Ancient Beer Production

A thesis presented in partial fulfillment of requirements for the degree of Masters in Food Technology

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Abstract

Background: Beer is considered to be one of the major historical achievements of mankind over the past several centuries in the area of fermented beverages. Beer has the ability to unite people under various cultural traditions and has geographically spread out throughout the world. It varies from nation to nation under the basis of its ingredients, production processes, sensory properties etc. However, the exploration of ancient beer research has been increasing only in the past few decades given the availability of modern analytical tools. Various civilisations adapted the concept of beer into their own cultures in a unique aspect as a safe-to-drink beverage, as opposed to drinking untreated water. Based on an archaeology study of a 5000-year-old beer recipe, one such civilisation named Yangshao (in Shaanxi, Northern China) was considered for this project.

Objective: To recreate the ancient beer recipe that has been obtained from the above-mentioned Shaanxi district and adopt its ingredients into contemporary beer brewing methods. In this project, the physicochemical properties were analyzed and a focus group was conducted to understand consumer opinions and attitudes about the sensory characteristics of this beer.

Methods: Initially, the ancient ingredients were identified and prepared to suit the modern brewing process. Processes such as milling, mashing, fermentation, conditioning were fine-tuned in order to suit them for the ancient beer reproduction.

Physicochemical properties such as brix, colour, pH, specific gravity, alcohol content etc. using methods such as spectrophotometry, gas chromatography, refractometry etc., were investigated. A focus group was used collect qualitative information on the opinions of modern-day consumers on the ancient beer samples.

Results: The beer was recreated by identifying the ingredients and their proportions, adjusting various production process parameters such as milling (15mm roller gap for barley & 10mm roller gap for adjuncts), mashing (double temperature mashing with 60 minutes), fermentation (primary and secondary fermentation), conditioning (at 4℃ for 1 week) etc. Recreated beer had similar physicochemical properties to certain commercial beers such as ales, lagers, Weiss beers etc. The similarities identified included alcohol content to modern-day beers (4.1% ABV), similar pH as ales (4.2) however focus group discussions revealed some uniqueness of this beer compared to modern beers. The unique factors included its pale colour, lack of bitterness, and increased sourness in its taste to its high malty aroma.

Conclusion: The optimisations made on the physical processes resulted in a mash which yielded maximum amount of sugar extraction from the grains and a well carbonated final beer. The physicochemical analysis revealed that certain attributes of the ancient beer like pH, alcohol content were similar to some modern-day beers but overall the final beer product was unique and contrasting. The recreated ancient beer was well received by the focus group participants and most of them indicated their preference for the sample that incorporated hops. Also, the results proved that an additional carbonation process can be recommended in order to enhance the fizziness of the beer. Overall, the ancient beer proved to be feasible in modern-day brew society considering certain changes in ingredients (hops) and production processes (carbonation, filtration) are implemented in future.

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1. Introduction

Beer is known to be one of the oldest cultural achievements of mankind in the area of fermented beverages, that became popular all over the world (Preedy, 2011).

Generally, the alcohol content in commercial beer ranges from 2- 12 %. It has a huge value due to its crucial role in our society and became a part of the day-to-day life of many people. Beer was involved in many rituals, practices and was made an occasional or frequent social convention and that became a leading factor for the initial domestication of cereals (Braidwood et al., 1953).

The basic ingredients to manufacture beer are water, malted barley, hops, and yeast, and as such it is fixed in Germany by the legislation governing commercial brewing, the Reinheitsgebot (Purity Law) (Sloane, 2012). Barley which is majorly employed for beer production is well known for its high yield of fermentable material that is easily and readily obtained from the stored-up starch. Hops is another main ingredient that is generally prepared in processed forms like sized pellets or extracts that are made with the help of liquid carbon dioxide. It also provides many interesting possibilities from a health perspective. Water also plays a vital part in beer as mostly all beers contain more than 90% of water. Since the water content in beer is so critical, it must be ensured that the water being used is of good quality. (Bamforth,2004).

The beer production process typically consists of individual procedures such as malting which is followed by mashing, boiling, and fermentation (Xu ,2007). It is a basic fact that beer is a product of fermentation of barley extracts by yeast. The sugars which are converted into alcohol mostly arise from the starch content in barley. It is soaked and steeped into water, then the enzymes which are present inside the malt later break down the starch molecules, thus resulting in the production of simpler sugars like dextrins etc. that make up a sugary liquid which is commonly known as wort.

This is then flavoured with hops; Later brewing takes place with help of yeast. There are certain types of beer in general like ales, lagers etc. The type of beer that is going to be produced depends upon the ingredients, method of production and the type of yeast used. The nature of the beer is derived from these raw materials and the two separate (but related) processes that have been used to make this drink for thousands of years (Bamforth,2004).

All over the world, more than 100 beer varieties are produced, from pilsner to lager and wheat beer, as well as non-alcoholic varieties. Differences are based on the careful selection of raw material varieties, yeast and modifications in the brewing process (Back, 2005; Bamforth, 2004).

Generally, beer brewing process involves these important steps such as

(i) wort preparation that includes milling, mashing
(ii) fermentation
(iii) filtration and/or stabilization
The characteristics of the beer produced is dependent on the precision of these steps , quality, type and quantity of ingredients used. e.g., Different types/quantity of malts that are used influence the color, texture, taste and other characteristics of the beer.

Brief Background on Geographical Widespread

The geographical ranges of ingredients in beer were found to be extended up to a local place called Jiahu, which is a Neolithic site in China. Analytical methods performed on the samples concluded that the beer which was consumed utilized rice as the main ingredient. Chicha was another main ingredient that was widely used in Peru. The beer made there was corn-based, whereas the beer which was produced in Egypt and the ancient Nigh East had the sole ingredient to be different cereal grains like barley etc., (Jennings, 2005). Though the raw materials and the brewing methods vary geographically, all the methods result in the same product that contains a faint alcohol content obtained via a biochemical transformation process where sugars are converted into ethyl alcohol.

1.1. Ancient beer

The Ancient beer recipe being used in this project has been identified to originate from Neolithic Yangshao culture (Liu et al.,2019). In these regions of Northern China, people experimented and innovated to produce various alcoholic beverages where the major ingredients were broomcorn millet, triticeae, Job’s tears, rice, snake gourd roots along with yam, lilly etc.as published in (Wang et al.,2016). These reports have become to be the basis for the reproduction of the recipe in this project.

Chinese liquor is typically obtained from cereals such as sorghum by complex fermentation processes using natural mixed culture starters (Zheng et al.,2011). The recipe that was adopted was primarily based on cereals but instead of sorghum, it possessed rare grains like broomcorn millet, Job's tears etc.

Even though only minimal archaeological findings were accomplished in these regions, most of them suggest that these beverages provided social (communal drinking), spiritual and even at certain times, served medicinal purposes.

Because fermentation can help in preserving and enhancing the nutritional content in food and also because of its certain sensory advantages, fermented foods have been a vital part of many cultures. Also, evidence revealed that certain areas of agriculture, food manufacturing and even horticulture have been intensified by alcoholic beverages (Xiang et al., 2019) .

Inscriptions also revealed that Shang palace posted officials for preparing these types of drinks which the king inspected regularly. Certain sacrifices for ancestors were offerings of fermented foods stored in bronze vessels which was followed by feasting. Two other beverages called Luo (fermented fruit drink) and Lao (fermented or an unfermented rice/millet beverage) were found in documents later and were known to be a traditional addition during the Zhou period (ca. 1046–221 B.C.) (Huang H.T, 2000).

Two traditional Chinese- originated drinks named Koji & Jiugu were discovered which made their way to other countries in South-eastern Asia including Japan. They are starters for traditional oriental fermented foods and beverages like vinegar, wine, liquor, etc. (Jin et al., 2017).

Overall, Chinese liquor played a vital role in its auspicious culture which included consumption in multiple day-to-day occasions like weddings, celebrations, business occasions, etc. (W. Hao 2005).

2. Literature Review

2.1. Ingredients in Beer Production

Barley

Barley is considered vital for most beers due to their possession of a major portion of starch. This is primarily due to the presence of husk which contains α amylase (a digestive enzyme) that is vastly helpful in converting the complex starches to sugars. Also, the husk is mandatory in the sparging of the brewing process (Bamforth,2004). The production of malt for brewing has a primary requirement which is the cell wall hydrolysis that results in grain softening which aids in milling and extraction convenience (Ault, 2007).

Barley's physiology consists of an endosperm (which is the food reserve), an embryo that is packed inside protective layers. The endosperm is of the main interest amongst brewers as it is the origin from which the fermentable material is obtained, this, in turn, would be later transformed into the beer.

Commonly two types of barley are utilized in the beer brewing processes. Two rowed barley and six-rowed barley: in two-rowed barley, kernels are developed on both sides of the ear in 2 rows whereas, six-rowed barley consists of three corns on either ear side. Although there is space restriction on the ear, meaning that some of the corns in the latter type must be twisted in order to fit (Ault, 2007).

80% of the grain bill in standard malts of craft beers is diastatic in nature whereas the rest of the 20% makes up of specialty malts that are non-diastatic and are added for the flavor and color provision. The diastatic malts consist of certain active enzymes which has the ability to convert its own starchy center into sugars while saccharification. So, higher the diastatic power, higher the starch to sugar conversion which leads to higher specific gravity value (Stephanie, 2014).

The primary reason for utilizing Pilsner malt is its high diastatic power [240°WK (Windisch-Kolbach units)]. Along with this high diastatic power, pilsner malt consists of a lot of enzymes which aid in hydrolysis of starch. Also, it contains a malty flavor that can suit any type of beer style. Along with these advantages, pilsner malt possesses a short saccharification period of 10 minutes which converts starches into sugar malts (Gladfield, n.d.).

However, approximately 60% of the grains that are included in the recreated ancient recipe are considered to be less diastatic. So, the high diastatic power in the pilsner malt can be utilized for its starch conversion tendency amongst unmalted ancient grains.

Malting in barley gives out enzymes that turn all starches that are present in the grain into fermentable sugars. Roasting times of Barley is also a key factor in this as variable roasting time periods and also temperatures are used to produce various colourations of the malt from the same grain. Thus, darker malts will lead to the production of darker beers.

Hops

The hops provide a flavoring aspect and also acts as preservative. The use of hops was noted by Jews in Babylon around the period of 586 BCE also has another interesting characteristic which provides a sense of bitterness so that sweetness of the malt is not overpowering. It also contains an antibiotic effect which helps the proliferation of Brewer's yeast more than other microorganisms. The preservative factor of hops arising from its acidity enabled manufacturers to transport beer over longer distances which led to the rise of commercial brewing industries (Bamforth,2004).

Hops are a source of polyphenols which give more color and astringency in beer (Shellhammer, 2010). A disadvantage about hops is that they are prone to many infestations than barley and other crops. The other disadvantage is that it consists of nitrate content which has a potential risk of causing cancer (Bamforth,2004).

Another main contribution of hops is that it gives floral and also herbal aromas while adding certain flavors to the beer. Hops also have an antibiotic effect which encourages the activity of Brewer's yeast which automatically doesn't allow other irrelevant microbes. "Head retention "is another added advantage as it will increase the foam time which is formed by carbonation (Bamforth,2004).

Water

Another main component of beer is water which is present from 92 to 95%. Surplus amounts of water are used in the brewing stage as much of it will be used in cooling, steam production and certain cleaning processes. Generally, breweries have a huge supply of water, so the water composition is reflected in the style of the beer. Thus, the pale-ale type of beer was formed due to the presence of surplus calcium, magnesium sulphates that is present in the hard waters of Burton-on-Trent, whereas certain soft waters of Pilsen have very little amounts of ions hence produced smooth palate containing lagers (Parker D.K.,2012).

Water used for brewing processes must not possess any traces of harmful constituents or taints and a brewer must make sure to treat the water that is utilized with processes such as charcoal filtration or ultrafiltration etc.

Yeast

Yeast primarily aids in the fermentation process in brewing. It aids in enhancing the beer's sensory characteristics and also in alcohol formation. Yeast are unicellular microbes that reproduce by budding, i.e., the daughter cell arises from the original parent cell by division of the parent nucleus to form a daughter nucleus which migrates into the daughter cell. There are various yeast species present and the common one is called *Saccharomyces cerevisiae* which is also known as the Baker's Yeast that is mostly used to create ales.

In all likeliness, in ancient beer production, spontaneous fermentation was performed at times. The key ingredients that were involved were generally barley, broomcorn millet, Job's tears. Yeast is considered to be the key ingredient that can't be substituted even though beer has other agricultural ingredients (Gump & Pruett,1993).

2.1 Ancient beer ingredients

Job's Tears

Also known as *Coix lacryma-jobi*, Job's tears are a type of barley which are also known as Chinese Pearl Barley. An archaeological dig revealed that around 5000 years ago, citizens in Shaanxi district utilized Jobs tears as one of their main adjuncts along with broomcorn millet etc.(Wang et al., 2016) to brew beer. Similar to other cereals, there are lots of cultivars of Job's tears, few of them being soft-shelled, easily-threshed along with a sweet kernel.

Certain other fermented drinks like Soju were also distilled from the Job’s tears grain which emphasizes that the grain had historical significance (Kang,2017).

Job’s tears consist of vital nutrients like vitamins, minerals, amino acids and even fiber. Job’s tears also consist of β-glucans and arabinoxylans that make up aqueous solutions which results in high viscosity after mashing process and also aids in lautering (Goode et al., 2005). The drawback with utilizing job’s tears is that it has been subjected to very limited research in beer context, hence unclear of all it’s effects on the sensory and physicochemical properties of beer (D K Hore & R S Rathi, 2006).

The ingredient bill that was obtained from the archaeological sites did not reveal traces of any hops, however, in one of ancient beer batches that would be prepared in this project will contain hops. This is due to the fact that the hops provide an evolved taste which is more familiar to the consumers and also add more colour and astringency to that beer. When hops are added along to that batch, it should not overpower the sensory attributes of the other ingredients in the brew and still save the authentic ancient recipe taste.

