cost of machines for 5 years plus upfront cost.

Which, Marcus, 2021

Milk froth is one of the features that is considered when buying a coffee machine. In the traditional method, milk is frothed in another jug using a steam wand. It is generally used in ground coffee and bean-to-cup machines. There are also automatic milk frothing machines. Used in bean-to-cup, some ground coffee, and pod machines. Milk is added to a separate container and the milk is sucked from this container. The frothing process takes place automatically and the milk froth is dispensed into the glass. Milk pods are used in pod coffee machines and contain pre-prepared UHT or milk powder. Another way to froth milk is to use a separate electric milk frother accessory.

Espresso machines are classified in terms of their use scenarios and components. Although all espresso machines have similar components, they differ from some aspects. The common components are group head, portafilter, and boiler. After water is heated by the system to desired brewing temperature. It is forced through the coffee grounds in the portafilter. Same heating system can be used to generate steam for frothed milk. Espresso machines use a pump to create

pressure while pulling the coffee. Water is added to espresso machines with a water tank and the first place the water goes when making coffee is the pump. 2 different types of pumps are used. In the vibratory pump, the piston is moved by the electric current. The magnet inside the coil moves up and down, providing the necessary pressure for the water to move into the machine. The electric current acts on the magnet, the piston moves because of the vibration. In the rotary vein pump, there is a motor that rotates the disc. After the water is pressurized, it is heated in the boiler until it reaches the appropriate temperature. There are several ways that boiling operation occurs. In some machines work with single boiler, there are two different thermostats. One thermostat is brewing the coffee while the other thermostat is responsible for generating steam. Both brewing and steam production do not occur at the same time in machines with a single boiler. In machines with dual boilers, water is pumped into 2 different boilers (Prinsloo, 2018). While water is heated for coffee in one boiler, steam can be produced in the other boiler. Machines with heat exchanger have a boiler and heat exchanger. Two different water temperatures are not in contact in this type. Machines with thermoblock contain metal with a heating coil. The piece of metal is heated which heats up the water. The heated pressurized water is in contact with the coffee at the group head. Group head is where coffee grounds are tamped and the water pressurized by the pump passes through it, it is brewed into the cup by extracting the coffee (Goodwin, 2019).

Hot brewed cold coffee can be made with the interchangeable stirrers used in bean-to-cup machine, De'Longhi Prima Donna Elite. This equipment, called the AeroStirrer, is designed for mixing ice and coffee. An exclusive ice tray is also provided with the product. Aero stirrer control is provided electronically by a magnetic tool, its speed varies according to the usage scenario. It also has functions such as making milk foam, mixing milk and cocoa powder with a different stirrer. There are other bean-to-cup coffee machines offering cold coffee in the market by brewing hot coffee/americano, but it is required to use ice cubes to cool beverage down as in De’Longhi Prima Donna Elite. The advantage is that product can crush ice with AeroStirrer.

Figure 6-5. De'Longhi Prima Donna Elite

De'Longhi

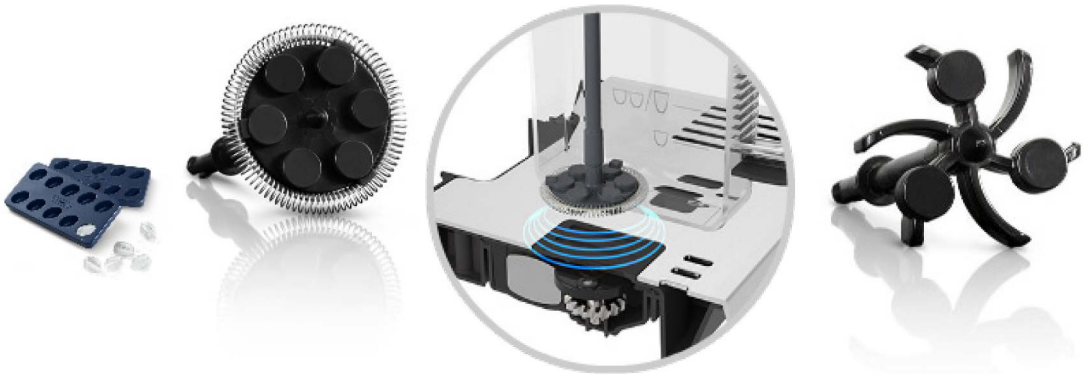

Figure 6-6. AeroStirrer, ChocoStirrer and magnetic control.

De'Longhi

Figure 6-7. Ice crush with AeroStirrer.

De'Longhi, Making cold coffees and foam wih Maestosa, 2019

6.2 Automation in Espresso Machines

Espresso machines are divided into 3 categories, manual, semi-automatic, and automatic.

6.2.1 Manual Espresso Machines

They are called piston machines which are controlled by a piston; the user is required to create pressure with the lever. User precision and focus are needed to operate manual espresso machines (Fisher, n.d.). After the advancement of technology, manual espresso machines still take a place in the market, are being used nowadays. Good quality espresso is achievable with these machines which provide full control to the user over brewing. The quality of the espresso can vary depending on the skill of the person making it. Physical strength is used more than other machines. Additional accessories can be required such as grinder (Jackson, 2018). There are 2 different types of manual espresso machines: spring piston machines and direct lever machines. The lever position is the way to understand the type. In spring piston machines, resting position of the lever is upright, pushing the lever down compress the spring mechanism. By leaving the handle, pressure released on the spring and water moves through the portafilter and coffee grounds. In direct lever machines, resting position of the lever is lower. Applied force prompt water through coffee grounds (Oden, n.d.).

Figure 6-8. Manual espresso machine (direct lever).

Coffeeorbust, 2021

6.2.2 Automatic Espresso Machines

They are categorized with different subcategories. It is divided into three subcategories as semi-automatic, automatic, and super automatic. The difference with manual machines is that pumping action is not physically controlled by user.

Semi-automatic espresso machines are different than manual machines, uses automated system for forcing water through the grouphead with an electric pump which eliminates the strength and endurance of the user. Other operations are manually handled such as grinding the coffee, loading the portafilter, tamping, and extraction time. It provides user more control over than automatic and super-automatic espresso machines.

Figure 6-9. Semi-Automatic Espresso Machine

De'Longhi

Automatic espresso machines prepare espresso at the push of a button. The grinding and tamping of the coffee are done by the user. Only difference between semi-automatic and automatic espresso machines is automatic flow stopping by using internal timer cut off for the shot (Oden, n.d.). There is no control need of user to stop brewing unlike semi-automatic machines.

Super automatic espresso machines can grind and tamp the grounds. There are many controllers in some machines which allow to change values such as cup volume, coffee temperature, brewing time, strongness and grind size also

including automatic milk froth and milk steam operations. Super automatic machines are categorized as most programmable ones helping to improve personalization (Haydon, 2018).

Figure 6-10. Super automatic coffee machine

Saeco, Xelsis

The futures are compared between semi-automatic coffee machine and fully automatic coffee machine by De'Longhi.

Features	Semi-Automatic Coffee Machine	Fully Automatic Coffee Machine
Built-in bean grinder	-	+
Integrated steam wand	+	+
Automatic grinding and brewing	-	+
Automatic milk dispenser	-	+
Automatic cleaning function	-	+
Hand-on brewing experience	+	-
Beverage personalization	+	+

Table 6-1. Automatic coffee machines future comparison.

De'Longhi

Chapter VII.

PROPERTIES OF BREWED COFFEE

7.1 Strength

The strength of the coffee is known as the soluble concentration which is the ratio of solids to the total amount of liquid. Dissolved coffee solids are soluble parts of roasted and ground coffee which dissolved and extracted by water which include chlorogenic acids, esters, and caffeine, organic acids such as citric, malic, lactic. These compounds, which vary according to many factors, form the body, aroma, and flavor of the coffee. Higher concentration results in a stronger cup of coffee. For instance, in filter coffee,1-2% consists of dissolved coffee components, while the remaining 98-99% is water. Espresso is one of the most concentrated coffees; therefore, the amount of dissolved ingredients is higher than most of the varieties (Korhonen, 2019).

Total dissolved solids (TDS) are measured with using tool which is called refractometer which works by deflection of the light as it passes through coffee. Different TDS values are determined based on brewing methods (Randolph, 2019).

Brewing method	Optimal TDS value
Pour-Over	1.2 – 1.5
AeroPress	1.4 – 1.7
French Press	1.4 – 1.7
Espresso	8 – 12

Table 7-1. Optimal TDS values for brewing methods.
Fellow

A study shows the amount of total dissolved solids has a bigger effect on the perceptible taste than the amount of extraction (Batali et al., 2021). The brewing ratio is one of the most important factors plays role on the strength and

extraction, therefore a ratio is suggested different for each brewing method based on tools and techniques. In general, 1:18 is recommended regular coffee. Adding water to brewed coffee is called diluting and used to lower the strength of the coffee which does not change the extraction yield. Espresso is stronger than its diluted and milk added variations which are called espresso-based coffees.

Figure 7-1. General Coffee to Water Ratio

Little Coffee Place

TDS can be calculated by formula.

$$TDS\ (\%) = \frac{Coffee\ mass\ extracted}{Beverage\ mass}$$

7.2 Extraction Yield

Coffee extraction is the process of dissolving ground coffee with water and extract desired compounds during the brewing of coffee. After coffee encounters water, compounds such as carbohydrates, lipids, melanoidins, and acids pass from coffee grounds to water. Roasting, water temperature, brewing time, grinding

size, coffee water ratio, and pressure factors affect extraction concurrently quality in the cup. Water is used as a solvent to extract the coffee which dissolves compounds giving different aromas such as sugars, oils, and acids. Acids and oils are the first dissolved components in the brewing process. Acids are easily soluble by water and contribute to the sour taste. Oils add body to coffee which is not dissolved easily as acids. Light aromas, floral and fruit flavors are extracted by the dissolution of oils. After that, sugars are dissolved which gives sweetness to the coffee and it is followed by dissolving plant fibers which are dry and bitter.

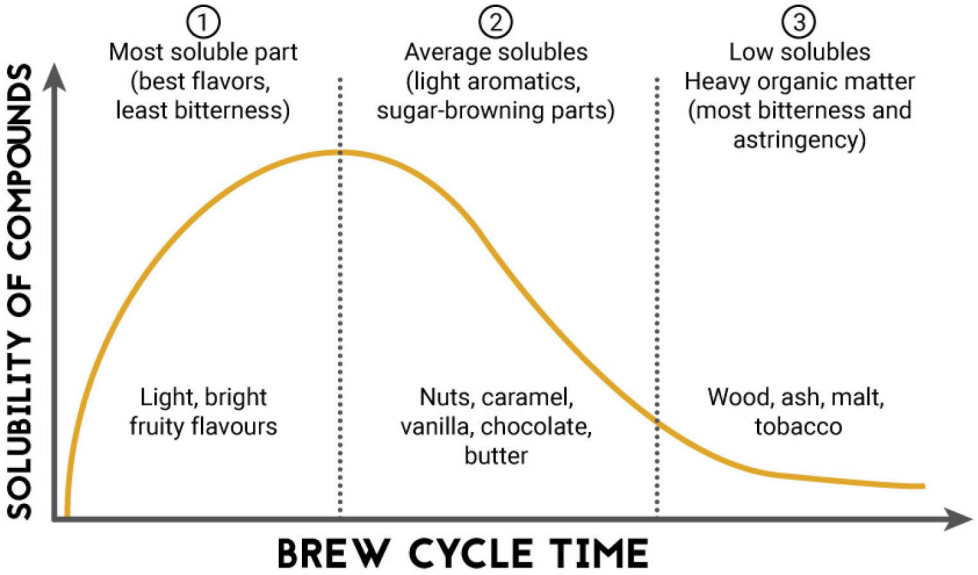

Figure 7-2. Solubility of coffee compounds by extraction

Tico Coffee

It is reported that extraction, pressure, coffee/water ratio, water quality, contact time, particle size distribution, and temperature factors modify the extraction of bioactive and volatile compounds which affects the flavor of coffee (Cordoba et al., 2020).