Broomcorn Millet

Panicum miliaceum L. aka Broomcorn millet is an ancient domesticated plant that has been a vital source of carbohydrates and proteins for a millenia. Broomcorn millet has been known to be called proso millet was widely cultivated in northern China (Tsang et al., 2017). Archaeobotanical studies at the Baligang site in northern central China revealed a unique type of farming with mixed grains like varieties of millet of rice (Weisskopf et al., 2015).

The grain count that was retrieved from the Mijaya sites consisted roughly about 28.5% broomcorn millet of the entire grain bill, hence proving its importance in the recreated recipe. Comparing with the commonly used wheat, both have similar nutrient profiles in terms of carbohydrates(Saleh et al., 2013). This provides an explanation how broomcorn millet was utilized in the past since carbohydrates consist of starches which will be converted to sugar during saccharification, maximizing starch hydrolysis. However, millets do not contain natural amylases, thus, requiring the use of commercial malt enzymes to assist in starch conversion. Studies show that malting may develop some amount of alpha amylase (Ariyalratne, 2014).

Other Adjuncts

Adjuncts that were utilized in our recipe were snake gourd root (*T. Kirilowii*), lily (*Lilium sp*.), yams (*Dioscorea sp*.). Ingredients like snake gourd root and lily were included in the ancient recipes due to their medicinal properties and unique flavors as well.

Snake gourd root is known to be a part of traditional chinese medicine, this explains its inclusion in several foods and beverages. Snake gourd root has medicinal properties that reduce phlegm stagnation, body heat, aids digestion, detoxifies the body etc., they're also known to have a sweet and sour taste with a hint of bitterness (Qi,2021).

Even though Lily is less known as a beer ingredient, it's well known to be a part of TCM (Traditional Chinese medicine). This explains its inclusion in the ancient recipe and its importance in our recreation. Its medicinal properties include improvement of lung health, improvement of skin complexion, reduces heart conditions like palpitations, irritability etc.,They also provide a sweet and starchy taste to the beverage (Shahrajabian et.al., 2019).

Yams are considered a superfood as they provide a variety of nutrition to the body such as fiber, carbohydrates, assortment of minerals such as copper, manganese, iron etc., they're also known to be a vital part of the traditional chinese diet, thus fittingly added to into the recipe.Commonly, the malt proportions would be substituted by the brewers with various other sources of adjuncts. This was done for certain purposes like altering or inducing necessary characteristics into the final beer product. Other adjuncts are added just to replace the malts as a whole and manipulate the beer as whole (Bamforth,2004).

Another vital reason for adjuncts being employed is due to economic conditions. Adjuncts unit cost of fermentable carbohydrate is comparatively lower than that of the malt, at the same time it does not affect the quality and the characteristics of the beer. Thus, it makes sense to replace a proportion of the malt (Bamforth,2004).

2.2. Ancient Brewing methods

At the time of beer origin, the brewing technologies were primitive but the basic requirements would have been sufficient in order to produce beer that has been safe for consumption (Hornsey, 2003).

The processes that were performed for producing beer during ancient times were definitely abbreviated in contrast to the making of modern beers. The modern processes include separate steps like mashing, boiling, fermentation etc. whereas the ancient beers mostly underwent a continuous mash process followed by fermentation (M.Kiefer, 2001).

The grains would be sprouted , ground and would then be mixed with water in a vessel or sometimes even in skin bags. Then the heating up process was done by either fire or setting up out in the sun or even sometime via the help of heat rocks. Fermentation was aided by the flora present in the air or even in the grains. After fermentation was completed, the water would be extracted from the grains which would be consumed as the beer, whereas the leftover gruel would be introduced to yeast and flour in order to produce a leavened bread (M.Kiefer, 2001).

Ancient beer fermentation would have included different yeasts and bacteria. A sour mash process would have been followed to keep the pH low in order to prevent the growth of noxious microbes. This sour mash process would have been done by inoculating grains with Lactobacillus from husks of grains. This however can grow some foul aerobic microbes hence the process was kept brief.

Post the ceramics were invented, the brewing process got refined. The mash was cooked over a fire, after which the liquid was drawn off and the the fermentation was carried out separately (Hitchcock, 2018). The fermentation flora was then chosen more specifically rather than random inoculation. Specific fruits were added that consisted of a certain microflora on its surface or by using sticks with which the pots were stirred and thus used to inoculate other batches with yeast (Hitchcock, 2018).

The common ground between the ancient and modern brewing methods is the principal starch source being broken down into simple sugars in order to obtain a fermented beverage. This saccharification process was peformed initially by chewing grain in order to produce a sweet wort. This wort would be ready for fermentation as the saliva contains an enzyme called ptyalin that can saccharify grains (McGovern et al., 2004). Since it is a tedious process for breaking down starch, tradition tied this process to ancient bridal showers where a group of women would chew the rice and fill a pot with salivated rice, enough for making a traditional brew for the weddings.

Whereas if the idea of spitting was not preferred, rice was instead spread out on a damp shelf which was maintained warm for a time period. This will result in sprouting which in turn produces amylase enzymes that result in a sweet malt. They also depended on insects (which carry any wild yeast strain) to initiate the fermentation (Hornsey, 2003).

Also, another remote procedure that was employed at the Shang Dynasty where the beverage makers steamed a cake of certain cereals/pulses around which a mat of fungal matter tends to form around the cake. These fungi fibers enter the cake and produce amylase enzymes which help in starch breakage (saccharification) (McGovern et al., 2004).

The yeast inoculation is however unique as there is no traditional way to do it, however, they are incorporated via passing insects that are attracted from the sweetness of the cereal cake or yeast falling from the ceilings of old buildings (McGovern et al., 2004). The fermentation was carried out in airtight jars. The jars were filled approximately a third of their volume and after the initiation of fermentation, the jars became airtight as they evaporated down.

2.3. Modern brewing methods

The advancements in beer brewing methods occurred organically as time evolved. There have been significant technological improvements in all the beer brew processes:

a) The malt is stored airtight for weeks in a cool, dry place before being used. This is mainly done to protect it against oxidation and any temperature-related damage.
b) The common modern-day brewer mills use two-roll mills and in large brewhouses. The mill may even contain six-mill rolls with various gap settings.
c) At times, the malt undergo steam treatment just to make the husk removal process easier (Benson, 2020). Mashing equipment have been incorporated along with steam jackets and also agitators which makes the temperature control easier. At the same

time, certain aspects still adhere to the old approaches so-called decoction approach, whereby portions of the mash are removed and boiled before reintroducing to raise the temperature (Colby, 2006).The mash tuns traditionally possess a single vessel where mashing and wort collection were done whereas now this single process has been split and performed at separate vessels in breweries. Instead of a single vessel, an initial mash mixer is utilized after which a lauter tun/mash filter is used. This would improve the efficiency of mashing by many folds (Colby, 2006).

d) There have been various improvements in reducing energy consumption. A wide range of novel boiling systems have been proposed which would help in improving the quality of the beer (Bamforth,2009).
e) The trub/hot break that is formed during boiling is removed by a created whirlpool before the wort is cooled in a heat exchanger that allows rapid, indirect cooling.

Areas of improvements

Fermentation processes have had huge improvements in the previous years where the process occurs in a controlled environment (medium for yeast growth) and also correct amounts of yeast (Allikian et al., 2019). The wort strength and composition are determined by its selection of raw materials and also by the regulation of parameters such as water–grist ratio, water sparging, boil length (e.g., percent evaporation) and also the changes occurred through additional processes like priming (adding sugars like sucrose or maltose corn syrup etc) to the wort at the bottling stage.

Although, certain traditional ales still employ a rapid fermenter to glass concept where the beer is directly racked into barrels and priming sugar is added. This will facilitate extra carbonation by the leftover yeast.

Likewise, modern day brewhouses have improved by employing advanced downstream packaging/packaging processes along with optimum storehouses where the beer is stored under optimal conditions to improve its shelf life.

Ancient beer recipe recreation

Few archaeology researchers have exhibited attempts in recreation of ancient beers (McGovern, 2004; Wang, 2016). In some of these research projects, the archaeological sites were explored to obtain old vessels that have been used for preparation and storage of food and beverages. The residues found in the vessels would be extracted and analyzed in the lab to determine the ingredients that were used in the recipe(Wang et al., 2016).

Jiajing Wang of Stanford Archaeology used this method and analyzed the chemical residues from the Mijaya site (China) which gave rise to a list of ingredients (barley, broomcorn millet, Job's tears, snake gourd root etc.,) that were proved to be used in the production of ancient beer. The starch grain types were determined from each vessel and all together revealed approximate quantities of ingredients that were used. Then that data was utilized to prepare a recipe that was subjected to modern brewing methods to form a recreated beer.

However, the results from the residues only exhibited the ingredient proportions in the final product hence in this study, by considering modern age brewing methods, mass balances were utilized to trace back to a recipe that would provide more accurate grain and water proportions that would be used to prepare ancient beer in this project.

Another attempt of recreated ancient beer was sourced from a tomb found at the sites in Central Turkey. The burials that were found there were traced back to 8th century BC which was found to be the time period when Midas ruled Phygria. This excavation occurred at late 1950s and the basic chemical analysis of sediments present in the ancient vessels were analyzed. A more detailed analysis of these residues were done via HPLC with a UV spectrophotometer. This aided in identifying the compounds present in the vessels that resembled barley beer (McGovern, 2004).

With assistance from archaeologists, certain ancient literary texts were interpreted to obtain possible ingredients on top of barley. From the majority of the translation, ingredients like dates, grapes and honey were added to the list. Dogfish Head brewers were approached later at the year 2000 for the detailed recreation of the "Midas" beer. With further research, it was foud that saffron played a widespread role in beverages in Turkey and so it was incorporated as well. With further reference to journals, the brewing conditions were approximately inferred and thus, "Midas Touch" ale was prepared (McGovern, 2004).

Another type of ancient beer was developed by McGovern which originated from the prehistoric sites of Wadi Kubbaniya & Nabta Playa (Africa). These sites were excavated to find vessels belonging to an ancient civilisation. When subjected to analysis, cereals like sorghum,millet,barley etc. were identified. Also additional adjuncts such as mustard, caper, rumex, legumes and fruits and seeds of a tree named *Ziziphus* were identified.

In 1993, additional vessels were found by the excavators and the residues inside them were analyzed via LC-MS-MS to find out various herbs like wormwood, Artemesis, coriander,balm, senns, mint and thyme were identified. All the collected research along with the help of Dogfish Head brewers, resulted in a spicy African/Egyptian ale called Ta Henket.

This ale contained Za'atar (a mixture of Egyptian spices) which helped the beer improve with age as the spices slowly mellow to blend over a period of time (McGovern, 2004).

2.4. Beer production processes

The typical modern brewing processes are depicted in a form of a sequential flowchart in Figure 1.

The objectives of these production processes are:

- To prepare the ingredients for mash. These include modification processes such as malting, milling etc.
- To release and breakdown the sugars for fermentation.
- To convert the released sugars via a two-stage fermentation process (primary, secondary).
- To condition and store the beer properly to preserve its integrity and sensory factors.

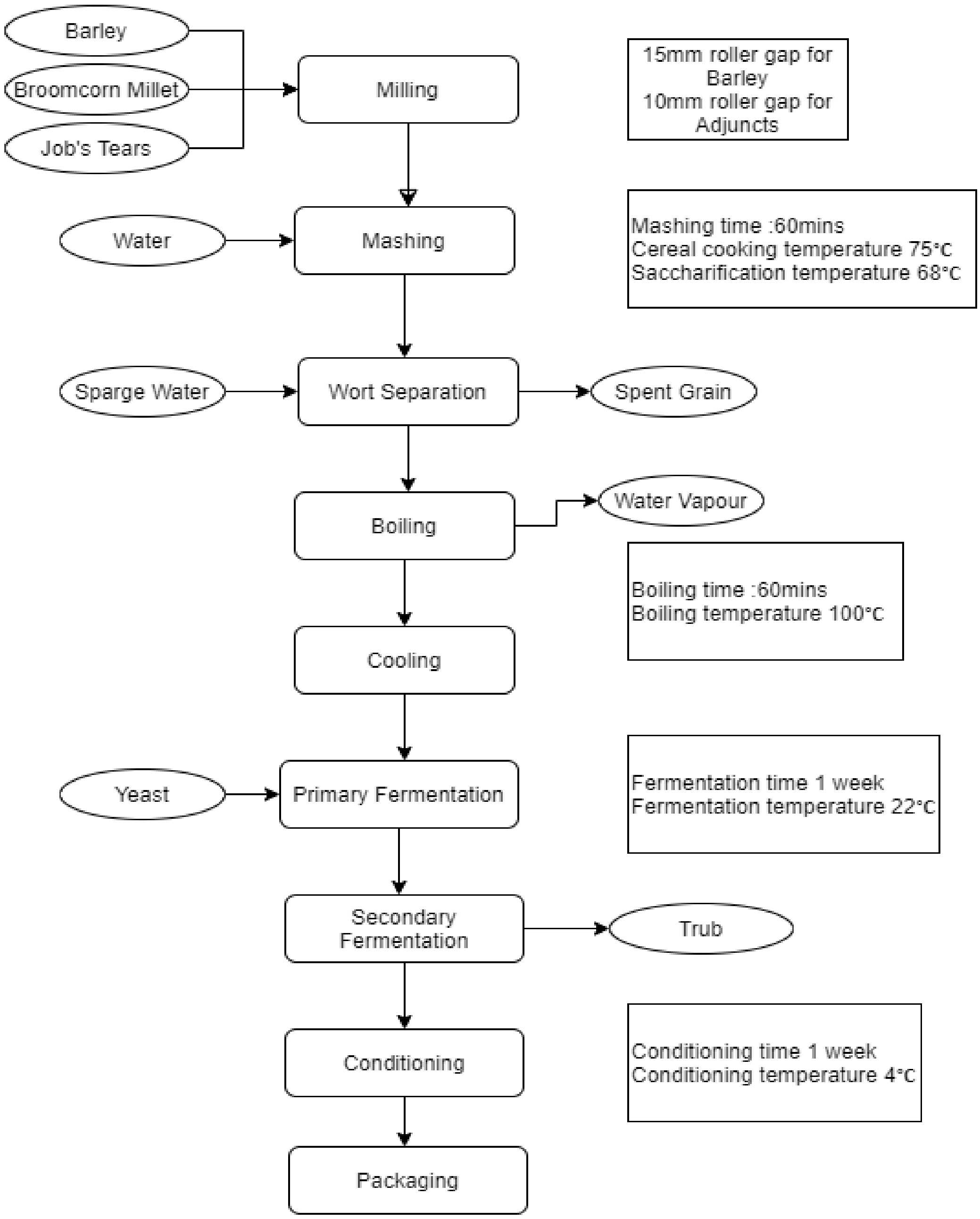

Figure 1. Modern processes in beer production

Milling

Milling is a process which helps in husk separation from the starch endosperm for effective enzymatic function while mashing and separation of wort. The aim is to produce a particle distribution that is best suited to that particular brew operation and for the type of malt used. For example, if the husk of the malt is required as a filter bed for the separation of the wort, then it will be necessary to have a setup that enables survival of its tissue, while at the same time milling the starchy endosperm to a consistency fine enough to allow easy access of water for dissolution (Briggs et al., 2004).