7.2.1 Calculating Extraction Yield

Extraction yield (EY) is the percentage of coffee grounds dissolved during brewing to total coffee grounds. Using TDS as a guide, how much coffee extracted to the while brewing can be calculated. Different extraction yield formulas are defined based on the brewing method.

The extraction yield for percolation:

$$Extraction\ Yield\ (\%) = \frac{Brewed\ Coffee\ Weight\ (g)\ x\ TDS\ (\%)}{Dose\ (g)}$$

(Wang, 2016)

The extraction yield formula for immersion: (Korhonen, 2019)

$$Extraction\ Yield\ (\%) = \frac{Total\ Water\ Weight\ (g)\ x\ TDS\ (\%)}{Dose\ (g)}$$

(Korhonen, 2019)

In one 5.5 – 6 cold brew experiment, TDS values are measured between 1,54 ± 0,06 range and extraction yield values are calculated between 20,89 ± 0,82 range by percolation formula (Angeloni et al., 2019).

7.2.2 Increasing Extraction Yield

Dissolving of a solid by water depends upon the collisions between the solvent molecules and the particles. Increasing the frequency of those collisions or giving collisions more energy will increase the rate of dissolving. For instance, the sugar dissolves faster in hot coffee than it would in cold coffee. There are several ways affect coffee extraction which are:

- Surface area,
- Agitation of the solution,
- Temperature,
- Pressure,
- Brewing time,
- Brewing ratio.

Grinding level can strongly affect extraction yield, total dissolved solids, total phenolic content, pH, and titratable acidity (Cordoba et al., 2019). The size of the ground coffee changes the surface contact area of the coffee with water and the extraction time. Finer grinding size increase contact surface area of coffee and water therefore the molecules inside the coffee beans reveals tends to get extracted more. Extraction changes with the amount of time which coffee is in

contact with water. There is a direct proportion between the brewing time and extraction until solute becomes saturated. Another fact is that there should be enough amount of solvent which is water in this case to get the aromas in the coffee to the desired consistency. An appropriate ratio should be defined and used, considering both the strength and extraction off the coffee. Water temperature directly affects the extraction due to heating process gives water molecules more kinetic energy. Rapid motion in water molecules collide with the coffee with greater frequency which allow occurring with more force. Higher temperature increases the rate of solving while affecting amount of solute that dissolves. The recommended brewing temperature for espresso is 93 ± 3 ° C as already explained in previous chapters. The brewing water temperature has a minimal effect on the taste when the extraction efficiency is constant. However, this research covers 87 °C, 90 °C, and 93 °C degrees. It does not include cold brewing conditions (Batali et al., 2021). It can be changed according to the brewing type such as cold brewing. Stirring is another factor which accelerates extraction which allows freshwater molecules to be in contact with the solute. However, stirring does not affect the overall amount of solute which dissolves. Neither of is not proportional to the caffeine increase because it is one of the first extracted compounds from coffee.

7.2.3 Water Importance for Extraction

Water acts as a solvent in the coffee. It plays dual and important role in the preparation as the solvent and as the main ingredient. In all types of coffee, water exists more than 90% of total, while the remaining percentage is the extracted coffee. Water quality effects the extraction and quality of the coffee. It contains natural minerals and chemical substances such as Chlorine which cleans microbiology and bacteria in water. However, its oxidizing effect can make the coffee more bitter when it is not filtered. Therefore, activated carbon filters are used or water is rested for a while by taking advantage of the rapid evaporation of chlorine leaves.

Calcium carbonate and magnesium are compounds that determine the hardness of water. Knowing the hardness and preparing the coffee accordingly

increases the quality of the coffee. It can be measured using objects such as water hardness test strips as many of the products offers.

Characteristic	Target	Acceptable Range
Odor 1	Clean/Fresh, odor free	
Color 2	Clear color	
Total Chlorine	O mg/L	
TDS 3	150 mg/L	75-250 mg/L
Calcium Hardness	4 grains or 68 mg/L	1-5 grains or 17 mg/L – 85 mg/L
Total Alkalinity	40 mg/L	At or near 40 mg/L
Sodium	10 mg/L	At or near 10 mg/L

Table 7-2. Determined water standards.
(SCAA, 2009)

Calcium carbonate concentrations below 60 mg/l is considered soft; 60 – 120 mg/l is slightly hard; 120 – 180 mg/l is hard; and more than 180 mg/l is considered very hard (McGowan, 2000). The pH value of drinking water should be between 6,5 and 8,0, as neutral as possible. A water sample can be characterized by the checking the hardness and alkalinity measurements. In different brewing methods, the ratios of water to coffee are very different, but still total hardness and alkalinity (both over 100 ppm CaCO3) could result in quality cup (Wellinger et al., 2017).

7.3 Brewing Control Chart

Brewing control chart is graph prepared by the Specialty Coffee Association to check if the coffee is “ideal”. Y-axis shows strength of the brewed coffee and X-axis shows the extraction. Red diagonal lines show the brewing ratio, in other words, the water and coffee used in the brewing process. Extraction value can be determined with using the graph with water, coffee amount, and strength values. The aim here is to reach the ideal, to enter the optimum balance zone. The optimum region was determined in the 1950s by surveys conducted by the Coffee

Brewing Institute. The SCAA has been repeated the questionnaire today and has received people's confirmation that the chart is still valid today. The chart assumes that the brewing is done with 1.9 liters of hot water, regardless of the weight of the coffee. The study concluded that the soluble coffee substance of optimum coffee has a strength between 1,15 – 1,35% and extraction between 18 - 22% in USA. Yields below 18% are considered underdeveloped, the resulting drink is associated with a sour taste. The reason is that acids are extracted earlier than sugars and bitter compounds during brewing. Yields above 18% are considered overly extracted and the bitter aftertaste of the beverage is predominant (Schulman, 2007).

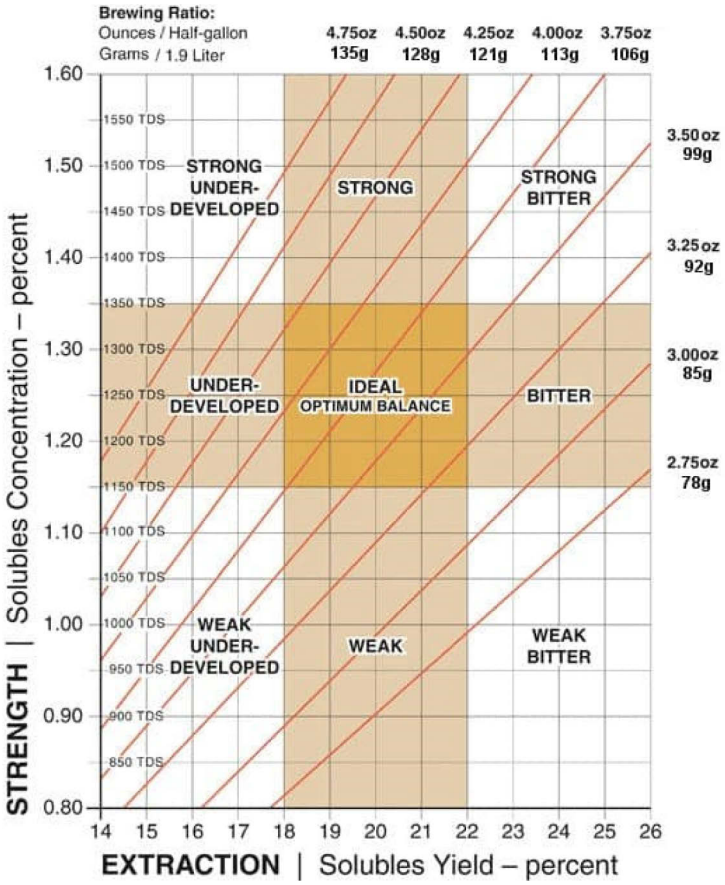

Figure 7-3. SCAA brewing control chart.

Golden Cup Standard, SCAA, 2015

There is European version of the brewing control chart. Although the strength standard preferred by the Special Coffee Association Europe is higher than SCAA (orange rectangle), the ideal extraction range is the same.

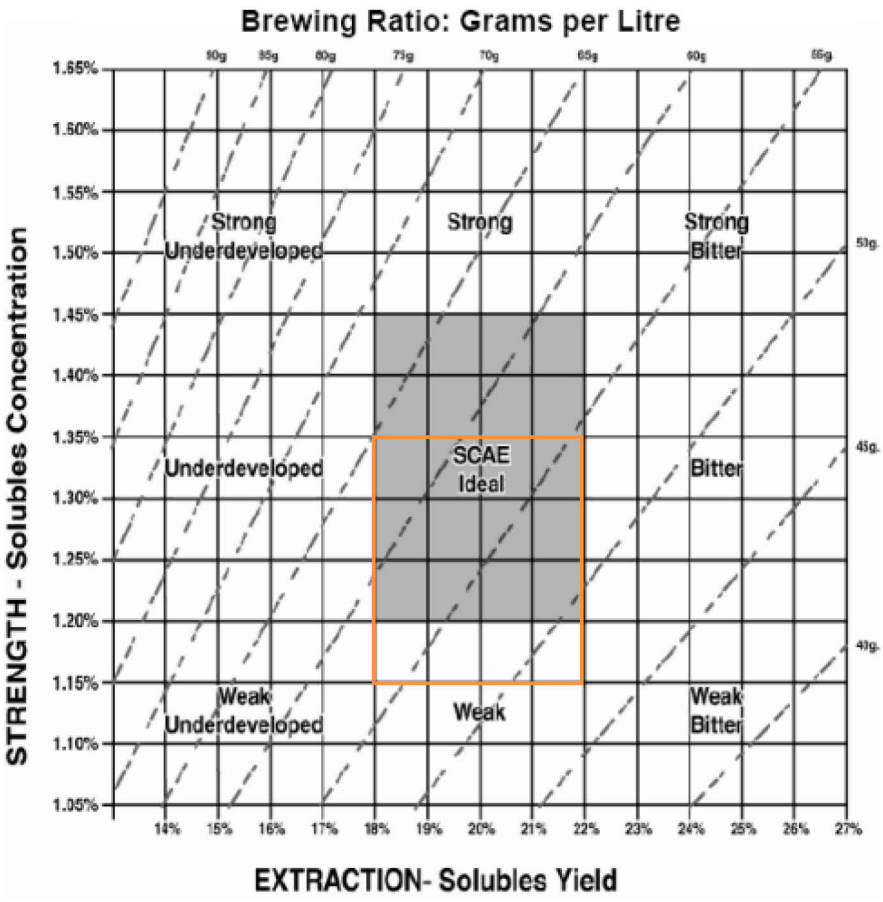

Figure 7-4. SCAE Brewing Control Chart

SCAE

7.3.1 Interpretation of the Chart

Information is provided about how to read the chart and meaning of the zones are explained.

- The brewing rate is the rate of water used per unit of coffee.
- Strong is the condition that the coffee particles dissolved in water are high.
- Weak is the condition that the coffee particles dissolved in water are low.
- Underdeveloped is the condition that coffee grounds do not have sufficient extraction.
- Bitter is the condition that coffee grounds are excessive extraction.
- Ideal optimum balance is the condition that the coffee grounds dissolved and extracted in water are within the optimum balance range.

Chapter VIII.

COLD BREW ACCELERATION TECHNOLOGIES

8.1 Stirring

Cold brew coffee can be prepared in a shorter time than traditional cold brewing methods with the spinning technology used in some products. Dissolving coffee in water will occur quickly if the mix is stirred by allowing fresh solvent molecules to contact with the coffee. The solute becomes saturated if it is not stirred which affects the rate of the brewing process.