Methods of milling are influenced by the miller's gap size as coarse grind produces even and loose permeable mash whereas tighter beds lead to stuck mash. Although fine grind can result in higher yield of extract, it may subsequently inhibit filtration and will tend to lose extract in spent grains (Asante, 2008).

Certain modified fine ground malts provide filtered mash in about an hour's time; however, the poorly altered mash will take a period of 6 hours or much more than that.

Some brewers employ wet milling, in which the malt is soaked in water before milling begins. It is believed that the hydration of the husk reduces the risk of its damage during milling. Increasingly the use of hammer-milling is becoming common but only with modern mash separation processes such as the mash filter, which don't require the husk as a filter bed (Briggs et al., 2004).

Mashing

Mashing is converting starch into fermentable sugars through the manipulation of temperature of a particular source of starch through a few stages. During these stages, the dextrins are broken down into simple sugars like glucose. This conversion is facilitated by enzymes such as amylases. The starch source decides the number of stages that are necessary for beer production (Green,2008).

Mashing process is also known as the enzymatic stage of the brewing procedure. The milled malt is mixed with the water, hence activating the enzymes. The main requirement is that These grains must be efficiently hydrated and be overly exerted in mashing times and temperatures.

In order to balance out the minerals, certain salts may be added to the mash, eg. Occasionally minerals like calcium are added in for of salts in order to lower the pH of the mash. The types of amylases that are involved in the mashing process are:

- ∝-amylase, that aids in hydrolysing starch molecules that are long chain in nature.

- β-amylase, that aids in further hydrolysis of these short chains.

∝-amylase is most active at approximately 7.0 pH & 70° C whereas β-amylase exhibits its optimum activity at approximately from 4 to 5.5 pH & at a temperature of 62° C (Mallawarachchi & Gunawardena, 2020). Over the past few decades, it has become clear that both of these enzymes can be activated at one mash temperature range which is 67-68 ° C

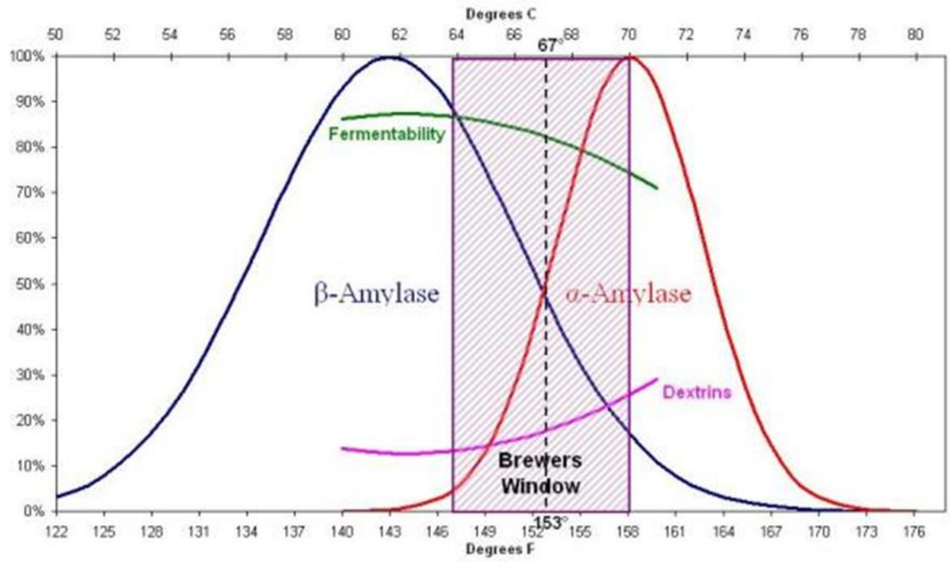

Figure 2. Enzyme activity within 1 hour mash during mashing process (Palmer, 2006)

As observed in Figure 2., ∝-amylase reaches maximum enzyme activity at a higher temperature than the β-amylase, hence a cooler mash would eventually result in a wort that is more fermentable resulting in a comparative dryer beer i.e., a moderately sweet beer (Palmer, 2006).

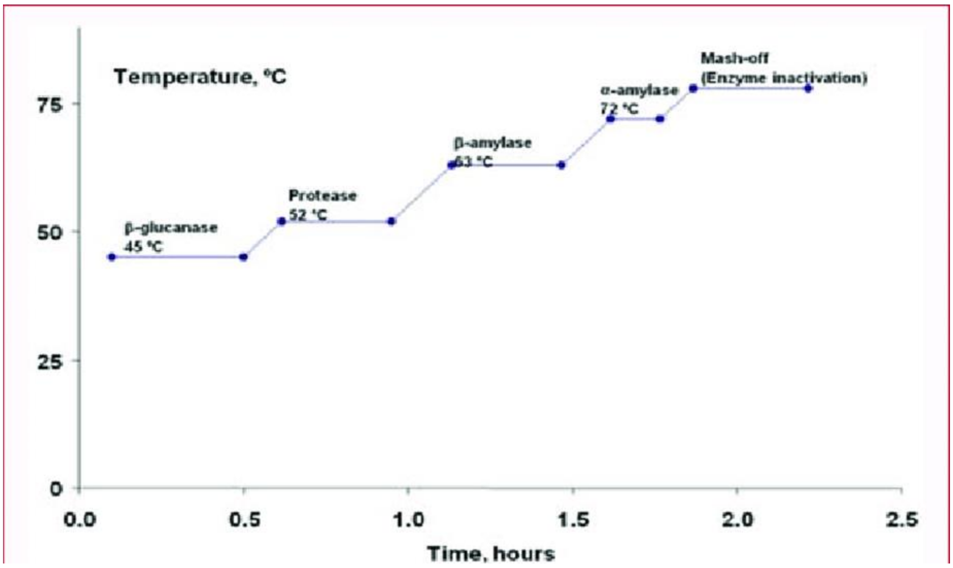

Figure 3. Denaturation of enzymes (Green, 2008)

The brew has multiple thermo-sensitive enzymes provided by the malt and adjuncts and these enzymes' activities can be manipulated under certain temperature ranges. Given below is a table consisting of all the enzymes present in the brew and their temperature limitations.

Table 1. List of enzymes present in a typical brew and their active temperatures (Green, 2008)

Enzyme	Optimal Temp. Range	Maximimum temp. for enzyme acticity	Denaturation teemperature
Phytase	86-126°F (30-53°C)	95°F (35°C)	140°F (60°C)
Beta-Glucanase	95-131°F(35-55°C)	113°F (45°C)	140°F (60°C)
Peptidase	113-128°F (45-53°C)	122°F (50°C)	145°F (63°C)
Proteinase	122-138°F (50-59°C)	136°F (58°C)	155°F (68°C)
Beta-amylase	130-150°F (54-66°C)	148°F (64°C)	160°F (71°C)
Alpha-amylase	150-160°F (66-71°C)	158°F (70°C)	170°F (77°C)

The point to be noted is that when the mashing temperatures are changed, the activity of the enzymes are not being turned on and off due to the simple mechanism of the enzymes, the control is not effective immediately (Green, 2008).

Excessive physical damage to particles will slow down the subsequent wort separation stage and lead to unacceptably turbid wort, but it will also cause a far greater uptake of air into the mash. It is now often said that this can promote staling in the subsequent beer (Green, 2008).

After consideration of various temperature limitations for these enzymes, a double-mashing process can be considered for these range of grains. In this system, two separate mashes are prepared where an adjunct cooker is utilized for cereals & for the malts with high diastatic power, a mash tun is utilized. Either pre- gelatinized adjuncts can be used, if not they can be separately boiled in an adjunct cooker for starch gelatinization (Goldammer,1999).

The main concept in double mashing is that the adjuncts are gelatinized separately in order to protect the enzymes that are present in the malt. The adjuncts have a higher gelatinizing temperature of 75°C and have to be gelatinized before the malt is added to save the saccharification process.

Also, the alpha amylase enzyme can convert the starch into small chained sugars like dextrins, maltotriose etc. (Goldammer, 1999). So, to save the malt, the temperature was reduced to 40°C after gelatinization. Post-addition of the malt, the temperature would be raised again to 68° C for the conversion of starches into sugars.

Wort Separation

Post activity of all the enzymes present in the mash, the wort is then separated from the spent grains (Bamforth, 2009). This separation is easier when there are fewer insoluble particles present in the wort. The challenging part is to perform this without losing much of the wort and also, to complete the separation within a time limit (Bamforth, 2009).

In this step, sparging is performed where the mash bed or in our case the mesh bags containing the grains, are rinsed to extract the maximum amount of sugars. The sparge water temperature is also taken into consideration as the husk tannins tend to turn soluble more than the limit temperature which is 76°C (Palmer, 2006).It is vital to use sparge water under this temperature as that could lead to excessive astringency in the beer.

One of the well-known sparging methods is the batch sparging which is a homebrewing practice in the USA where the whole volume of the sparge water is directly added into the mash (Conn, 2004). The grain bed is settled and the wort is drained and the recirculation step takes place in the first few minutes of the sparge. Whereas in this project, sparge water is added through the grain bags. More than one batch of water can be used if in need. This method is different from the English method where the mash isn't held for any significant period of time at saccharification temperature before draining is done.

Boiling

Post mashing and sparging, the wort needs to be subjected to a steady boiling procedure at (100℃) for a fixed period of time, extract brewers generally specify the time for 60 minutes. This step is performed in order to deactivate the enzymes in the wort, concentrate the wort and isomerize the alpha acids (Pierce, 2007). The protein coagulates in 10 minutes but the isomerisation process of hop alpha acids that are responsible for the bitterness factor, takes a longer period of time (mostly 60 minutes, which would result in approximately 90% isomerisation completion).

The wort darkens due to the boiling process, hence inhibiting the extent of the process would result in a lighter color. Another vital factor that determines the color is wort density, hence it is advised to perform a full volume boil rather than diluting the concentrated boiled wort later in the fermenter (Hughes, 2019).

The boiling process is vital due to the fact that the extreme heat will inactivate any robust enzymes that are still present post the mashing and wort separation processes. Boiling also sterilizes the wort, killing leftover microbes that might infect the brew while it is being fermented later (Pierce, 2007).

During this boiling process, complex changes would occur which will result in the formation of hot break or trub. This will aid in clarification of the wort, hence brightening it, also helping it to improve its color (Briggs et al., 2004).

Wort boiling also helps when hops are added, as the boiling aids in isomerization of the α - acids into the iso- α -acids which is a bitter form. This is also known as bittering of the hops. Generally, the bittering hops are added at the starting of the boiling phase in order to facilitate any chemical changes. The only disadvantage of adding the hops at the initial phase is that the hoppy flavors and aroma would be boiled away volatile compounds. Hence, to provide a better hop flavor, Aroma hops are added at the last 10 minutes of the boiling process. Boiling also helps in the removal of undesirable flavors from the malt.

Post boiling, the wort is subjected to cooling and aeration before they get pitched with yeast and subjected to fermentation.

Wort Cooling

After the entire wort boiling process, the wort must be subjected to intense rapid cooling to the temperature at which the yeast is pitched/inoculated. The cooling needs to be performed in an asceptic manner so that there is no chance for the microorganisms to multiply and contaminate (Colby, 2002).

As the cooling process takes place, the beer gets hazy, cold break occurs and trub gets accumulated separately. This trub generally consists of

- 50% protein,
- 15-20% polyphenols
- approximately 30% wort carbohydrates.

This break occurs because of 2 factors, one is that the breaks in wort have different grist having various properties. Another one can be due to the mixture of cold break with hot break that has not been removed completely in the previous trub removal. Hot breaks are precipitates that are formed due to rapid cooling in which proteins and polyphenols coagulate in the wort and settle down as sediments & cold breaks are the same protein coagulate precipitates that are formed due to a rapid cooling process.

Cold break mostly is removed by filtration, sedimentation or floatation. Among these methods, filtration or floatation is the most commonly used method for cold break removal. These methods are combined with aeration and pitching of yeast in order to decrease any microbial contamination (Kunze,1996).

The cold wort is pitched with yeast, when the wort is aerated for small batches, it is openly shaken and stirred to induce O2 into it for the yeast to consume. A layer of trub may arise on the surface which will subside into a thin layer later and remain coherent with the vessel. This is then followed by the primary fermentation stage.

Fermentation

The wort which has been subjected to boiling, cooling, aeration and pitching the yeast, is now transferred to a fermenter vessel (depending on the batch size) for primary fermentation. The principle that occurs in the fermentation process is the same regardless of the type of fermenter employed. The yeast takes up the simple sugars that have been prepared for consumption through the previous processes. The yeast consumes the sugars in the wort and converts it into carbon dioxide and ethyl alcohol (Bamforth, 2009).

The temperature plays a vital role in the speed of fermentation. Commonly, lagers ferment at a lower temperature and take a fermentation time of 3 weeks whereas ales ferment at a higher range temperatures (16 to 21°C) and can take approximately a week to ferment. Thus it is inferred that the rate of fermentation is faster at higher temperatures which eventually plays a vital part in beer flavor (Stika, 2009).