Figure 8-1. CuisinArt automatic cold brew coffeemaker.

CuisinArt

The CuisinArt cold brewer product works with this technology and is similar in structure to the immersion method. Before the valve is opened, coffee and water are added to the upper compartment. Unlike traditional methods, the coffee-water mixture rotates while brewing. As stated by the company, the brewing can be completed at 3 different times. It is possible to reach mild brew in 25 minutes, medium in 35 minutes, and bold in 45 minutes.

Figure 8-2. Dorothy rapid cold brewer.

Presto

Presto Dorothy product uses the same technology. The firm claims that the cold brew is completed in 15 minutes. The user can change the brewing speed and the resulting change will affect the whirlpool speed. After the water is added to the glass carafe, the speed is adjusted, and coffee grounds are added into the water. After the brewing process is completed, filtering is completed by pushing the plunger down. The brewing capacity is 650 mL.

8.2 Sonic Vibration

Sonic Dutch claims that cold brew time is reduced to 5 minutes with sonic vibration technology. This technology uses a sound wave vibration system. The brewed coffee capacity is 1 liter. The song can be played by connecting another device to this product that provides Bluetooth connectivity. The new technology used can connect the sound waves in the speakers to the magnetic circuit and the coffee is extracted with the vertical vibrations created which increases agitation of the solution. The TDS values between 3,56 – 3,66 is reached with 100 grams of coffee and 500 mL of water.

Figure 8-3. Sonic Dutch cold brewer.

Sonic Dutch

It can be set up to 1 hour and the coffee is brewed with sound waves from 20 to 35 Hz. At the same time, the vibration intensity can be adjusted from 0% to 99%.

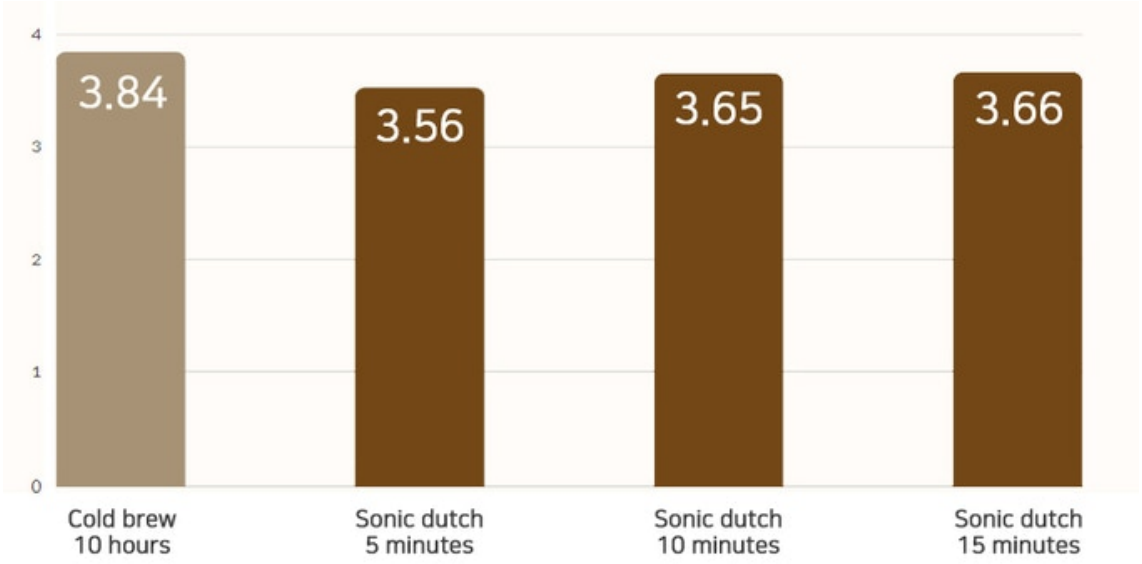

Figure 8-4. Sonic Dutch brewer total dissolved solids values.

Sonic Dutch

8.3 Vacuum

Figure 8-5. Gourmia GCM7800 Brewdini cold brew coffeemaker.

Gourmia

With its vacuum technology, Gourmia Brewdini offers cold brewing in 4 different strength options. According to the company's product description, it brews lightly in 2 minutes, medium in 4 minutes, strong in 7 minutes, and concentrate in 15 minutes. After brewing is completed, the brewed coffee is automatically poured into the carafe below. With suction power, the brewing time is reduced, and coffee is obtained in a shorter time compared to traditional cold brewing methods.

Figure 8-6. Dash cold brew coffeemaker.

Dash

Another product that works with vacuum technology is Dash Cold Brew which is used in the experiment in further chapters. It has a carafe of 1250 mL. While using vacuum technology, it also creates circulation and extracts the cafe. Coffee is poured into the coffee container on the left and the carafe on the right is filled with water. The water moves through the coffee matrix while the upper and lower filter in the coffee keeps the ground coffee grounds contained. It forces the water to permeate the structure of the grounds, thereby dissolving and extracting the coffee oils. The product offers brews of different strengths between 5 minutes and 15 minutes.

Chapter IX.

CONSUMER RESEARCH

9.1 Coffee Consumers Survey

9.1.1 Data and Method

Coffee consumer survey conducted to investigated how often coffee drinkers consume coffee and iced coffee, how often do they drink iced coffee, which type of iced coffee and ice do they prefer, and how interesting the iced coffee function is for them for the ones who has coffee machine at home.

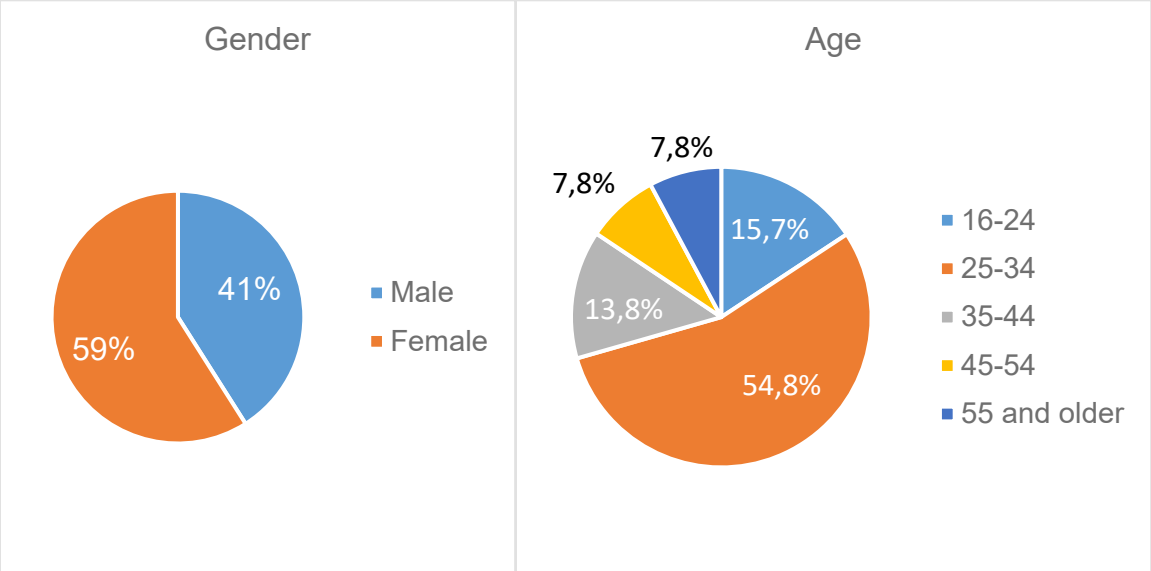

Figure 9-1. Consumer gender and age distribution.

Survey is prepared by using Google Forms and 217 respondants participated in June 2020 from Facebook coffee groups and social circle by sending the survey link. Google Forms pie charts are collected and used to analyze the results of the survey. 54,8% of the participants are aged between 25-34. Majority of the respondents are from Europe with 71,9% while 13,4% are from Asia and 11,5% are from North America.

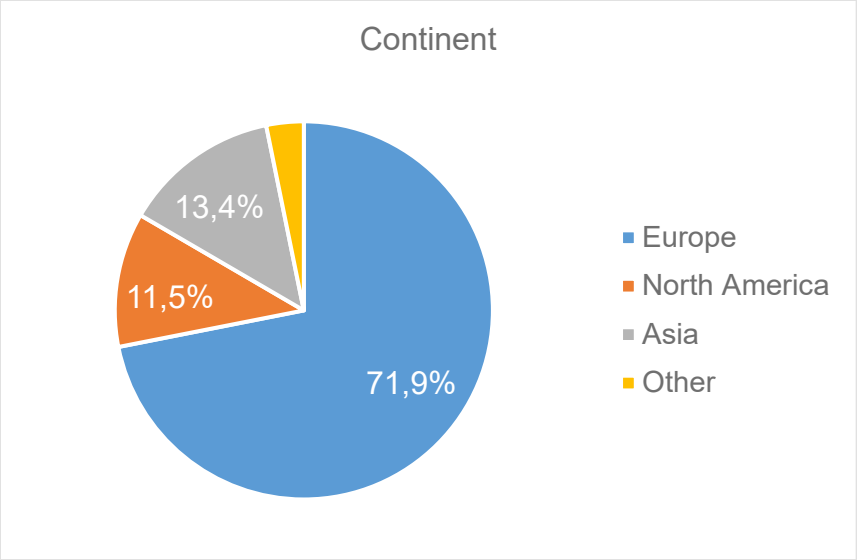

Figure 9-2. Consumers living place.

9.1.2 Results

According to the survey results, 61,8% of the people drink coffee 1-3 times a day. People who drink coffee several times a week and more than 4 times a day constitute a minority with 38,3% in total.

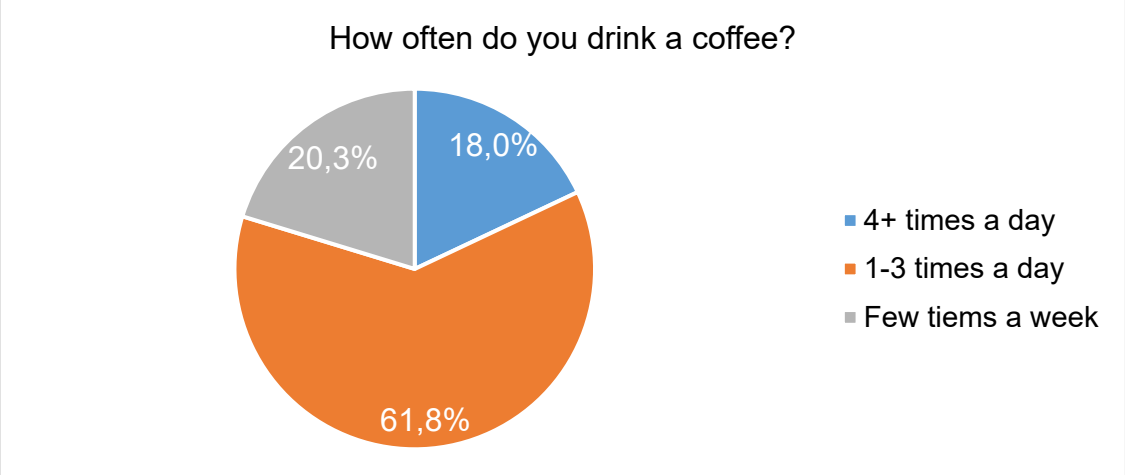

Figure 9-3. Frequency of coffee consumers drink coffee.

22% of the respondents never drink iced coffee, while 13% of the respondents drink every day, 28% drink few times a month, 29% drink few times a week, and 8% selected other and stated that they only drink when the weather is hot.

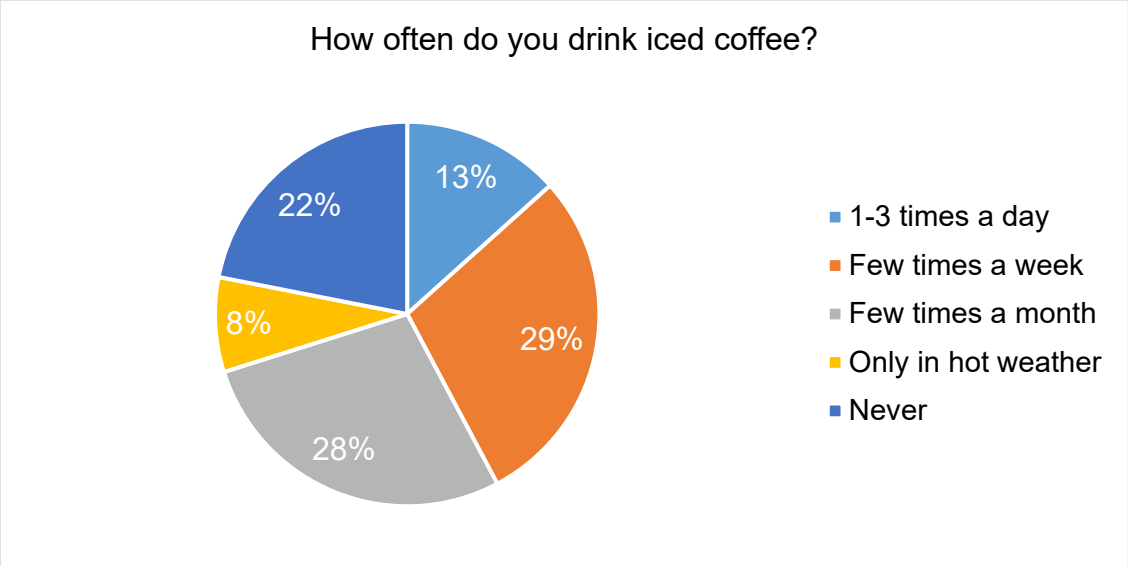

Figure 9-4. Frequency of coffee consumers drink iced coffee.

Although the responses for the ice type preferences are similar, ice cubes (55,3%) is slightly higher than blended ice (44,7%). When asked about type of iced coffee preferences; iced latte is the most preferred one which is followed by cold brew, iced americano and iced cappuccino.

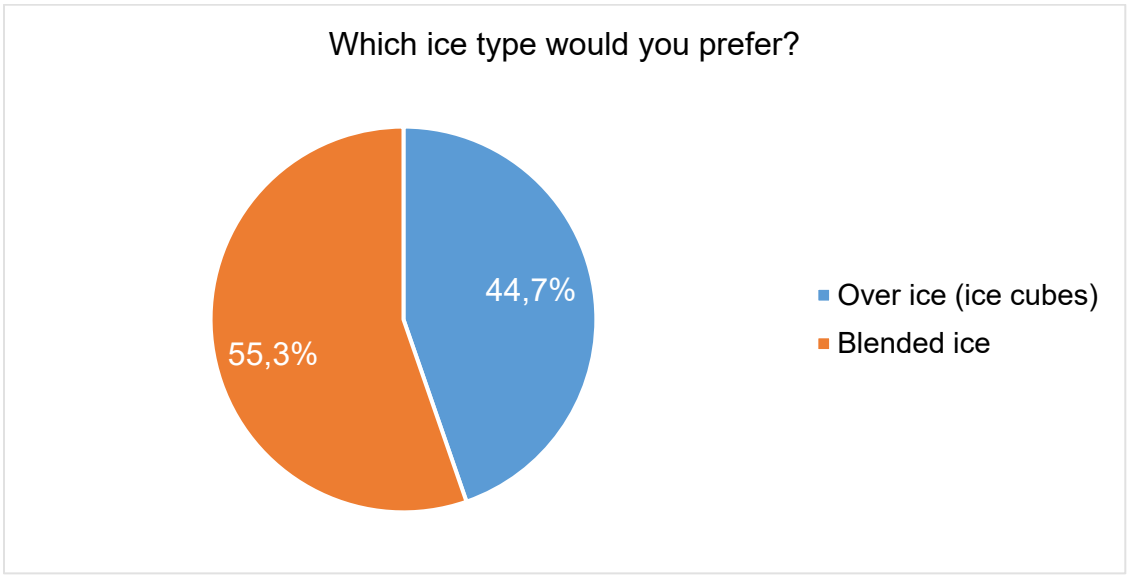

Figure 9-5. Coffee consumers' ice preferences.

Half of the survey respondents have an automatic coffee machine at home and 70,1% of these people stated that seeing the iced coffee feature in their machines would be interesting for them.

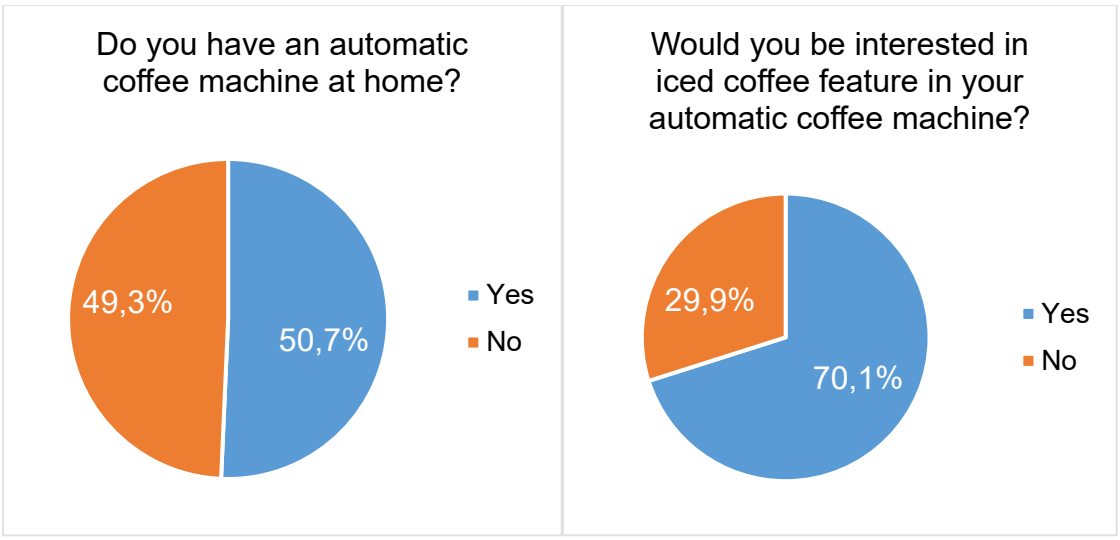

Figure 9-6. Automatic coffee machine owners' interest in iced coffee feature.

9.2 Fully Automatic Espresso Machines Users Survey

9.2.1 Data and Method

User survey was conducted to find out the fully automatic espresso machine owners' thoughts about cold coffee to investigate do they drink cold coffee, when and where do they drink, their cold coffee and ice type preferences, how they would be interesting to see the cold coffee future in their machines and how often would they use the future.

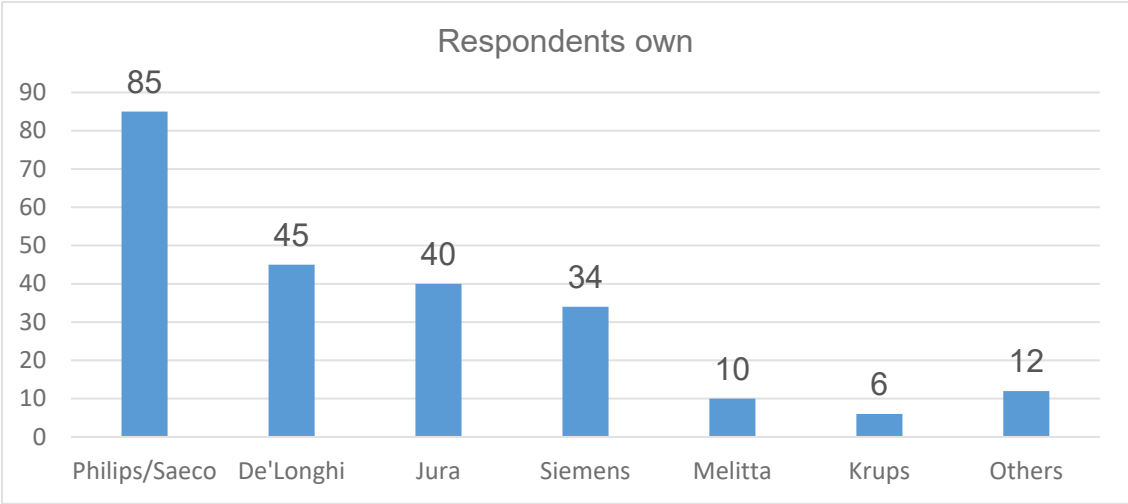

Figure 9-7. Users' fully automatic espresso machines.

248 people from Netherlands participated to the survey from panel who are holders of different brands of fully automatic espresso machines. Most of the participants are aged between 45 and 64, which is the Philips' product target.

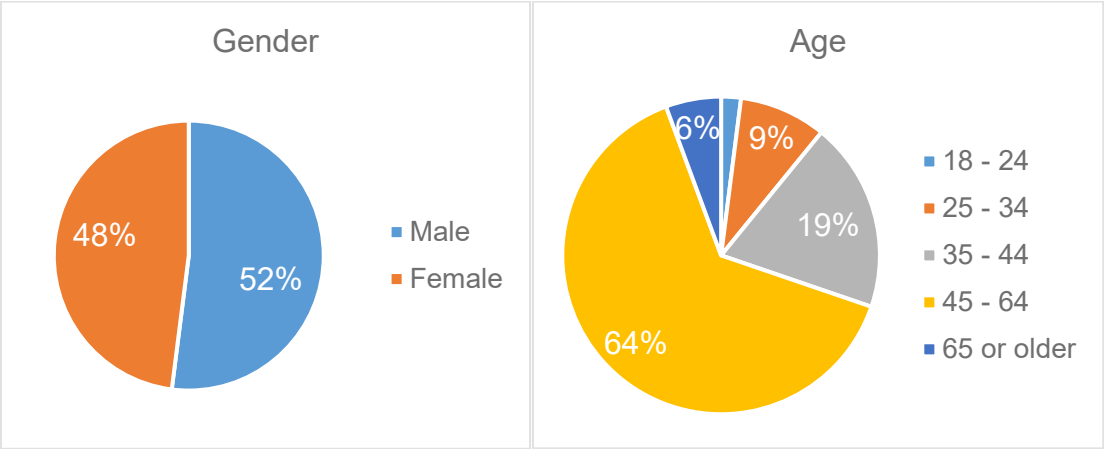

Figure 9-8. Fully automatic espresso machines users' gender and age.

9.2.2 Results

31% of the respondents drink cold coffee and, 79% of the cold coffee drinkers stated that they prefer cold coffee during the hot season.