The fermentation progress can be monitored by measuring the specific gravity in the wort. There will be a decrease in the density as the alcohol has a relatively less specific gravity than the sugars present in the wort. Also, there is a decrease in pH due to the accumulation of a mixture of acids by the yeast.

During fermentation, yeast produces a number of esters, higher alcohols and also diacetyl molecules which adds on to the flavor of the beer, also it is known to not have excess of diacetyl present in the beer which can spoil the flavor of the beer(Campbell, 2017).

Secondary Fermentation

Post primary fermentation, the beer still consists of some active yeast and fermentable sugars. In this process, siphoning (transferring a liquid from one vessel to another by creating a vacuum through a tube) is involved which will then leave the fermenter with remnant yeasty sediment that has been formed during beer production and it sinks to the bottom of the fermenter. This sediment is discarded as it consists of gluten, dead yeast and remnant grains from the beer production process (Bamforth, 2009).

Fermentation products generally go through maturation & filtration process before being subjected to packaging. The beer can be conditioned by storing it temporarily at 0-4°C for at least 3 days for the product to stabilize and sediment any unwanted materials. After it’s in the cask, the beer undergoes a secondary fermentation which helps in the development of flavor and also facilitates carbonation. The cask beer attributes to a shorter shelf life of 5 to 7 days before it starts to get an acetic flavor.

Filtration

Beer filtration is often carried out only in larger scale breweries where it involves the usage of certain filter aids (e.g., perlite, kieselguhr) which maintains the filter bed’s loose nature and stops it from clogging up. Many varieties of beers receive a small conditioning session after the fermentation, e.g., ales or lagers. Generally, it’s stored at -1°C for at least 3 days, where the proteins move out of the beer easily during filtration, making it less likely to go cloudy in glass. The use of certain materials help in stabilizing the beer for a long period of time. It removes the protein responsible for the haze production (K.Thomassen, 2001).

Post fermentation process, two types of particles are filtered out from the beer, they are yeast remnants and the cold break. Along with that, certain unwanted substances that were present in the solution at that stage would tend to form into larger particles that must be eliminated from the beer (Bamforth, 2009).

There are generally 3 ways to remove these particles. Either by usage of silica gels for adsorption, using tannic acid obtained from gallnuts to precipitate them or using papain enzyme obtained from pawpaw for hydrolysis. This enzyme is also used for tenderizing meat (Bamforth,2004).

Pasteurization

Pasteurization is an additional stage for processing beer but it is generally an optional stage where the beer is heated slowly and then cooled to eliminate bacteria so that it can obtain an extended shelf life. This process is not used in high end beers, still its common in bulk produced beers such as American style beers or certain bulk-produced lager. It is not common to perform pasteurization on Ales as its flavors can tend to change (Edwards,2009).

Packaging

It is well known that packaging plays a significant role in beer production. It has a psychological effect on the consumers on their perception of the beer's quality (Aquilani et al., 2014).

The example of consumer preference can be seen based on the choice of packaging in European countries. Research indicated that most Czech consumers prefer beer to be packaged in cans or bottles as from their perspective, beer tasted better from cans or glass bottles rather than plastic bottles (Petr, 2018).

Research also indicated that the main reason why consumers prefer packaged beer are:

1) Habit
2) Price
3) Environmental impact

68% of Czech beer consumers believe that the beer taste improves if its packaged (Zavondy,2020). Even though glass remained to be the preferred form of packaging material for beer drinkers, the acceptance for canned packaging has been increasing over the years (Merlino et al., 2020).

Therefore, beer that has been subjected to filtration, can either be directly stored into cans, bottles or kegs or can be infused with artificial CO_2 before being packaged. This would aid minimizing any air ingress as oxygen might encourage beer staling (Bamforth,2004).

Storage

Temperature is a vital influential factor that can manipulate the ageing of beer through moderation of various chemical reactions that occur in beer, e.g., oxidation (Jaskula-Goiris et al., 2019).

It was noticed that storing lager at high temperatures resulted in development of cardboard notes in taste and storage at relatively lower temperatures resulted in development of caramel notes (Furusho et al., 1999). Hence it was evident that in order to slow down any flavor changes occurring in beer, it is best to store and transport at a colder temperature ranging 0–4°C (Bamforth, 1999).

In addition, laboratory scale trials projected that there is a necessity for more research on the quality of beer that has been subjected to vibration during transportation, relatively questioning its impact on beer flavor as well. It was reported that the oxygen levels altered as vibrations were applied, also the color and aldehyde concentrations increased whereas levels of trans-isohumulone decreased when the beer was subjected to vibrations (Jaskula-Goiris et al., 2019).

Temperature along with vibrations has a negative impact on the colloidal stability of the beer. This is due to the high probability of particles colliding resulting in molecular interactions that accelerate most of the unwanted changes in beer. Due to these factors, the beer quality was said to be impaired, as a result, it was reported that the distribution should be maintained at a lower temperature (7°C) and with equal importance, to minimize the vibration through better packaging as well (Jaskula-Goiris et al., 2019).

2.5. Physicochemical analysis:

Examining the physicochemical characteristics of beer during its production and post-production is vital as it aids us in understanding the conversion process of raw materials to the final product and also aids in identifying unwanted reactions occurring during the process.

These analysis methods are commonly validated by the American Society of Brewing Chemists (ASBC) or the European Brewing Convention (EBC).

Alcohol content

Alcohol content can be estimated using a digital refractometer-based method to estimate the %ABV (Gosset,2012) or for more accuracy, detection with gas chromatography method (Buckee & Mundy, 1993) was utilized.

In the refractometer-based method, an initial Brix reading is taken off the sample, then the ethanol is driven off by boiling the sample to a volume down by 20-25% of the initial volume. Post the boiling process, the remnant beer is reconstituted back to the initial volume by addition of distilled water and a final reading of Brix is taken. The %ABV is determined by measuring the difference between the Brix values taken pre-boiling and post-boiling process and this difference is divided by a previously determined factor of 0. 353.This will provide with the %ABV of the original sample (Gosset,2012).

Gas chromatography (GC) is one of the most accurate tools to identify and quantify the components present in a mixture. In this process, the beer sample is injected into the chromatography column where it is converted into vapor phase and after that the inert carrier gas (either nitrogen or helium) sweeps the vapor phase through isothermal column and components detected at the end of the column with an appropriate detector (Falaki, 2019).

When the sample progresses through the column, the components present in the sample start to have interaction with the stationary phase filling the column. Periods of time that the components remain in the column are known as retention time: from sample injection to sample detection).As retention times are specific to components/columns, the resulting peaks (time and concentration) are then compared with the library of data.

Sugar content

Brix is a measurement that analyzes the total dissolved sugars (TDS) in a given sample with a Brix refractometer (Echolls, 2017). It is utilized for measuring simple sugars such as sucrose in many fruits, vegetables and several beverages or dissolved lactose.

The prominent sugars that are present in the beer are alpha or beta sugars of sucrose, fructose, maltose and so on.

The resultant reading from a refractometer is assigned a value on the Brix scale, so that it is convenient for comparisons of various concentrations in the solution, e.g., 0 for water and higher values for dissolved sugars (Echolls, 2017).

In the case of specific gravity, refractive index is not applicable for finished beer as alcohol affects the refractive index immensely, so refractometers are used only in case of unfermented wort (Barth, 2013) but for convenience and better accuracy, hydrometer can be used for measuring brix in fermented beers.

Beer density

Specific gravity is defined as measuring the density of a liquid relative to water. When the yeast converts the sugars present in the wort into alcohol with the release of CO_2, the wort's density decreases. This is due to the alcohol release, as it has lower density (0.789 g/mL)(Barth, 2013).

Specific gravity can also aid in determining the apparent degree of fermentation and even alcohol content. If the gravity reading is consistent for approximately 2 to 3 days, it indicates that the fermentation has been completed (Fuchs, 1997).

Original gravity (OG) is a measurement of all the fermentable and non-fermentable materials in a beer wort pre-fermentation. These materials are commonly sugars that would be converted into alcohol during the fermentation (Barth, 2013).

Final gravity (FG) is commonly measured by a hydrometer whereas OG can be taken with the help of a refractometer. A refractometer aids well especially in all-grain brews because the specific gravity can be taken at various intervals of mashing and boiling processes (Eddings, 2019).

OG aids in providing an idea of potential alcohol content in beer. Post fermentation, the OG (Original gravity) & FG (Final gravity) are mathematically compared and the alcohol content can be calculated.

Fermentation progress

Attenuation or Apparent attenuation (AA) is known to be the decrease of a property concentration in a substance. This decrease occurs when the fermentation takes place that converts the sugars into alcohol and CO_2 (Palmer, 2009).

Attaining a certain level of attenuation is vital commonly for all the beers, but it is extremely important for specific beer types. This is because less attenuated beers are overpoweringly sweet due to the high sugar content. In Belgian Tripel beers, the expected FG should be low regardless of its high OG in order to obtain its signature style. Also, in dry beers, the attenuation level is expected to be higher beyond the "normal" beers in order for it to be refreshing (Palmer, 2009).

Commonly, attenuation is difficult to measure due to 2 probable causes,

1) Low fermentability in wort due to ingredients producing unfermentable starches or due to higher mashing temperature.

2) Poor yeast performance due to weak yeast preparation or environment/conditions of fermentation.

The apparent attenuation can be tracked by either a hydrometer or a refractometer. The hydrometer measures the density of the solution by buoyancy whereas the refractometer measures the brix (concentration of sugar) with the refraction of light principle. The higher the concentration of sugar, higher the refraction (Barth, 2013).

Sugar breakdown

Diastatic power is known as the enzymatic power of the malt itself and its ability to convert the complex starches into simple sugars during mashing so that it can be later fermented by the yeast. The enzymes that are being referred to as "diastatic" are commonly the diastase enzymes (alpha amylase and beta amylase which are the primary enzymes that get activated during the mashing process at the temperature ranges of 64-70℃ (Smith, 2010).

One of the main reasons for analyzing the diastatic power of the mash is to prevent low amounts of enzymatic activity which will affect the mash and the entire fermentation process. This would result in a sweet beer with lower alcohol content (Smith, 2010). By analyzing the diastatic power, we can adjust the recipe in a way that would provide an overall better-quality beer.

Diastatic power is measured in °Lintner (commonly represented as °L). A malt needs a diastatic power of approximately 35 °L to be considered "self-converting"(Acker et al., 1967).

Given below are a few of the commonly used malts along with their diastatic power. Some of the newest American 6-row malts can have a diastatic power as high as 160 °L (Noonan, 2020). Reference to diastatic power of malt is vital as almost all of the enzymes required for the conversion of mash are present in the base malt, so the selection of a good base malt is important.

Table 2. Diastatic power of different malts (Noonan,2020)

Type of Malt	°L (Lintner)
American 2 Row Pale Malt American 6 Row Pale Malt	140 °L 160 °L
British Pale Malts	40-70 °L
Maris Otter Pale Malt	120 °L
Belgian Pale Malt (2 row)	60 °L
German Pilsner Malt	110 °L

pH of beer

pH measurement is an indicator of fermentation progress and allows product consistency. The more vigorous the fermentation is, the more citric and acetic acid it produces thus, lowering the pH. pH has a substantial effect on beer quality while little influence on flavor and suppression of microbial growth (Bible, 2007).

pH meter is commonly used to measure the pH of the solution where electrical potential of the probe is dependent on the pH. The probe utilizes a glass electrode that possesses a thin glass envelope into which the H+ ions (hydrogen ions) penetrate (Barth, 2013).

Beer color

Determining the color of beer (pale to dark) can be achieved experimentally via recording the absorbance values of the samples via spectrophotometer. Light absorption at a specific wavelength of 430 nanometres is measured where the beer absorbs light in blue region.

Interpretation of absorbance values utilizes two scales that are widely in use. American Society of Brewing Chemists (ASBC) utilizes the Standard Reference Method (SRM), which provides results that are near to Lovibond scale. The other scale that is utilized is known as European Brewing Convention (EBC) which is approximately twice the SRM value. This Absorbance value at 430 nm is then added into an equation which assists in the conversion into SRM values which is subsequently interpreted to EBC values. The equation that aids in this conversion is explained in the methodology section.

Clarity

Clarity is an important visual stimulus for finished beer and haze is interpreted as beer cloudiness. Approximately 150 years before, all beers consisted of haze and were preferred that way (Barth, 2013).

Typically, the haze is controlled in beer via certain precautions in production processes and ingredient proportions such as filtration, choosing a strain of yeast with high flocculation tendency. In this project it is not a concern as the recipe utilizes Safe Ale US-05 yeast (a common species of yeast with high flocculation tendency). However, the recipe uses high protein content grains such as broomcorn millet, job's tears which can lead to a mild haze formation, that can be minimized in mashing process and cold/hot break.

To avoid haze, substances called finings (such as carrageenan, collagen etc.) are added to the wort to encourage haze-forming materials to settle out. Finings are mostly added during either the boiling process or the conditioning process in order to encourage the hot break or cold break process respectively (Barth, 2013).

2.6. Qualitative methods in consumer research

Qualitative methods have been helpful in acquiring a detailed insight of consumer reaction on various product concepts. It aids them to define any critical aspects of the product from the view of a consumer. Several methods such as focus groups, ethnographic research techniques, interviews (group & one-on-one) have been used to gather qualitative information about products for decision in research and industry (Kemp, 2009) .

Qualitative methods were opted in this project as they are well suited for exploring a new product concept and also prevent overlooking any conceptualization flaws. Occasionally, technical breakthroughs can blindside the researcher from viewing the product from a consumer perspective (Marlow, 1987).

Utilizing qualitative methods is vital for exploration, rather than verification and since this project development was in its earlier stages, the priority was given to obtaining consumer opinions, examining prototypes and product motivations (Marlow, 1987). The following qualitative methods were reviewed to determine the most effective method that can be adopted for this research.