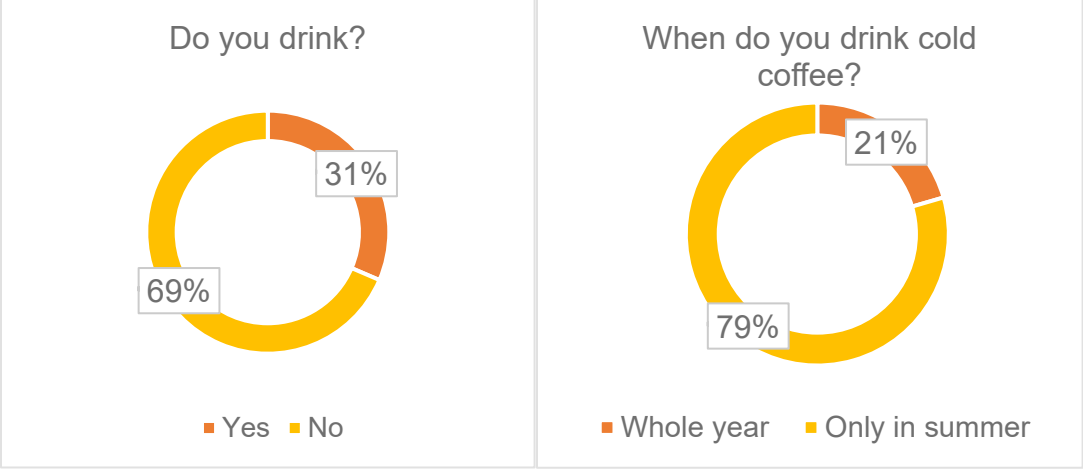

Figure 9-9. Fully automatic espresso machine users' cold coffee consumption.

30% of respondents who drink cold coffee stated they drink it at home while 36% drink in cafes or restaurants, and 34% drink as ready to drink from the supermarket. According to ice preference answers, 57% of the respondents prefer crushed ice while 23% prefer ice cubes and 20% prefer no ice.

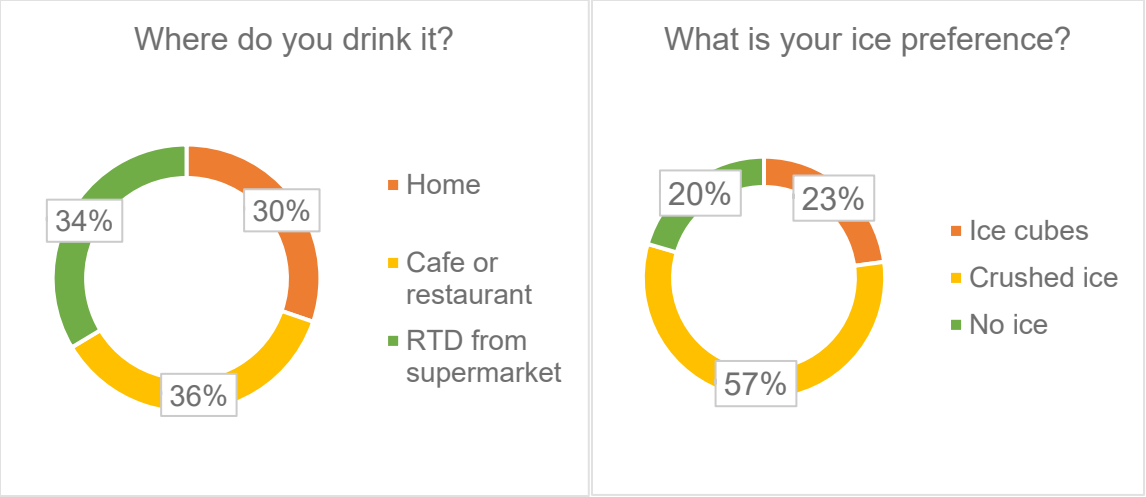

Figure 9-10. Where cold coffee is consumed and what is the ice preference.

60.1% of the people are interested to see a cold coffee function in their fully automatic espresso machines. 40,8% of the people mentioned they would use at least once per week cold coffee function while 21,4% would never use it.

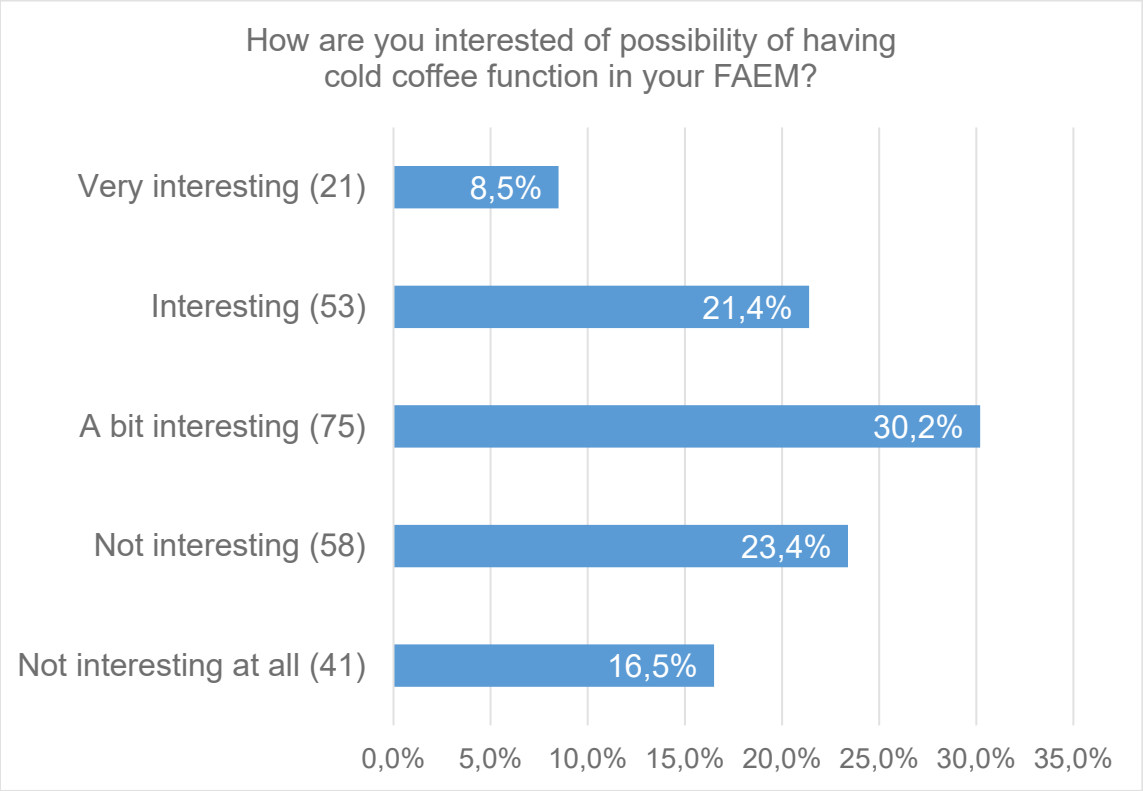

Figure 9-11. Users' interest in cold coffee function.

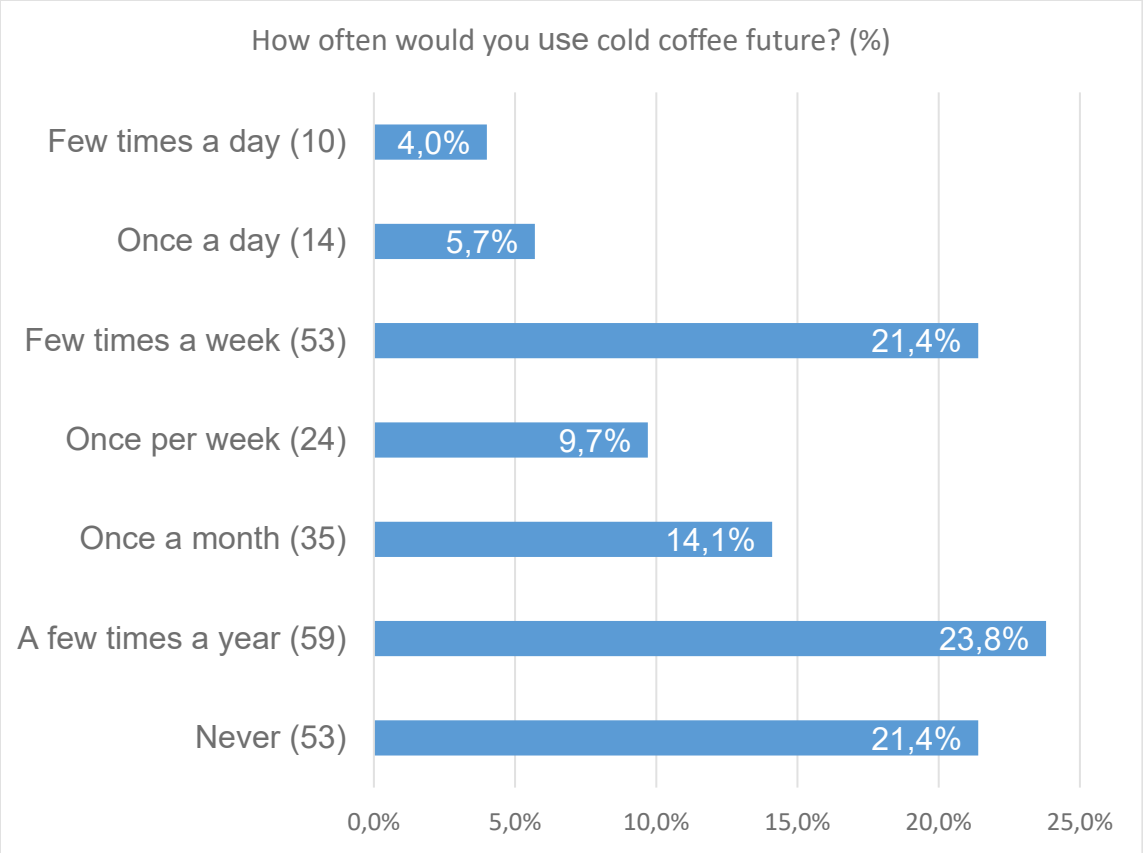

Figure 9-12. How often cold coffee function would be used?

9.3 Interviews

9.3.1 Data and Method

An interview was held in Starbucks Roastery Reserve Milano to learn about the thoughts of people consuming cold coffee. First of all, people who drink coffee were asked whether they consume cold coffee or not. Then, the answers were investigated to the questions of when they drink cold coffee, whether they prepare it at home, how they prepare it at home, do they make cold brewed coffee at home, which cold coffee and ice type they prefer, and whether they use any other ingredients.

9.3.2 Results

As a result of the interviews, it has been revealed that coffee consumers like cold coffee, and most of them prefer it during hot seasons. Some coffee consumers stated that they do not know about cold brewed coffee and some have not tried it yet. Cold coffee at home is usually prepared by mixing hot espresso with ice cubes and sometimes milk. Cold brewed coffee is generally consumed in coffee chains or bought ready-to-drink from supermarket.

"The cold brewing method is time-consuming, and you need to give lots of effort to prepare. Also, there was another interviewer who mentioned, I drink coffee whenever it comes to my mind at that moment so that is the reason cold brew is not a sufficient way of brewing for me." Is quoted from one interviewer.

Chapter X.

CONDUCTED EXPERIMENTS

10.1 Traditional and Accelerated Cold Brew

10.1.1 Data and Method

In the research, it was aimed to reach the cold brew extraction value obtained by traditional methods with a fully automatic espresso machine. Therefore, to determine the targeted extraction values, coffee was cold brewed with traditional methods which are immersion and cold drip. Dripster 2 in 1 product was used in the experiment which offers both immersion and cold drip method.

Illy Classico beans were used in the experiment which was classic roast (medium), illy blend and 100% arabica. Coffee beans were grinded with Breville BCG800XL Smart Grinder in the coarsest level. Particle sizes were measured with Malvern Mastersizer 2000 which uses laser diffraction system and in both brewing methods mean 880 μm coarse grind size was used with coffee to water ratio 1:8. Brewing was completed in room temperature (21 – 23 °C) with using water at room temperature. Sartorius CPA2202S weigher was used in all weighing measurements.

Figure 10-1. Measuring particle size distribution (Malvern Mastersizer 2000).

Cold drip brewing was completed in 6 hours 40 minutes as experimented in some researches (Angeloni et al., 2019; Fuller and Rao, 2017). Immersion brewing was completed in 6 hours 40 minutes and 15 hours to see effect of the brewing time on the results. 75 grams of coffee used with 600 mL of water in immersion method and 50 grams of coffee used with 400 mL of water in cold drip method. Total dissolved solids (TDS) measurements were checked 3 times for each brew with VST LAB Coffee III Refractometer, the average of 3 results was considered as a final total dissolved solids result. TDS values are used to calculate extraction yield (EY) of the coffees.

Extraction yield in percolation (Wang, 2016):

$$Extraction\ Yield\ (\%) = \frac{Brewed\ Coffee\ Weight\ (g)\ x\ TDS\ (\%)}{Dose\ (g)}$$

Extraction yield in immersion (Korhonen, 2019):

$$Extraction\ Yield\ (\%) = \frac{Total\ Water\ Weight\ (g)\ x\ TDS\ (\%)}{Dose\ (g)}$$

Dash Cold Brew was also explored to see the results from a product which claims it shortens cold brewing time to 5-15 minutes with vacuum technology. Medium grind size (mean 541 μm) was used as it was suggested in the manual and brewing was completed in 15 minutes and 30 minutes with room temperature water. Illy Classico beans were used in the experiment which was classic roast (medium), illy blend and 100% arabica. Coffee beans were grinded with Breville BCG800XL Smart Grinder at the 12th level in espresso section. Particle sizes were measured with Malvern Mastersizer 2000 which uses laser diffraction system. Coffee to water ratio kept the same as 1:8. 150 grams of coffee used with 1200 mL of water. Sartorius CPA2202S weigher was used in all weighing measurements. Total dissolved solids measurements were checked 3 times for each brew with VST LAB Coffee III Refractometer, the average of 3 results was considered as a final total dissolved solids result. TDS values are used to calculate extraction yield of the coffees. Immersion extraction yield formula is used in Dash Cold Brew.

10.1.2 Results

In immersion method the TDS value was measured as 2.39% and the extraction yield value was calculated as 19,10%. In 15 hours with the same brewing method, the TDS value was measured as 2,58% and the extraction yield value was calculated as 20,66%. 8 hours and 20 minutes more brewing provided an increase of 0,19% in the TDS value, and 1,56% increasement was observed in the extraction yield value.

In cold drip method, the TDS value was measured as 2,92%, and the extraction yield value was calculated as 18,76%.

As a results of 15 minutes brewing with Dash Cold Brew product, the TDS value was measured as 1.86% and the extraction yield value was calculated as 14.85%. Brewing time was increased to 30 minutes to enhance values. TDS value was measured as 2.54% and the extraction yield value was calculated as 20.34% with 30 minutes of brewing.

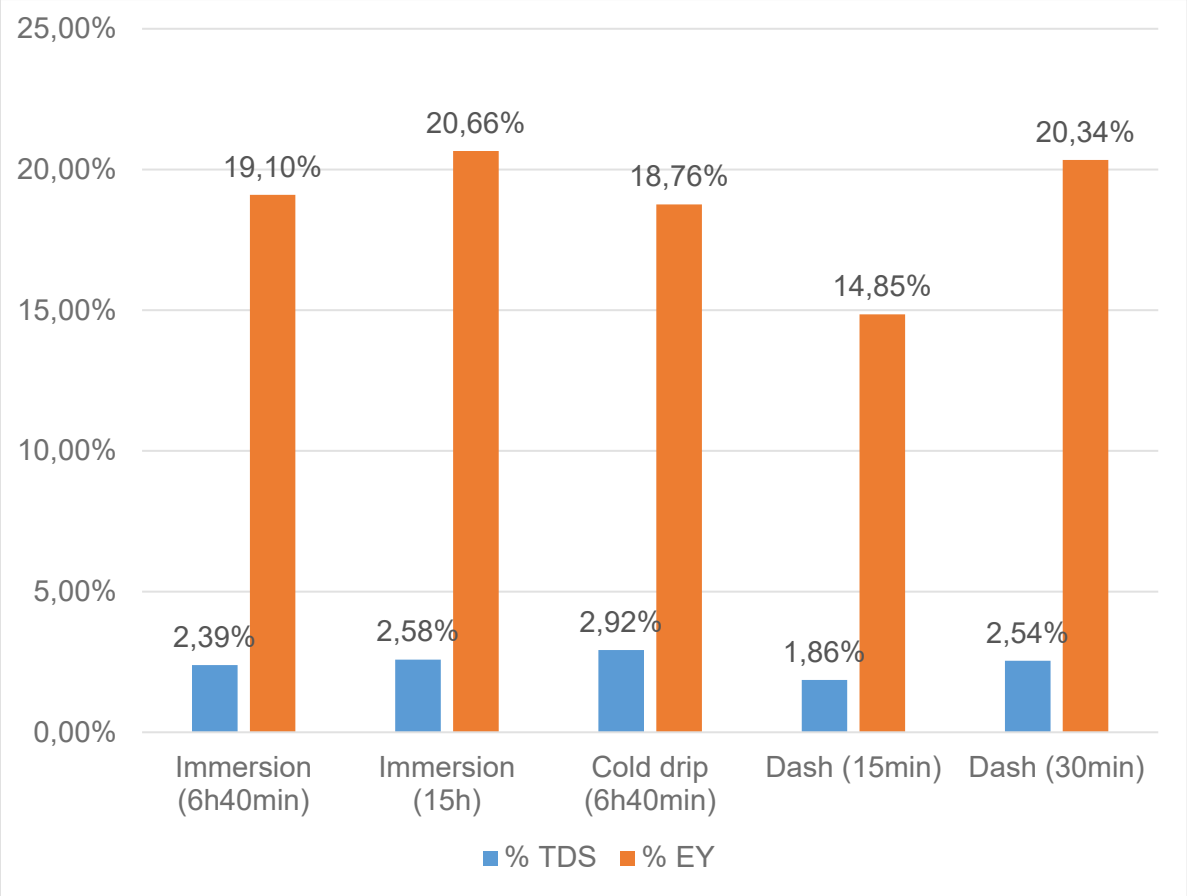

Figure 10-2. EY and TDS values of traditional and accelerated cold brew.

10.2 Fully Automatic Espresso Machine Cold Brew

10.2.1 Data and Method

Design of an experiment was made to define new cold brewing parameters of Philips 3200 Series EP3221/44. After definition of parameters, measurements were taken to understand closeness with traditional cold brewing results. The standard temperature, pressure, brewing time and grinding size data of each method was checked to estimate design of the experiment parameters for Philips cold brew.

Method	Water temperature	Pressure	Brewing time	Grinding size
Traditional cold brew	21 – 23 °C (Ambient)	1 bar	400 minutes	880 µm
Dash cold brew	21 – 23 °C (Ambient)	Unknown	30 minutes	541 µm
Philips 3200	90 – 96 °C	9 bars	35 seconds	Fine

Table 10-1. Existing brewing parameters.

The factors of the experiment and the levels of the factors were determined. After temperature drop comparing to standard Philips 3200 hot brew, the parameters with current settings will be insufficient to provide adequate extraction. For this reason, brewing time, coffee volume, and grinding size parameters were selected to change for enhancing extraction yield. Illy Classico classic roast (medium), illy blend and 100% arabica beans were grinded with Breville BCG800XL Smart Grinder at finest level (mean 339,42 µm) and at 8th level (mean 472,12 µm). Particle sizes were measured with Malvern Mastersizer 2000 which uses laser diffraction system.

Factors	Level 1	Level 2	Level 3
Temperature	21 – 23 °C (Ambient)	40 °C	60 °C
Brewing time	90s	180s	360s
Volume	120 mL	240 mL	360 mL
Grinding size	339,42 µm	472,12 µm	

Table 10-2. Design of experiment factors and levels.

Three different temperatures, brewing times, coffee volume values, and two different grinding size values were determined. Three levels for the temperature factor were determined as room temperature (21 - 23 °C), 40 °C, and 60 °C. Three levels for the brewing time factor were determined as 90 seconds, 180 seconds, and 360 seconds. Three levels for the coffee volume factor were determined as 120 mL, 240 mL, and 360 mL. For the grinding size factor, two different sizes were used which are 339,42 µm and 472,12 µm.

Figure 10-3. Grinding with Breville BCG800XL Smart Grinder.

The flow rate was determined from the relationship between the beverage volume and the brewing time.

$$Flow\ rate\ \left(\frac{mL}{s}\right) = \frac{Brewed\ coffee\ volume\ (mL)}{Time\ (s)}$$

Minitab 19 software was used to analyze data. The selected factors and their levels were inserted to find the most appropriate parameters that would provide the optimized solution. General full factorial design was created, the number of factors was chosen as four, and the determined values for each level were entered. Each variation was made for two replicates to make the results more accurate. The number of base runs required to complete the design of the experiment were 54, and the number of total runs were 108.

Figure 10-4. TDS measurement tool (VST LAB Coffee III Refractometer).

A total of 108 experimental variations were transferred to the excel table to fill data such as used dry grounds, brewed coffee weight, TDS measurements, and T_{out} after each brew. Sartorius CPA2202S weigher was used in all weighing measurements. To brew coffee in these different settings of temperature, brewing time, and flow rate parameters of the Philips 3200 Series EP3221/44 were

changed with software update. Brewing water temperature was set to 40 degrees and 60 degrees editing the boiler temperature. In cases where the brewing was done at room temperature, the boiler was turned off and water at room temperature was filled into the water tank. The temperature of the brewed coffee coming out of the spout was measured with a Fluke 52 II Dual Probe Digital Thermometer during each brew to ensure and check the temperature. Seven different flow rates were determined and adjusted by changing the standard pump settings with the software to get desired volume in cup in required brewing time. To minimize the effect of used dry grounds coffee, it is only used between 9.48 - 9.58 range in grams. The weight of brewed coffee was measured after each brewing. Coffees were filled into 3 different cups and TDS (total dissolved solids) measurements were taken with VST LAB Coffee III Refractometer. The extraction yield value for each brewing was calculated by percolation extraction formula. The TDS (total dissolved solids) value used in the formula is the average of 3 measurements in a row.

Dry grounds and brewed coffee weight, total dissolved solids values and T_{out} were measured, and extraction yield values were calculated for all 108 brewing.

Figure 10-5. TDS measurements of brewed coffees.

In Minitab, parameters with significant effect on the extraction yield and TDS values were explored. A pareto chart was used to determine the significance and magnitude of effects. The bars to the right of the reference line were defined as statistically significant.

The main effects plot used to display the means for each group within a categorical variable. Slope of the line on the graph was checked to understand main effect. Response optimization feature used to define the best brewing parameters in line with the extraction yield and total dissolved solids target inputs. The extraction yield (EY) target set as the primary priority, the importance value in the software has been increased compared to total dissolved solids value.

10.2.2 Results

All data collected from 108 brewing results were written in the excel table which includes used dry grounds weight, brewed coffee weight, total dissolved solids, and calculated extraction yield value and the data was transferred to Minitab 19 to analyze the results.

Figure 10-6. Philips cold brewed coffee.