2.6.1. Focus Groups

Focus Groups are utilized for gathering the ideas, opinions and beliefs of people on a specific product. Generally, surveys are utilized which can be helpful but they do not adequately capture the respondents' feeling or thought. This is where focus groups come into play. Since questions used during focus groups are mostly open-ended and with a focus on qualitative information, the responses would give more depth and capture people's feeling on the product (McDaniel & Gates, 2002).

The focus group aids the researcher to obtain more information in a short period of time (Average of 2 hours). Focus groups also provide insights into topics that are complex where the opinions/attitudes are conditional. Also focus groups are useful when there are strong differences of opinions amongst the participants and professionals, as well as aid in researchers' preparations for bigger scale study.

Focus groups are led by a moderator or facilitator. The facilitator begins the session by welcoming participants and going over the reasons for the study and how data will be captured and stored. Using techniques such as questioning and summarizing, a facilitator stimulates discussions that uncover concerns and opinions held by groups of people about particular issues. Analysis of the data synthesizes these concerns and opinions. Used alone or combined with quantitative data such as surveys, the information guides choices about the best course of action (Bader & Rossi, 2002). Market researchers utilize the focus groups and also group interviews with consumers to improve the products and also to make predictions on which products can be sold easily.

A few vital benefits of a focus group are that they are a more structured/organized method for collecting information. Also, focus groups are fast and effective for generating ideas.

Data obtained in a focus group produces more information than other methods like surveys. Also, discussions in a focus group can offer qualitative data which provides a greater understanding.

Focus groups on Beer Production

Several breweries have tasting rooms so that brewers can communicate to the consumers directly but these communications are not precise and do not provide much important information in order to accurately improve the product. In order to extract useful and practicable information, it is important to host formal focus groups so that most technical terms that are involved in production can be explained in detail to the average consumer.

Also when the description of a particular beer is conflicting with the perception of the customer, it might result in confusion thus inhibiting the consumer from buying the beer again.

A focus group study from Cornell Enology extension aided in understanding the consumer's point of view of specific beer descriptions. This focus group consisted of hiring consumers of different demographics and also possesses various experience levels in beer consumption (Sara, 2017).

The focus group panel was divided into three groups depending on their consumer experiences. Each session was approximately 90 minutes and when the samples were served, it was ensured of 3 digit coding. The panelists were given full freedom to express their views about the different sensory attributes of the beer (appearance, taste, smell). After the individual discussions were completed, the panelists were gathered to have a brief discussion of their views of beer in general. These steps helped guide the current focus group that we would conduct for our project.

When the Cornell focus group results were interpreted , the key descriptive words were observed and noted down which were later analyzed to see which terms were the frequently used ones for each attribute amongst all expertise levels and also within each level. Apart from just positive descriptors, common negative descriptors were noted and analyzed in that focus group as well. Additionally, the reasons for the negative descriptors were asked and noted as well.

Apart from common descriptors, unique descriptors were also observed and noted for various attributes. All this information was filtered down to extract useful information about the beers and their attributes. The short and common words that inhibited creative writing were discarded.

Different levels of expertise provided different levels of information regarding the usage of various descriptors and also the viewpoint of how each individual perceived sensory attributes. Certain attributes were perceived differently by panelists belonging to different levels. Overall, the consumers were well informed, all the information provided by all levels of panelists were noted with no biases and the transcription was done effectively to obtain only the useful information. All these steps were utilized and adopted in such a way that it would benefit the focus group (Sara, 2017).

2.6.2. Ethnographic research method

Ethnographic methods are one of the types of qualitative research methods that take people and their cultures into account. In this method, the ethnographers would tend to observe the participant behaviour and engage in interviewing them as well. The ethnographers would live amongst people that belong to a different culture and focus on their various cultural attributes such as languages, rituals, ceremonies etc., (Tracy, 2019).

In addition, through various contexts, the ethnographers would also augment field observation through interviews. They tend to focus on analysing either single or a couple of concepts at a time rather than exploring a variety of concepts relating to the corresponding culture (Tracy, 2019).

Types of Ethnographic research methods

There are various ethnographic methods that have been widely used for the development of food and beverages, with each type having its own advantages and disadvantages (Sheridan, 2010). Few of those research types are as follows:

a) Passive Observation

This form of ethnographic research involves following the study subjects and without any interactions or interference. In this method the ethnographer has to carefully shadow and observe the participants' organic actions (Murchison, 2010). In order to collect data, certain ways like audio/video recording, note collection, photographs etc., are carried out. In this method, the full focus is relied on to the research subject while an outsider perspective is being maintained.

b) Active Participant observation

This is a more hands-on method of ethnography where the researcher cooperates along with the study subjects to form a team. This method resembles the tradional ethnographic research as it is more focused on product development (Mannik & McGarray, 2017).

Although the documentation methods are similar to the ones used in passive observation, the vital difference is that the researcher is within the group,as a member. This is an important benefit of this method as the researcher becomes a part of the natural flow of the subject's process.

c) Interviews

This research is more standalone compared to the other type of ethnographic methods. These interviews are follow ups where the subjects are asked questions in order to collect more insight about the ongoing process (what, why and how type questions) (Murchison, 2010). Although an effective method, an interview on its own cannot qualify to be ethnographic. It should be included before and after the observation to be insightful and also must have follow ups if more details are needed.

Ethnographic research methods used for alcoholic beverages

In terms of ethnographical research, consumption of alcoholic beverages is known to be an integral aspect of several cultures. In order to understand the consumers' needs (actual and potential), a study was perfomed focusing ethnographic research on wine enthusiasts (Cuomo, 2016).

Though the main principle of ethnography was applied, an interesting research sub-type known as netnography was utilized in the study. The various attributes of wine enthusiasts in terms of their imagination, lifestyle , expectations etc. were supervised through social media (Instagram, Facebook etc.,). The next step included testing profile accuracy through a questionnaire that was distributed to the community.

The findings showed that the identities of wine enthusiasts in social media can be arranged better keeping their awareness and knowledge in wine consumption into consideration.

However, the research presented a basis for further in-depth researches that has the potential to explore more values, attitudes etc. of wine enthusiasts on the internet.

Through this ethnographic study, it was understood that in early stages of developing a product that is user- centered, this type of research is not the most effective tool as that could not help in obtaining insights which are vital to understand the design problem or the users' needs. Hence the focus group method has been chosen to be applied in this research instead. This would aid in filling out the shortcomings that resulted when ethnographic research methods were used.

2.7. Future Trends and growing market

Even though there has been an overall flat consumer market in the last few years for beer, the sales have steadily grown for light beer. Considering the report by World Market for beer which Euromonitor published in the year 2005, light beer with comparatively fewer calories and carbs will continue to come into the market.

There has been an increase in demand for beers that are mainly imported in many countries like the UK and USA. This is because people having more disposable income are insisting on the consumption of quality beer. The markets in the United States are projecting an increased and a sustainable growth for craft, light and premium types of beer in the next few years. Many specialty beers tend to struggle as they are manufactured by microbrewers and it's also due to the fact that the demands for traditionally manufactured beers are region-specific and less. Another important trend which was again found by the Euromonitor International are the flavored beers in locations like the USA and Japan. Types such as Gingseng-flavored beers have entered the market and are already making tremendous progress (Xu,2007).

2.8. Impacts of Beer on Health

The ancient rice beer that consisted of the herb mugwort or wormwood possessed a medicinal compound called artemisinin linked to anti-cancer properties. This compound's derivative called Artesunate was highly effective against various types of cancers, effectively lung, colon, liver, ovary etc. This compound is still undergoing clinical trials and is underway for legit human treatment (Trendafilova et al., 2021). Artemisinin compound has also been found to be an effective antimalarial agent. Both mugwort and wormwood have been a vital part of ancient Chinese medicine and are still being used. These herbs are used along with plants like Qinghao and ai ye in acupuncture treatments (Edwards, 2011).

Ancient Egyptian wine has been found to have certain medicinal properties. Most beverages that were listed in the medical papyri were alcoholic. These beverages consisted of various organic compounds that were found in tree resins such as fir, pine, myrrh etc. and also in certain herbs were detected in these beverages which possessed compounds that could cure ailments of all kinds. Even now these formulations are being used in Egyptian medicine and date back up to circa 1850 B.C (McGovern et al., 2009).

Beer doesn't have any cholesterol content or fat. Few studies showed that it helps people reduce their weight and also helps get rid of LDL cholesterol. Certain other studies have also shown that a normal consumption (12 to 24 ounces) of beer can decrease the chances of heart failure and the alcohol content from the beer can help reduce the clotting factor in blood and also decreases the blood cells stickiness (Xu,2007).

3. Research aim & objectives

The aim of the study is to recreate a 5000-year-old ancient beer recipe that was discovered from Shaanxi (Northern Chinese region).

The product concept adopted in this work was based on an archaeology article that analyzed grains bill from ancient pottery that looked similar to brewing vessels at the Mijiaya site in northern China (Wang et al.,2016).

Literature surveys show lack of scientific information on the production process, physicochemical properties, sensory evaluations or even the feasibility of that recipe to produce beer. The recipe lists grains like broomcorn millet, Job's tears that are typically not utilized in modern beer making. Hence the project attempts to recreate this beer based on archaeologically identified ingredients fill this gap through the following objectives:

1) To obtain a feasible beer recipe for recreation from archaeological articles.

2) To obtain the required ingredients and their appropriate preparation.

3) To incorporate modern brewing processes into the ancient ingredients.

4) To analyze the physicochemical parameters of the recreated beer in order to observe its unique properties and also compare it with the modern beer.

5)To perform a focus group and gather consumers' feedback on the product and assesses the consumers' acceptability of the recreated beer.

4. Methodology

4.1. Raw Ingredients

The ingredients required for recreating the ancient beer recipe consists of grains from the Neolithic era, that are used as adjuncts along with typically used in modern brewing. The main ingredient, barley, has been sourced locally from Hauraki Homebrew (Rosedale) in the form of German Pilsner malt (providing highest diastatic power). The rare grains such as broomcorn millet and Job' tears were also locally sourced (www.njk.co.nz).

The tertiary ingredients which were required in smaller quantities such as snake gourd root was found online (www.maxnature.com), yams and lilies were obtained from a supermarket (Countdown). Yeast (Safe-Ale 05) was obtained from Hauraki homebrew shop.

4.2. Processes applied in the beer production

Processes such as milling, mashing, fermentation process etc. were performed in the corresponding pre-planned facilities. Small scale batch operations enable control at each stage of processing and perform alterations if necessary. Thus, the data can be obtained in each individual step, such as rate of breakdown of sugars/decrease in beer density ,alcohol content and so on. These indicators allow adjustment of parameters such as composition, temperature or time to monitor the efficiency.

Subsequently, each individual operation as shown in the flow chart in Figure 1 will be described in detail.

4.2.1 Preparation of the ingredients for the fermentation

Milling

In the milling stage, the malt kernels were crushed into finer particles thus preparing them for mashing and lautering. The main aim of the milling process was to separate the husk from its endosperm of the starch to enable high activity of enzymes in the mashing process.

The gap size of the miller determines the size of the crushed kernels . Therefore, milling grinds were manipulated to find a balance between fine and coarse grind that results in a consistent permeable mash (Verlag, 1999).

The broomcorn millet size was smaller than pilsner malt and Job's Tears grains, therefore milling was carried out through a mill gap size required for exposure of the endosperm but without over-grinding of the broomcorn millet in powder (Asante, 2008). The grind size adjustment subsequently improved the filtration function during wort separation and lautering processes.

Mashing

Post the milling process, mashing was carried out where grist was treated with water of high temperature in a mash tun for approximately 80 minutes.

Crushing the grains aided the starches present in them to be easily hydrated in the mashing process. After that, gelatinization occurs where the heat passes through the starches along with the action of certain enzymes to convert soluble starches to sugars (Palmer, 2006).

Initially the grains were mashed via a single temperature mashing method, however a double mashing process was more effective for the starch extraction.

In single temperature infusion process, all the grains were mashed at the same temperature of (68°C) for about an hour.As shown in Figure 4, the grains were subjected to 70°C strike temperature, then after including the grains, the temperature became 65°C. Temperature was adjusted to 68°C till all the sugars were extracted and the mash out temperature 75°C was applied at the end. This was less effective because the saccharification process was incomplete and alpha amylase can only then breakdown soluble and insoluble starch into short chain maltotriose and dextrins (Goldammer, 1999).

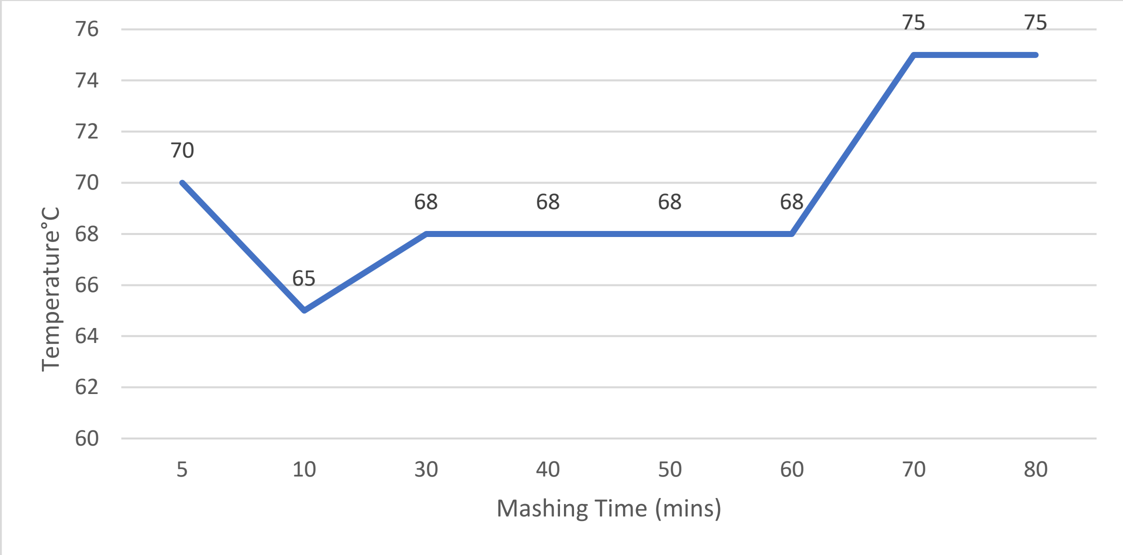

Figure 4. Single temperature infusion mashing graph (Time vs Temp)

In double mashing, the broomcorn millet and Job's tears were gelatinised at 75°C in a separate vessel from pilsner malt. This was due to the fact that almost all the enzymes (excluding alpha amylase) which are present within pilsner malt will be deactivated at that extreme temperature. After the acid rest is completed at 40°C, the temperature is again raised to 68°C for saccharification.Finally after the sugars have been extracted, mash-out was carried out at 75°C. This double mashing regime is expressed in the form of a graph in figure 5.

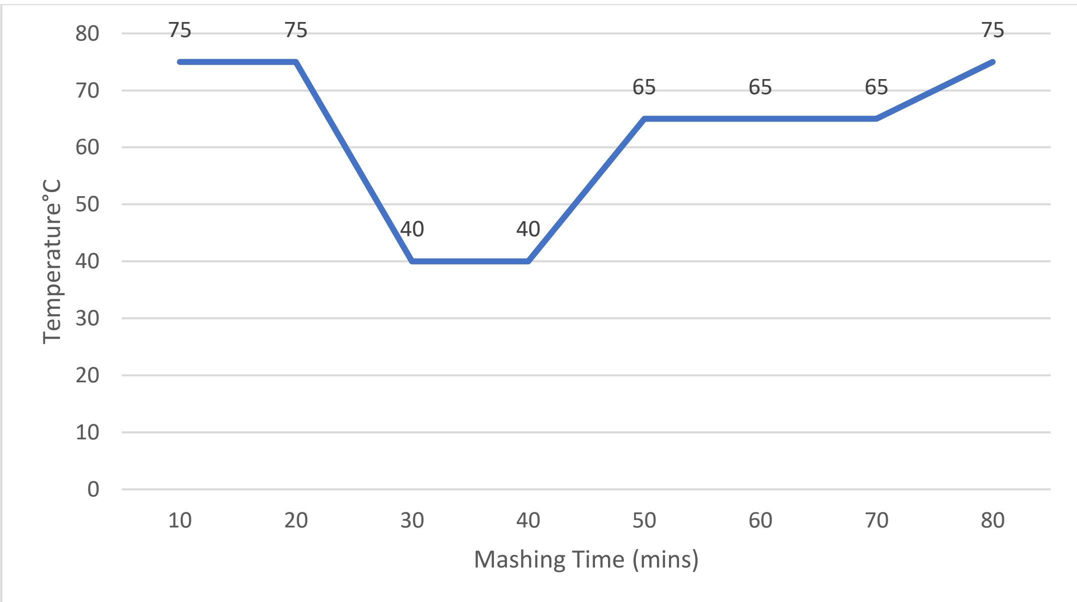

Figure 5. Double mashing regime (Green,2008).

For adjuncts the process of double mashing was used. Incorporating broomcorn millet and Job's tears from the ancient recipe must be included as adjuncts along the process of double mashing where these adjuncts are subjected to separate heat treatment for gelatinizaing the starch compounds and also included along the mash tun where malted barley is present (Goldammer,1999).

Boiling

The mashed wort was boiled at a temperature of 100°C for up to one hour. In the later stage of boiling,hops have been added in multiple doses, the first dose at 15 minutes, second at the 30-minute mark and the last addition at 45 mins into the boil to preserve volatiles (Miller, 1995).

Boiling would also result in loss of water content and so some sparging water was added, post the mashing process in order to compensate for the loss., Also, after the 45-minute mark, the clarification (whirlfloc) tablet was added to the boiling wort so that it can have better clarity post boiling. After completion of an hour of boiling, the wort is subjected to immediate cooling.

Cooling

Cooling process was carried out immediately after the boiling process. In this process, the boiling wort was subjected to spontaneous cooling to aid the separation of the trub from the wort. An ice bath was used for 20 minutes for attaining cold break.

Post chilling, the wort was checked for a yeast friendly temperature before being added to the fermenter for yeast addition. Also, before the addition of yeast, the wort was well stirred to aid oxygen flow so that the yeast can survive.

Fermentation

During fermentation, yeast converts the broken down sugars into ethanol and CO_2. In this process, the cooled wort was transferred to the fermenter vessel where the dry yeast was added that initiated fermentation. After the initiation of the fermentation process, O.G (Original gravity) is measured using a hydrometer to monitor the initiation of fermentation.

Fermentation is usually carried out anywhere from between 2 to 7 days or can go upto a total of 2 weeks (Evans, 2006). To assess the completion of fermentation, final gravity (F.G) was measured and observed for a series of saturated values.

Fermentation was deemed to be completed if the final gravity of the beer has not changed over the course of 3 days. This estimation is important as it can result in loss of alcohol content and also result in weak sensory properties if the process is abruptly stopped before attaining completion (White, 1999).

When the pace of the airlock slows down and not much activity can be observed, this gravity estimation was done. After the gravity value stays the same for 3 days consecutively, the yeast has completed its action on the wort.

The fermentation temperature kept in consideration was 21℃ due to this temperature being the common fermentation temperature between Ale and Belgian beers whereas the possibility of having a higher or lower temperature would have been unlikely as the methodologies utilized by the ancient Yangshao community was similar to the modern brewing conditions and methods (P. E. McGovern et al., 2004; Wang et al., 2016).

Table 3. Fermentation time periods kept into consideration

Primary Week	Secondary week	Type
1	1-2	Light
1	2-3	Amber
1	3-4	Dark

Since the recipe obtained consists of Triticeae, millet and Job's tears (grains that provide a would result in a lighter colored beer) (EBC), due to the small quantity and also considering the final gravity (beer density), after multiple trials the fermentation time was fixed at 1 week and the secondary fermentation was set at from 4 to 7 days after observing few trials. This was done to avoid loss of beer quality and effectively retain CO_2.

Post the primary fermentation time period, the beer was transferred to the secondary fermenter which was initially a glass carboy, but in order to effectively trap the CO_2, air tight glass bottles were utilized. When the beer was transferred, caution was taken so that the trub is left behind in the primary fermenter (Carpenter, 2015).

The bottles are air sealed to aid carbonation to the beer, thus giving its fizziness. During the secondary fermentation process, the yeast completes fermenting the leftover sugars to produce more ethanol and CO_2.

4.3. Physicochemical Characteristics of Beer

Instruments and methods including UV-spectrophotometer, HPLC, pH meter etc. were utilized to conduct the analysis of factors such as color, pH, ethanol content, density etc.,

Alcohol content

The alcohol content was measured by two methods. One was the gas chromatography method utilizing Carlo Erba 6000 Vega Series 2 instrument for GC along with a Hitachi D-2500 Chromato-integrator as the printer. The second method was using a digital refractometer method (Atago PR-101,Japan) by (Gosset,2012) where brix values of alcoholic beverages at different levels of alcohol content were estimated using graphs.

For the first method that we used (Gas chromatography vis 6000 Vega series 2), the column was filled with Porapak Q and the Gas settings for the GC were H2 at 150kPa, CO2 was at 200kPa and the air was at 180kPa.

The ethanol standards that were used were at 20g/L, 40g/L, 60g/L, 80g/L ,100g/L which were introduced by only single injections (RO water was used for rinsing syringes).

The inert gas was turned on from the main gas cylinder with appropriate pressures. The temperature and number of cycles was set. The alcohol standards were then injected one by one after the calibration curve starting to print. 2Ul of samples were injected which were run for 6 minutes, halfway through hitting the peak. A minimum of two samples were performed in order to obtain suitable duplicates. Subsequently, the beer samples were analyzed and compared with the standards.

There is a certain contribution that %ABV makes to apparent brix of the beer and the second method is based of that principle. It was performed by taking a brix reading from the beer/wort sample, then the sample of beer is boiled down to approximately 20 to 25% of the initial sample volume.

Post boiling, the volume of the sample is recovered to its original value by addition of distilled water. Post this step, a final brix value is obtained. Difference in brix is obtained between the pre boiled and post boiled (reconstituted) and is divided by a conversion factor of 0.353 in order to give the ABV% of the original beer sample (Gosset,2012).

A 100mL beer sample was taken in a 100-mL volumetric flask at 15˚ C and was transferred to a stainless-steel saucepan which was thoroughly rinsed with a distilled water squirt bottle. The beer sample was then subjected to boiling till there was approximately 25 mL in the pan. This remaining sample was poured back to the volumetric flask.

The sample in the flask was now made up to 100 mL with distilled water and the contents were then mixed via repeated inversion. Equilibration was performed by placing the flask in a 15˚ C water bath. When there is a drop in temperature, the fluid starts to go below the 100 ml mark, so we make It up by adding more distilled water ensuring that the boiled sample was reconstituted to 100 mL at 15˚ C. The liquid in the flask was again mixed and the brix value was measured on the reconstituted sample.

The recorded brix values were substituted in the following formula:

%ABV original sample = [(Brix original sample – Brix reconstituted after boil) / 0.353]

(Gosset,2012).

Specific gravity (density)

The initial density was measured before the yeast was included. This was done using a refractometer and the final specific gravity value was recorded using a hydrometer, post fermentation.

Since post fermentation wort relatively possesses higher alcohol content, it would disrupt the accuracy in refractometer readings, hence hydrometers were used (Barth,2013).

To calculate the final gravity, the hydrometer stem was carefully placed into the liquid, holding it at the top and released when it's approximately at the equilibrium position. After the stem is risen slowly & after a few oscillations it tends to settle down to its equilibrium position.

When the meniscus remains unchanged after the hydrometer oscillations, the surface of the hydrometer and the liquid surfaces are stable so the readings can be taken. The accurate scale reading was taken at the plane of intersection of horizontal liquid surface & the stem (Atkin, 2016). This reading was taken by viewing the scale through the liquid & adjusting the line of sight until it aligns with the plane of the horizontal liquid surface.

Brix

The Brix was measured with the help of a refractometer. The instrument was calibrated by utilizing a distilled water sample. Few drops of distilled water were added on the sample plate making sure there were no bubbles and calibration was completed. Refractometers are temperature sensitive, so the sample was allowed to reach room temperature.

Diastatic power

In order to predict if the mash brew possesses sufficient diastatic power, it is recommended to average out the diastatic power of the ingredients to observe if the final number is more than the 30 Lintner that is needed minimum to convert (Smith, 2010).

The overall diastatic power for the mash is known to be the sum of the diastatic power for each ingredient multiplied by the weight & divided by the total grain weight. In order to achieve that number, diastatic power for each grain was multiplied with the weight of that grain. Post that the numbers for all the grains were added up and divided by the total grain weight.

Lintner for batch = Σ (Lintner for grain * weight of grain) / (total batch grain weight)

It is noted that this calculation is an approximation. This is mainly due to the fact that certain specialty grains are partially fermentable and may possess unfermentable, but it's usually preferred to err on the side of enzymes than ending up short in the mash. This calculation is only required for grain bills that possess a high percentage of specialty grains like the ones in the current recipe. This is mainly due to the fact that these specialty grains have a high diastatic power.

Apparent Attenuation

Apparent attenuation (AA) is known to be the amount of sugars that has been consumed by the yeast during the fermentation process. By means of calculating the apparent attenuation, the extent of fermentation was monitored. AA for various yeast strains differs with their respective fermentation periods.

The value for apparent attenuation can be determined with the help of Original gravity (OG) and the Final gravity (FG), which were initially measured via refractometer and a hydrometer respectively.

Apparent attenuation was calculated by using the formula

AA = (OG-FG / OG-1)

Apparent attenuation is most commonly represented as percentage by multiplying the result of the above equation with 100.

pH

The electrodes are equilibrated according to the manufacturer manual, by immersing in a proper buffer solution. The mechanical zero of the meter is checked and adjusted if necessary.

The electrodes were rinsed with distilled water and blot. The calibration was done with pH buffers 4.0 and 7.0 respectively. Beer sample was attemperated to room temperature & degassed thoroughly. The rinsed electrodes were then inserted into the beer sample & the pH was recorded.

Careful calibration was performed for precise measurements and within normal conditions. Considering interlaboratory precision, values were reported to nearest 0.1 pH. After recording pH values of a set of beer samples, instrument calibration was rechecked with buffers at pH 7 and pH 4 to be certain that drift has not occurred. After stable fluctuation, the pH value should be noted down.

Color (Standard reference method or EBC)

Determination of color was experimentally performed by obtaining the value of absorbance of beer samples with the help of a spectrophotometer. The color of the beer was reported in a standard reference method (SRM) units or European Brewing Convention (EBC) color scale.

Absorbance 700nm value should be ≤0.039 times absorbance at 430 nm if the sample should be considered to be free of turbidity for reading accuracy. This Absorbance value at 430 nm was then added into the below mentioned equation which was converted into

SRM = 10 × 1.27 x Absorbance430 (ASBC, 2011b).

A 10mm inner dimension cuvette was filled with 18MW reagent water and utilized to zero the spectrophotometer before taking measurements at wavelengths of 430 nm and 700 nm.

At certain occasions, there might be alterations in the formulations of the beer sample recipes which may result in slight variation in readings noted. They must be corrected as soon as possible and the processes must be rerun so that we obtain the required results.

4.4. Scale up of Laboratory beer batches

The scale up of the small-scale batches were performed. Firstly, the ingredient quantities in the recipe were calculated for a scale up from a 2L batch to a 10L batch.

Due to the large scale, the milling process for the various grains was done with the assistance of Hauraki Homebrew (Rosedale). Post the milling process, the grains were mashed with the help of a 20L stainless steel vessel and extra-large mesh bags in which the grains were soaked in. The similar double mashing regime took place after which the grain bags were squeezed and removed. Trub removal can be neglected in this process as large grain bags were utilized instead of direct grain pitching.

Boiling was performed through the same method as it was for a small scale but the cooling process varied. Large scale requires a cooling system but since this batch was not of extremely large quantities, the vessel was manipulated to cooling conditions manually.