Temperature (°C)	Brewing Time (s)	Targeted Volume (mL)	Grinding Size (µm)	Dry Grounds (g)	Brewed Weight (g)	Extraction yield (%)	Mean TDS (%)
22	90	120	339,42	9,57	121,23	17,35	1,37
22	90	120	472,12	9,53	120,88	15,52	1,22
22	90	180	339,42	9,55	166,74	17,29	0,99
22	90	180	472,12	9,55	180,83	15,46	0,82
22	90	240	339,42	9,53	246,72	17,52	0,68
22	90	240	472,12	9,55	252,75	15,70	0,59
22	180	120	339,42	9,56	125,44	18,89	1,44
22	180	120	472,12	9,52	114,73	16,87	1,40
22	180	180	339,42	9,50	185,32	18,86	0,97
22	180	180	472,12	9,50	188,75	17,09	0,86
22	180	240	339,42	9,56	248,71	20,12	0,77
22	180	240	472,12	9,57	243,51	18,41	0,72
22	360	120	339,42	9,53	123,10	19,50	1,51
22	360	120	472,12	9,57	131,68	18,67	1,36
22	360	180	339,42	9,55	186,43	20,37	1,04
22	360	180	472,12	9,52	192,01	18,76	0,93
22	360	240	339,42	9,50	224,78	20,51	0,87
22	360	240	472,12	9,50	233,98	18,80	0,76
40	90	120	339,42	9,50	112,74	20,49	1,73
40	90	120	472,12	9,51	127,60	19,10	1,42
40	90	180	339,42	9,54	172,42	20,54	1,14
40	90	180	472,12	9,53	191,17	18,72	0,93
40	90	240	339,42	9,50	226,16	20,55	0,86
40	90	240	472,12	9,55	261,15	19,32	0,71
40	180	120	339,42	9,56	131,03	21,29	1,55
40	180	120	472,12	9,49	131,32	19,70	1,42
40	180	180	339,42	9,54	187,11	20,99	1,07
40	180	180	472,12	9,50	193,92	19,60	0,96
40	180	240	339,42	9,51	242,99	20,95	0,82
40	180	240	472,12	9,51	256,63	19,70	0,73
40	360	120	339,42	9,55	120,52	21,62	1,71
40	360	120	472,12	9,52	127,28	20,14	1,51
40	360	180	339,42	9,53	202,00	23,17	1,09
40	360	180	472,12	9,57	193,24	20,39	1,01

Temperature (°C)	Brewing Time (s)	Targeted Volume (mL)	Grinding Size (µm)	Dry Grounds (g)	Brewed Weight (g)	Extraction yield (%)	Mean TDS (%)
40	360	240	339,42	9,48	235,42	21,36	0,86
40	360	240	472,12	9,48	246,30	19,83	0,76
60	90	120	339,42	9,51	110,90	22,39	1,92
60	90	120	472,12	9,56	125,19	20,65	1,58
60	90	180	339,42	9,52	162,85	22,75	1,33
60	90	180	472,12	9,54	180,37	20,55	1,09
60	90	240	339,42	9,56	230,65	22,84	0,95
60	90	240	472,12	9,51	255,79	21,79	0,81
60	180	120	339,42	9,51	135,71	22,45	1,57
60	180	120	472,12	9,48	141,38	21,43	1,44
60	180	180	339,42	9,58	190,69	22,89	1,15
60	180	180	472,12	9,49	199,67	21,88	1,04
60	180	240	339,42	9,51	241,03	22,64	0,89
60	180	240	472,12	9,50	247,53	21,45	0,82
60	360	120	339,42	9,48	134,84	22,38	1,57
60	360	120	472,12	9,58	142,13	23,19	1,56
60	360	180	339,42	9,52	195,92	23,46	1,14
60	360	180	472,12	9,53	198,76	23,22	1,11
60	360	240	339,42	9,49	220,25	24,52	1,06
60	360	240	472,12	9,58	231,93	23,32	0,96
22	90	120	339,42	9,50	124,13	17,38	1,33
22	90	120	472,12	9,54	118,61	15,50	1,25
22	90	180	339,42	9,54	172,75	16,96	0,94
22	90	180	472,12	9,57	172,73	15,52	0,86
22	90	240	339,42	9,56	237,13	19,43	0,78
22	90	240	472,12	9,57	252,70	16,64	0,63
22	180	120	339,42	9,55	130,07	19,07	1,40
22	180	120	472,12	9,51	113,56	16,60	1,39
22	180	180	339,42	9,51	178,94	19,13	1,02
22	180	180	472,12	9,54	177,62	17,25	0,93
22	180	240	339,42	9,52	243,64	19,88	0,78
22	180	240	472,12	9,52	245,82	18,25	0,71
22	360	120	339,42	9,49	128,21	19,77	1,46
22	360	120	472,12	9,54	122,12	18,31	1,43

Temperature (°C)	Brewing Time (s)	Targeted Volume (mL)	Grinding Size (µm)	Dry Grounds (g)	Brewed Weight (g)	Extraction yield (%)	Mean TDS (%)
22	360	180	339,42	9,55	189,12	20,13	1,02
22	360	180	472,12	9,55	199,93	18,98	0,91
22	360	240	339,42	9,56	224,32	20,49	0,87
22	360	240	472,12	9,52	258,09	20,15	0,74
40	90	120	339,42	9,58	120,03	20,88	1,67
40	90	120	472,12	9,57	133,71	18,72	1,34
40	90	180	339,42	9,48	167,81	21,30	1,20
40	90	180	472,12	9,57	188,14	19,59	1,00
40	90	240	339,42	9,48	221,46	20,17	0,86
40	90	240	472,12	9,56	238,47	18,21	0,73
40	180	120	339,42	9,55	132,84	21,42	1,54
40	180	120	472,12	9,56	132,87	19,23	1,38
40	180	180	339,42	9,57	187,92	20,68	1,05
40	180	180	472,12	9,57	189,45	19,33	0,98
40	180	240	339,42	9,55	246,73	20,67	0,80
40	180	240	472,12	9,56	259,70	19,29	0,71
40	360	120	339,42	9,56	129,89	21,65	1,59
40	360	120	472,12	9,52	132,58	20,05	1,44
40	360	180	339,42	9,57	198,60	22,62	1,09
40	360	180	472,12	9,52	198,68	21,43	1,03
40	360	240	339,42	9,51	240,09	21,63	0,86
40	360	240	472,12	9,57	241,75	20,55	0,81
60	90	120	339,42	9,57	116,16	22,41	1,85
60	90	120	472,12	9,53	130,81	20,63	1,50
60	90	180	339,42	9,54	152,66	22,62	1,41
60	90	180	472,12	9,51	175,25	20,52	1,11
60	90	240	339,42	9,50	221,20	21,58	0,93
60	90	240	472,12	9,58	244,35	20,58	0,81
60	180	120	339,42	9,54	137,71	22,86	1,58
60	180	120	472,12	9,48	140,68	21,42	1,44
60	180	180	339,42	9,51	187,73	22,70	1,15
60	180	180	472,12	9,48	202,43	21,71	1,02
60	180	240	339,42	9,51	235,72	22,72	0,92
60	180	240	472,12	9,51	252,83	21,09	0,79

Temperature (°C)	Brewing Time (s)	Targeted Volume (mL)	Grinding Size (µm)	Dry Grounds (g)	Brewed Weight (g)	Extraction yield (%)	Mean TDS (%)
60	360	120	339,42	9,55	136,74	23,20	1,62
60	360	120	472,12	9,52	136,00	22,38	1,57
60	360	180	339,42	9,55	197,55	23,31	1,13
60	360	180	472,12	9,53	198,91	22,61	1,08
60	360	240	339,42	9,52	234,74	24,66	1,00
60	360	240	472,12	9,50	237,52	23,17	0,93

Table 10-3. Philips cold brew measurements and calculations.

By processing the data obtained result of the experiment into the software, it was explored which parameters have a significant effect on the extraction efficiency and TDS values. The bars to the right of the reference line are statistically significant (Minitab, 2021). According to the information obtained from the chart, all factors for extraction yield including grinding size, temperature, brewing time, volume are statistically significant at a significance level α 0.05. It has been observed that the interactions of some factors with each other are statistically significant which are AB (temperature and brewing time), AC (temperature and volume), BD (brewing time and grinding size), AD (temperature and grinding size), ABC (temperature, brewing time, and volume).

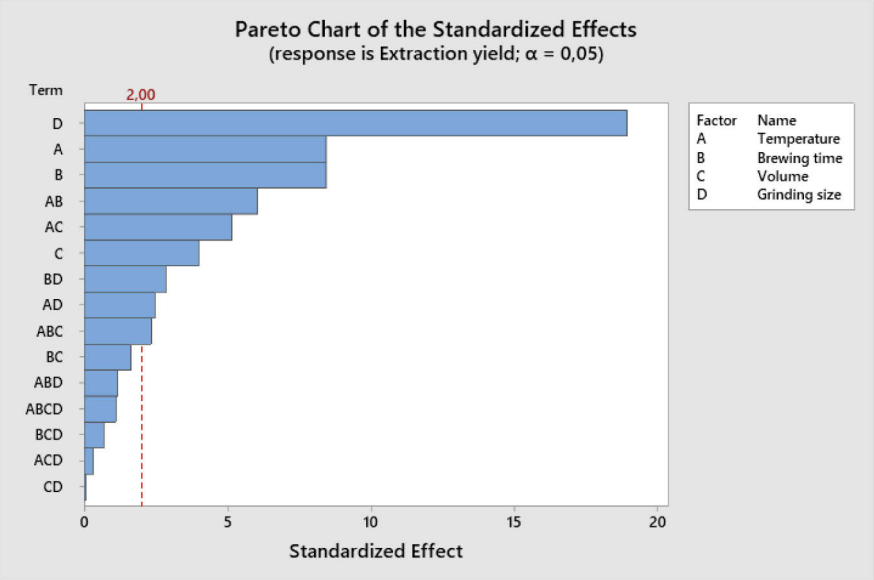

Figure 10-7. Statistically significant factors on extraction yield.

According to the information obtained from the chart, all factors including grinding size, temperature, brewing time, volume are statistically significant at α 0.05 for total dissolved solids (TDS). The dual and trio interactions of all factors with each other are statistically significant.

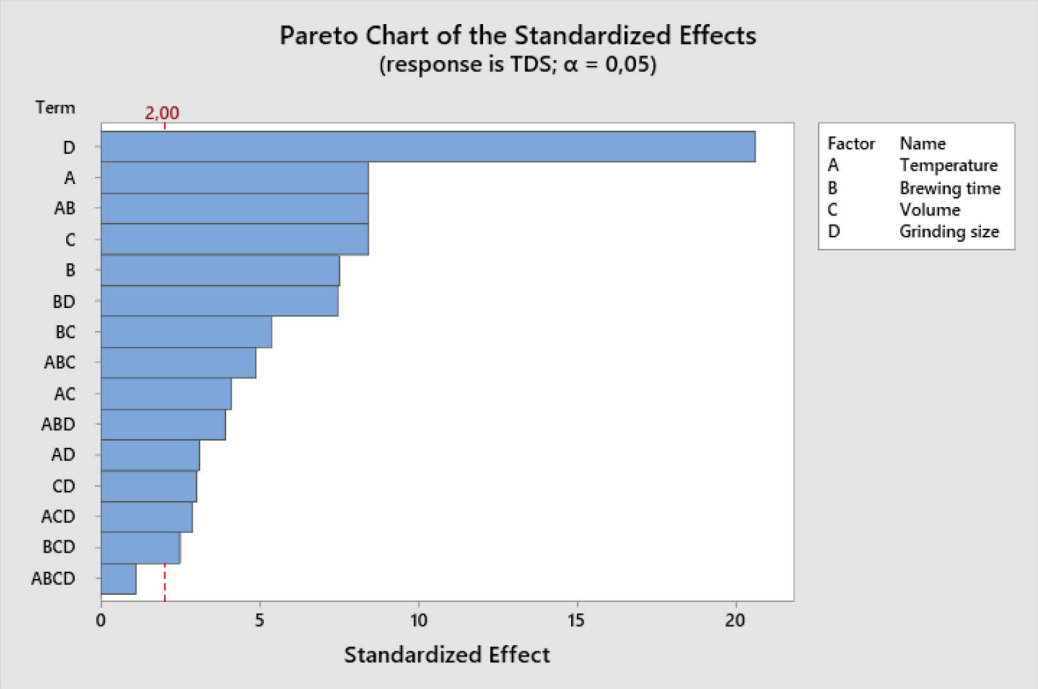

Figure 10-8. Statistically significant factors on TDS.