After cooling, the cold break was removed as per the same procedure and the cooled wort was transferred to the 15L fermenter carboy, the surrounding temperature of the fermenter was set to be 21°C until the fermentation is completed. Post fermentation, the leftover trub of dead yeast and unused starches were removed and the beer was siphoned off into air-tight bottles and labelled. This beer was then conditioned for a week at 4 °C.

4.5. Focus Groups

One focus group session was conducted to understand the opinions and attitudes of participants (n=10) to 2 ancient beer and 1 commercial beer samples. Consumers from the age of 21 to 40 were invited to the session and provided with certain incentives for their cooperation. The participants were given the 2 samples of beer produced as shown in Figure 1. Participants were not informed about any formulation details in order to prevent bias. Their views and opinions aided in understanding the consensus on sensory properties of the samples.

Since the product being analyzed was beer, all the focus group participants were of age 21 or above. Also, the participants needed to be avid beer consumers. This was not a priority but since beer lovers can provide more information (opinions or feelings about beer consumption), a lot of active beer consumers were invited.

The panelists (i.e., beer consumers) of which 80% belonged to Massey university were asked to answer a set of general observation questions in order to understand their thoughts and opinions on beers. In these sets of questions, their familiarity with beers and its brands along with common consumption patterns were sought. The details of the samples used in the focus group are provided in Table 4.

Table 4. Beer samples with specific 3-digit codes

Sample code	Identification
Sample 108	Ancient Beer (without hops)
Sample 101	Ancient Beer (with hops)
Sample 200	Commercial Modern Beer

4.5.1.1. Focus group protocol

First part was the arrival and welcome where the participants were greeted, and were made to feel comfortable (provided refreshments and made them sit in the Massey Accomodation common hall where the focus group was conducted).

Next, it was ensured if the participants had knowledge about what they were volunteering to do. Participants were instructed to sign a consent form before the discussion started. This aided them to be more familiar with the focus group.

The focus group had a turnout of 10 participants (14 invited) and the session was recorded to a time of 62 minutes.

Introduction: Introduction was initialized after everyone settled in the room, some ground rules were stated based on the focus group. Before starting the focus group, the recorder was turned on.

Then basic interests of participants on beer consumption were taken into account, explained the intention of this research etc. While collecting the opinions, it was ensure that they spoke clearly. The reason to do this was because everyone's opinions were valuable and to be noted down.

Warm Up: In this part, everyone in the room got a turn to speak, basic starter information was obtained from people regarding their opinions on beers (likes, dislikes, favourites etc.).

Then the list of questions prepared (Refer Appendix) were asked orally in order to gather the panellist's views on changes in beer branding, taste, packaging etc. The answers were written down on the white board and was photographed at the end of the session.

Depth: Later, the samples were provided to the participants one by one and after consumption of each sample, the participants were asked to fill out a small sensory questionnaire which will provide information on sensory aspects of the beer.

After questions on each sample were discussed, few common open-ended questions were asked regarding the overall product.

Closure: End part of the focus group where the concept of the product was reviewed. Any issues or concerns regarding the product were also discussed. Also, discussions on product variations, suggestions, satisfactions and recommendations were carried out to get additional valuable information.

After the end part, a note of thanks was given for the participants for their interest in the session. Also provided them with incentives for their time and the focus group was concluded.

4.5.1.2. Focus Group data interpretation

In order to analyze and interpret the data obtained via focus groups, huge deal of care and unbiased judgement was required, just as how other scientific approaches were performed .

It was vital to keep in mind the main purpose of the focus group, which was to explore a topic of limited knowledge in detail and depth. For that kind of research, a simple descriptive narrative was more than necessary. More in-detail analysis is simply neither efficient nor productive unless a particular research objective needs to be completed.

4.5.1.3. Transcribing the discussions

The first step in focus group data analysis was to transcribe the entire session. Since it was expensive to hire a transcriber, the alternate approach was executed, which was to take detailed notes which was done by the focus group observer. Transcriptions were not always complete, so the gaps, missing words, spelling etc. were corrected.

Nonverbal communication such as gestures, behavioral responses were also noted down which were normally ignored in the transcripts. Also, the tone in which the participants answered was considered as well because the answers are vital information and can be misinterpreted if the tone is not observed carefully.

For the project, classic analysis strategy was used that aids in relating the most with the answers that the participants provide.

In this strategy, all the answers that have been given by the participants were covered.

Then these answers were categorized into a group in accordance with each question.

The relevant answers were grouped under a common code whereas the irrelevant answer went into the discard/irrelevant pile.

This process was applied to all the questions and their answers except for the sensory questionnaire that was provided to help the focus group participants come to a consensus about the levels of key sensory attributes in the samples. This part did not need any transcribing.

Considerations:

- Understanding the focus group environment in such a way in order to extract the maximum data out of it.
- Not every answer was worth of analysis. (Certain vain answers were discarded).
- Most of the focus group data analysis we did depended on pattern identification (similarities, differences etc.)
- Biases were nullified
- The note taker was cautious of participants' body language while interpretation.

- After analyzing the data, a report was added to the results and discussions section based on the categories of sorted and edited data with a background of purpose and procedures.
- Findings were noted by themes/questions, recommendations and suggestions along with a conclusion.

4.5.1.4. Data Collection and Analysis

The methods used for analysing quantitative data is not deemed to be appropriate for qualitative methods as the sample sizes are comparatively very small. Due to this fact, generalizing the results obtained from qualitative methods to a bigger population is not possible. However, the trends that are observed from the consumer responses can be highlighted in the results (Kemp, 2009).

The information collected from the focus group was qualitative; where participants were asked to describe the key attributes such as appearance, aroma, smell which were specific to the samples. For appearance it was clarity and foam retention. For aroma it was floral, fruity, hoppy, caramelized and for taste it was sweet, bitter, sour, phenolic (pepper-like,smokey) and grainy. They were also asked to provide additional comments for each of the samples.

The samples were labelled with 3-digit codes before being provided to the panelists for ease of sorting the collected information. Additionally, a histogram was plotted only to find panellists attitude in terms of the "likelihood of regular consumption" of the two beer samples (if they were likely, neutral or unlikely to consume ancient beer again regardless of the small sample size). To create a histogram showing the number of consumers in each of these these likelihood categories, each category was assigned a nomimal value as shown in Table 5.

Table 5. Nominal values for likelihood of regular consumption of beer samples

Likelihood of regular Consumption by panellists	Nominal value
Likely	1
Neutral	2
Unlikely	3

Post obtaining all the data, the consumer responses for both the samples were analysed to obtain descriptive quotes, comments (positive or negative) and they were summarised into a table showing general trends and individual quotes about attributes for the 2 ancient beer samples.

For detailed sensory attribute analysis, another tabulation was created in which the consumer comments about each sensory attribute from both beer samples were extracted and summarised. This provided additional information which aided in finding out the key sensory attributes in each sample that panellist liked and disliked. It must be noted that since, these results have been obtained from a qualitative research method, it cannot be applied to a large population.

5. Results and Discussions

Certain processes that were carried out for producing beer like milling, mashing, fermentation, filtration were manipulated as given below in order to obtain an ancient beer product that possessed good quality characteristics and was efficient to produce.

Table 6. Ingredient variations and methodology variations for the beer samples

Sample 1	**Sample 2**	**Sample 3**	**Sample 4** **(Sample 108)**	**Sample 5** **(Sample 101)**
Ingredient variations Malt: Water ratio = 1: 3 No Job's tears added No Yam or Snake gourd root added	Ingredient variations Malt: Water ratio = 1: 4 No job's tears added Yam and Snake gourd root added	Ingredient variations Malt: Water ratio = 1: 4 No job's tears added Yam and Snake gourd root added	Ingredient variations Malt: Water ratio = 1: 4 Job's Tears added Yam and Snake gourd root added	Ingredient variations Sample 4 formulations plus addition of hops

Methodology variations	Methodology variations	Methodology variations	Methodology variations	Methodology variations
Mashing time :20 mins Cooled down to yeast temperature in 30 mins. Broomcorn millet, Jobs tears and malt were added at the same time	Mashing time :70 mins (Single temperature mashing) Cooled down to yeast temperature in 15 mins. Broomcorn millet, jobs tears added along with malt Primary Fermentation 1 week Secondary fermentation 1weeks	Mashing time :70 mins (Double temperature mashing) Cooled down to yeast temperature in 10 mins. Broomcorn millet, jobs tears added before malt was added Primary Fermentation 1 week Secondary fermentation 1 week	Mashing time :60 mins (double temperature mashing) Cooled down to yeast temperature in 10 mins. Broomcorn millet, Jobs tears added before malt was added Primary Fermentation 1 week Secondary fermentation 4 days	Addition of hops: The amount of hops is split into 3 doses which is added to the wort during at different intervals. 1st doses – after 15 mins into the boil 2nd dose- 30 mins into the boil 3rd dose- After 45 mins into the boil

5.1. Experimental lab trials

5.1.1. Recreated ancient beer recipe

The ancient beer recipe evolved from archaeology journals, where the researchers analyzed the vessels in the Neolithic sites that revealed the main grain bill of the ancient beer (Wang et al.,2016). This grain bill consisted of Barley (Triticeae), Broomcorn millet, Job's tears and other non-grain adjuncts which were discussed in section 2.1 (ancient beer ingredients) and are revealed below in table 8.

Table 7. Grain bill (mass%) inferred from (Wang et.al.,,2016)

Grains	Percentages
Barley	39.6
Broomcorn Millet	32.9
Jobs tears	27.5
TOTAL	100

Table 8. Ingredients for nominal 10 L batch

Ingredients	Weight /10L
German Pilsner Malt	1.14 kg
Broomcorn Millet	0.95 kg
Job's Tears	0.79 kg
Snake gourd root	0.09 kg
Yams	0.19 kg
Lily	0.17 kg
Yeast (US-SafeAle-05)	3 g
Hops (NZ-Cascade) (Sample 101)	15 g
Water	17L

5.1.2. Milling (Grain Size)

The adjuncts (broomcorn millet and job's tears) were milled with the finalized roller gap size of 10 mm whereas the barley was milled with the gap size of 15 mm . After multiple trials, the gap size of 15 mm was finalized for the pilsner barley as this setting provided the most effective separation during the mashing process and also didn't make the milled grains too floury. The smaller gap size for the adjuncts was chosen because naturally both job's tears and the broomcorn millet are of comparatively smaller grain sizes compared to barley. After multiple trials, it was observed that 10mm size grind did not powder the grains and also provided easier filtration post mashing.

Figure 6.1 (a) Pilsner barley before milling at 15mm (b) After milling at 15mm

Figure 6.2 (a) Broomcorn millet before milling at 10mm (b) After milling at 10mm

Figure 6.3 (a) Jobs tears before milling at 10mm (b) After milling at 10mm

5.1.3. Mashing

Two types of mashing (single temperature and double temperature) were performed (2 trials each) to determine the effect of mashing technique for a beer that consists of malt and these specific adjuncts. The main point of interest is the time when the maximum sugars are extracted from the grains. Brix was used as a measure to track the release of sugar from the grain.

5.1.3.1. Single temperature mashing

For the single temperature mash a constant temperature of 68°C was used. This was a common mash temperature in modern brewing (Palmer,2006) and this temperature is known as the Brewer’s window (Figure 2). Both adjuncts and malt were mashed in the same vessel for 90 minutes in the first trial and 100 minutes in the second trial. The mash ingredients are given in Table 6. Water (17L) was added at a strike temperature of 70°C and the Brix was measured in time intervals of 10 minutes.

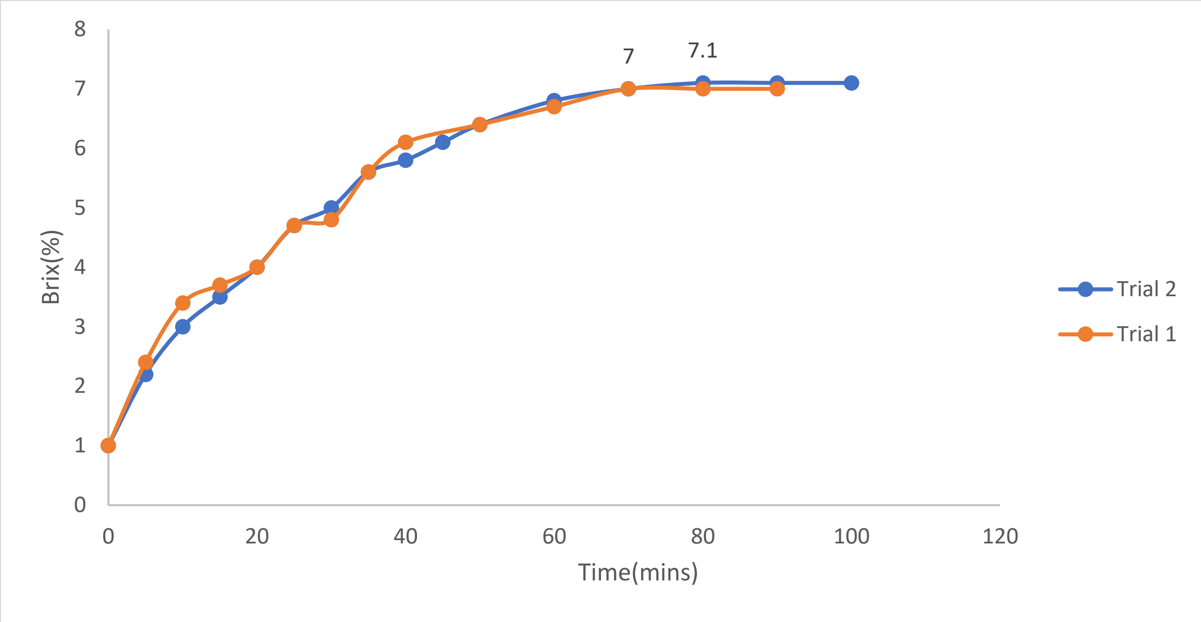

Figure 7. Brix % for single temperature mashing at 68°C

The final brix values as indicated on the figure for both trials were 7% (trial 1) and 7.1% (trial 2). From Figure 5 the final average brix that was obtained was ≈7% and the mashing time was ≈75 mins.