Temperature extraction has the biggest effect of variation among the factors for extraction yield which is followed by the brewing time and grinding. Higher slope, the greater the magnitude of the effect (Minitab, 2021)

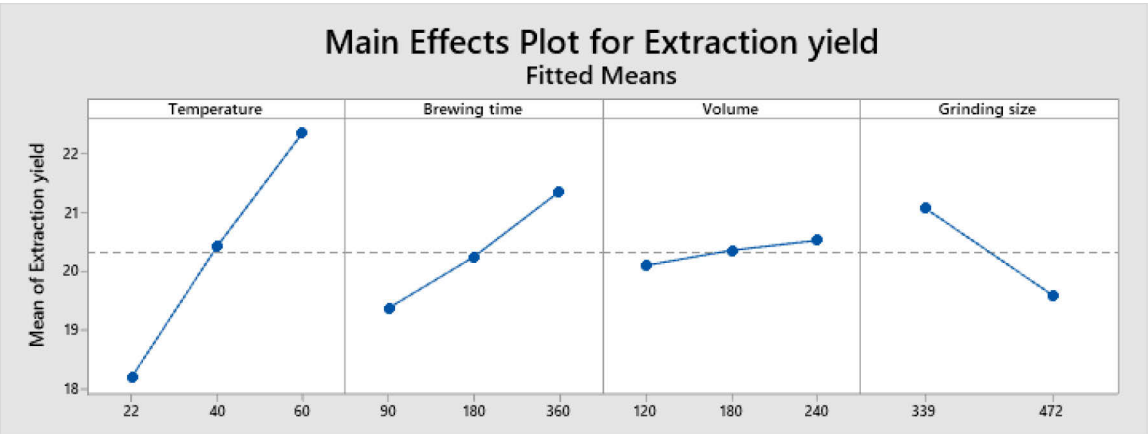

Figure 10-9. Main effects plot graphs for extraction yield.

Volume has the biggest change effect among the factors for total dissolved solids. It is followed by temperature and grinding. It is observed that total dissolved solids decrease as the volume increases.

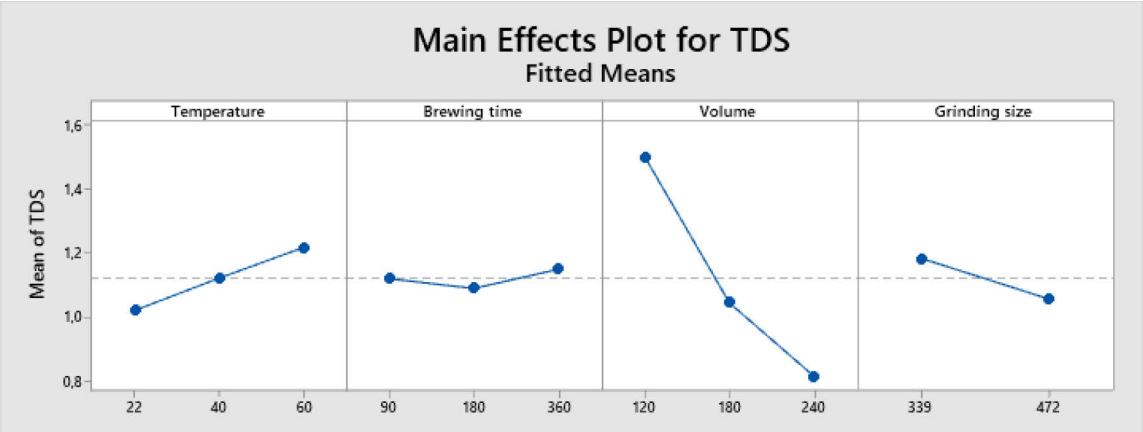

Figure 10-10. Main effects plot graphs for TDS.

Software's response optimization feature is used to define most appropriate brewing parameters with the targeted values (Minitab, 2019). The target of extraction yield was determined as 18,93 from collected traditional methods data, which is the mean extraction yield (EY) value of cold drip and immersion method in 6,7 hours. The total dissolved solids (TDS) value is tried to be maximized while meeting the extraction yield target.

Response	Goal	Lower	Target	Upper	Weight	Importance
TDS	Maximum	0,5933	1,92		1	1
EY	Target	15,4636	18,93	24,6576	1	5

Table 10-4. Defined goals to optimize the response.

After Philips Cold Brew results were checked, it was seen that the targeted extraction yield value could be reached at room temperature. Therefore, temperature value was constrained to room temperature in Minitab while other parameters have no constraints.

Variable	Values
Temperature	22
Brewing time	90; 180; 360
Volume	120; 180; 240
Grinding size	339; 472

Table 10-5. Variables and their ranges.

The optimized solution proposed by the software was brewing 120 mL in 180 seconds at room temperature with using 339 µm grinding size. These parameters offered a result which confidence interval was 1,37 – 1,46 for TDS and 18,40 – 19,56 for the extraction yield.

Temperature	Brewing time	Volume	Grinding size	TDS Fit	EY Fit	Composite Desirability
22	180	120	339	1,42	18,9813	0,917288

Table 10-6. Philips cold brew optimized parameters.

Chapter XI.

SENSORY TEST

11.1 Cold Brew Sensory Test

11.1.1 Data and Method

A sensory test was carried out with 10 coffee sensory experts in the factory to understand the perceived difference between cold brew coffee made with a fully automatic espresso machine and cold brew coffee made by traditional methods. The test included standard coffee; 120 mL brewed hot by Philips 3200. Same grams of dry grounds and 339,42 µm grinded coffee is used with Philips cold brew. After hot brewed, it is cooled down to room temperature. Extraction yield and total dissolved solids values of cold brewed coffees are kept very close to each other. Coffee obtained by the traditional method had high initial total dissolved solids, and it was diluted with water to bring it to the same strength level after brewing. The purpose was to minimize the sensory differences and avoid misleading results in sensory testing. The strength of the hot brewed and cooled coffee have not been changed.

Method	Brewed coffee	Dry grounds	TDS	Diluted TDS	E.Y.
Cold drip	349.71 g	50.05 g	2,72%	1,42%	18.95%
Philips cold brew	130.07 g	9.55 g	1.40%	N/A	19.05%
Philips hot brew	126.67	9.55 g	1.77%	N/A	23.37%

Table 11-1. Properties of sensory tested coffees.

All drinks are served at room temperature. Blind test set up which experts did not know what they were drinking. 3 coffees (Philips cold brew, traditional cold brew, Philips hot brew) were served with a sticker on the cup and asked experts to fill the form with questions about the smell, bitterness, acidity, aroma,

sweetness, body, aftertaste, overall balance, and personal evaluation for each beverage. The pleasantness was questioned with questions such as smell, aroma, aftertaste, and personal evaluation. Bitterness, acidity, sweetness, body, and overall balance were questioned to evaluate intensity. All questions were asked to be answered by grading 1-7.

Figure 11-1. Sensory test of cold brewed hot brewed coffees.

11.1.2 Results

Radar chart was created with the collected data, and it is observed that the results of fully automatic espresso machine (FAEM) cold brew, and traditional cold brew are close. The only difference in aftertaste between the two is noteworthy. A big difference is observed in the results of hot brewed and cooled coffee compared

to cold brewing. Hot brewed coffee has a strong bitterness and, according to the data, left an unpleasant taste.

Smell	Bitterness	Acidity	Aroma	Sweetness	Body	Aftertaste	Overall balance	Personal Evaluation
3,7	3,0	2,7	3,4	3,6	3,1	2,9	3,5	3,9
2,9	5,7	3,3	2,5	1,8	2,6	2,3	2,4	2,0
3,9	3,0	2,6	3,8	3,8	3,3	3,9	3,7	4,1

Table 11-2. Mean values of evaluated sensory test characteristics.

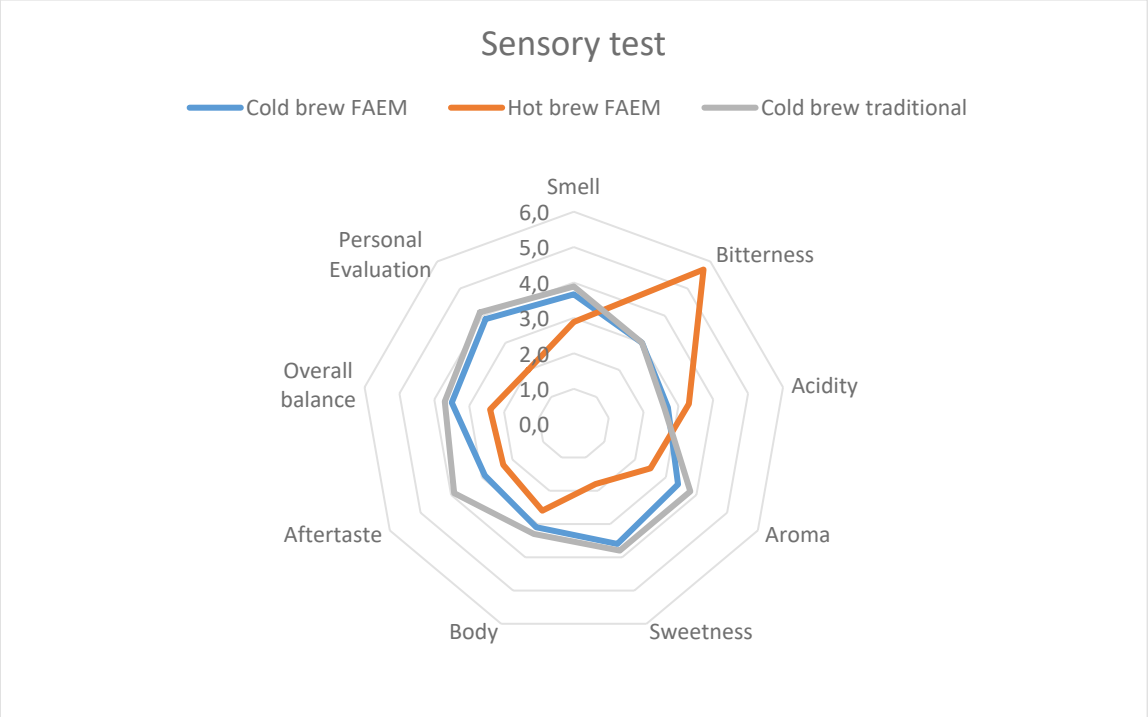

Figure 11-2. Radar chart of sensory test.

Chapter XII.

DISCUSSION AND CONCLUSION

This research aimed to reduce brewing time of cold brewing with using fully automatic espresso machine. Based on experiments findings, it can be concluded that extraction of cold brewing depends on many important factors such as temperature, brewing time, volume, pressure, and grinding size. The results indicate that cold brewing time can be reduced to 3 minutes from 6,7 hours with fully automatic espresso machines by using different brewing parameters than standard hot brewing.

Although people's interest in cold brewing has increased, the required brewing time and usage of manual tools in preparation makes it difficult to prepare cold brew at home. The findings are important in this sense to increase the popularity of cold brew and its home use. The market is focusing on solutions that can offer cold brewed coffee in a short time. Technologies such as vacuum, stirrer, sound wave vibrations are currently being introduced to the market to increase cold brew coffee extraction. However, no study has been conducted on cold brew feature in fully automatic coffee machines, which constitute an important part of home coffee machines.

As a result of the sensory test, it was observed that traditional methods and cold brewed coffee with Philips product were close. However, it is not chemically known how the compounds of the brewed coffee was affected by finer grind size and applied pressure which is different from traditional cold brewing methods. Due to the Covid-19 situation, the sensory test was limited with coffee experts. For future research, it will be important to investigate the consumer acceptability of cold brew coffee made with a fully automatic espresso machine with large quantities of cold brew consumers.

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