5.1.3.2. Double temperature mashing

Double temperature mashing technique as explained in the methodology chapter, is a technique where the adjuncts are separately cooked from the malt at a higher temperature (75°C) so that the enzymes will get deactivated at such high temperature. Post the adjunct-cooking, the temperature is lowered to cook the malt.

Strike temperature for adjuncts were 75°C and for barley it was 70°C .Steps such as acid rest,saccharification and mash-out were performed at target temperatures of 40°C,68 °C and 75°C respectively. Brix readings were taken at 10 minute intervals via digital refractometer (Atago PR-101,Japan).

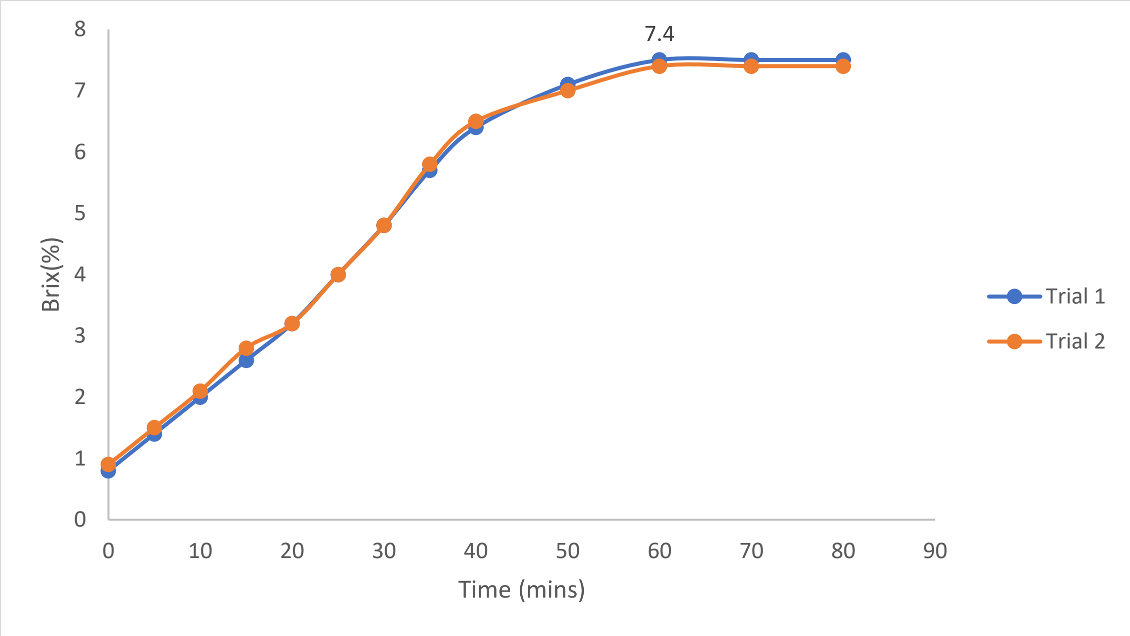

Figure 8. Double temperature mashing (both trials)

For both trials a maximum Brix value of ≈7.4% was reached after ≈60 minutes. This had a higher brix value (greater sugar content) and quicker processing time than that of a single infusion temperature mash.

This proved to show that double temperature mashing was more effective and efficient and hence it is recommended.

5.1.4. Fermentation

Both primary and secondary fermentation were applied to this brewing process. The primary fermentation was performed for 1 week in the fermenter whereas the secondary fermentation was performed in a carboy at the initial stages. The secondary fermentation lasted for approximately 1 week (secondary fermentation was to mainly promote carbonation) at the fixed temperature of 21°C as mentioned in the methodology section.

The primary fermentation was completed in 8 days. This was observed through the final gravity values. The FG reading on days 8,9,10 was plateued at ≈1.050 g/ml.

During the course of fermentation, through multiple trials it was observed that the beer that was transferred to an airtight bottle 2 days before the completion of fermentation provided additional carbonation that aided beer's sensory characteristics. Transferring it a day before resulted in insufficient carbonation & 3 or more days before, resulted in incomplete fermentation & too much carbonation). Hence,even though the fermentation time was 8 days, the beer was transferred to air tight bottles on the 6^{th} day to instigate natural carbonation & to obtain a fully fermented beer.

Figure 9. Beer transferred to air tight bottles on 8th day (left) & on the 6th day (right)

In terms of secondary fermentation, it was found through various trials that the beer that was subjected to atleast 1 week of secondary fermentation, had better foam retention than 2 weeks or more,Hence the secondary fermentation was reduced to ≈1 week and also it was done in air-tight bottles instead of the glass carboy to avoid the escape of CO_2 from the brew.

The resultant final sample (sample 4) that was prepared in these conditions displayed a better result in terms of carbonation. That was inferred from observation during experiments as shown in the figure 9 and was backed up in the sensory analysis section later.

Packaging and Storage

Air-tight dark tinted glass bottles were utilized, that served the purpose of reducing CO_2 loss and preserving beer quality . The beer samples were also stored in a fixed-temperature chiller where the temperature was set at 4°C for maintaining effective beer quality.

5.2. Physicochemical Analysis

5.2.1. Alcohol content:

The alcohol content from the recreated beer samples were determined via 2 methods as explained earlier in the methodology.

a) Gas chromatography method (Carlo Erba 6000 Vega Series 2 instrument for GC along with a Hitachi D-2500 Chromato-integrator as the printer).
b) Digital refractometer-based method (Atago PR-101,Japan).

The refractometer-based method were compared two samples of ancient beer [Sample 108 (without hops) & Sample 101 (with hops)] and the last sample 200 was 5% commercial beer for reference.

Table 9. The initial brix, final brix after reconstitution and Alcohol content of finalized samples

Samples	Initial brix	Brix after reconstitution	Alcohol by volume
Sample 108 (Ancient beer without hops)	4.1%	2.7%	3.98%
Sample 101 (Ancient beer with hops)	4.2%	2.7%	4%
Sample 200 (Commercial 5% beer)	5%	3.3%	5%

After brix values have been measured before and after reconstitution. They were subjected to computation as explained in the methodology section (J. Gossett,2012) and was utilized to obtain the final ABV% for all the 3 samples. The obtained results are displayed in Table 9.

The results from the Gas chromatography were obtained through the solvent retention time/area graph. The brew sample was tested with 10% ethanol standards in order to find their unknown alcohol content. The retention time and the retention area of the peak were determined from the graph. The alcohol content of the recreated brews 108, 101 and commercial beer are listed below in Table 10.

Table 10. Alcohol content for beer samples obtained from Gas Chromatography method

Samples	Alcohol by volume
Sample 108 (Ancient beer without hops)	4.1%
Sample 101 (Ancient beer with hops)	4.1%
Sample 200 (Commercial 5% beer)	5%

When both alcohol content determining methods are compared, it is inferred that the commercial beer sample provided similar results whereas both the ancient beer sample results slightly differed from each method. The differences may have been due to minor inaccuracies in either one or both the methods or storage conditions, it is assumed that the recreated brews contain an ABV of ≈4.1%.

As it was discussed before, the average alcohol content for commercial beer ranges from 3 - 10% amongst which most beers have from 4 to 5% on an average, which implies that the recreated ancient brews possesses alcohol content that is well within the ranges of commercial beer.

5.2.2. Density

The samples were analyzed for original gravity (OG) initially after mashing and before fermentation. The figure below provides the average values of original gravity for all the four samples. As explained in the methodology, the original gravity varies on the basis of starch/sugar quantities in the sample. As exhibited below, there is no significant difference in the original gravity which can be observed from the error bars (maximum difference being only 0.006 g/ml).

Observation can be made where the samples that have been mashed for a longer period of time has released more simple sugars hence giving a slightly greater OG value and sample 1 which has been mashed for a significantly lesser time period has a less OG due to the scarce sugar content.

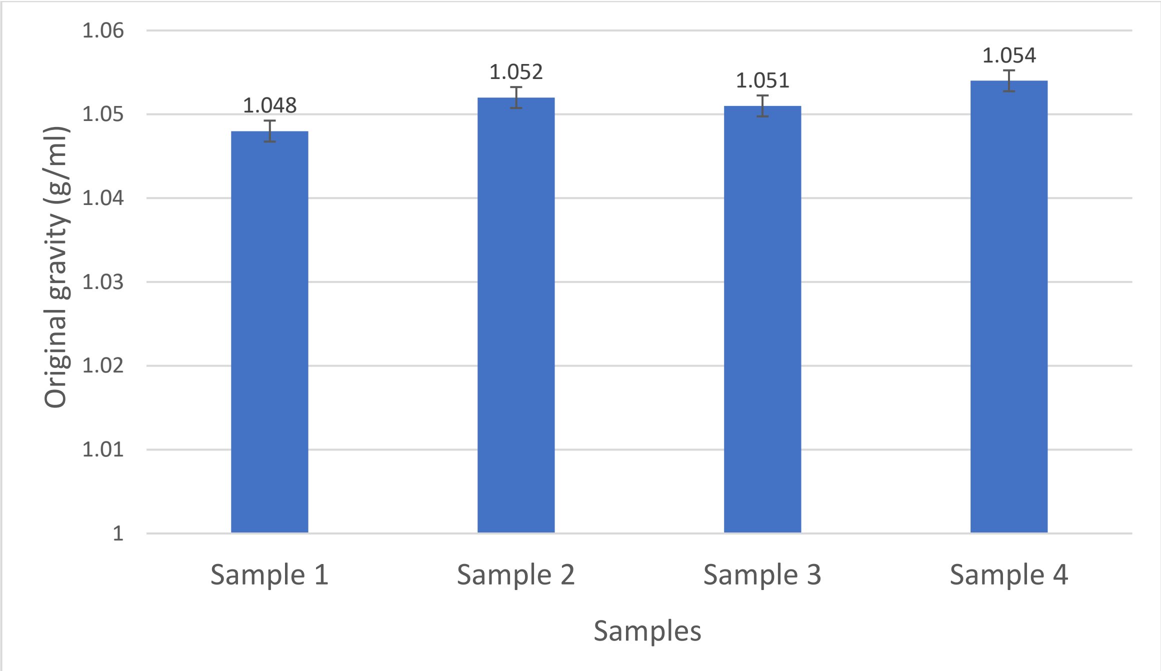

Figure 10. Avg. Original gravity of beer samples

Even though all the OG values of different samples are varied, it is still evident that the average OG value stays around 1.050 g/ml. This means that the mashing time does have a minor impact on the original gravity but considering the results, it is clearly inferred that this impact is insignificant when it comes to different beer samples.

However, it is advised to mash for the full optimum time that has been previously determined in order to extract the maximum sugar content from the mash and avoid irregular fermentation.

Final gravity (FG)

Final gravity was measured to check the end of the fermentation process. The values which are in the table given below represent the end values (final values) that were taken at the near end of fermentation period. It was duly noted that the readings were finalized after 3 days of saturated FG value. These values express the extent to which the fermentation was completed.

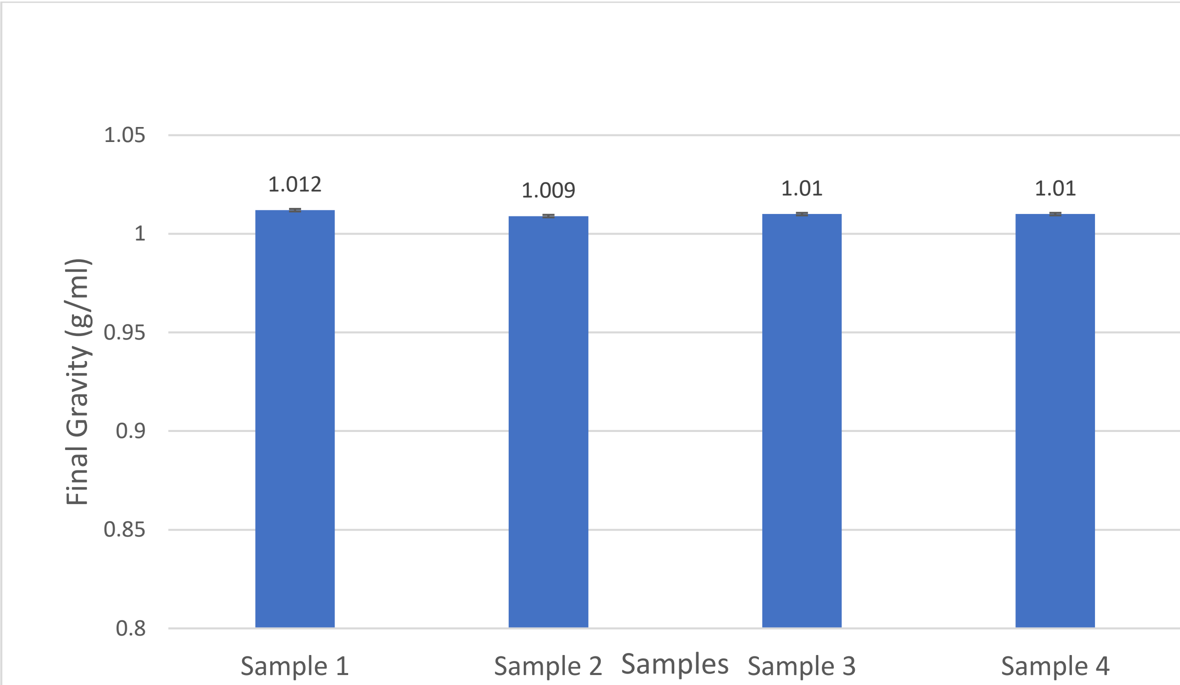

Figure 11. Avg. final gravity of beer samples

The wort undergoes fermentation and the simple sugars present in are converted to alcohol which is less dense than sugars in water which explains the brix reading being reduced from the original gravity. It is evident that the specific gravity value has reached closer to that of the water, thus indicating good fermentation. For beers, the final gravity value generally ranges around 1.015–1.005 g/ml, in our case our ancient beer has an average FG value of ≈1.010 g/ml which can be observed from the graph, is under the normal range for a commercial beer.

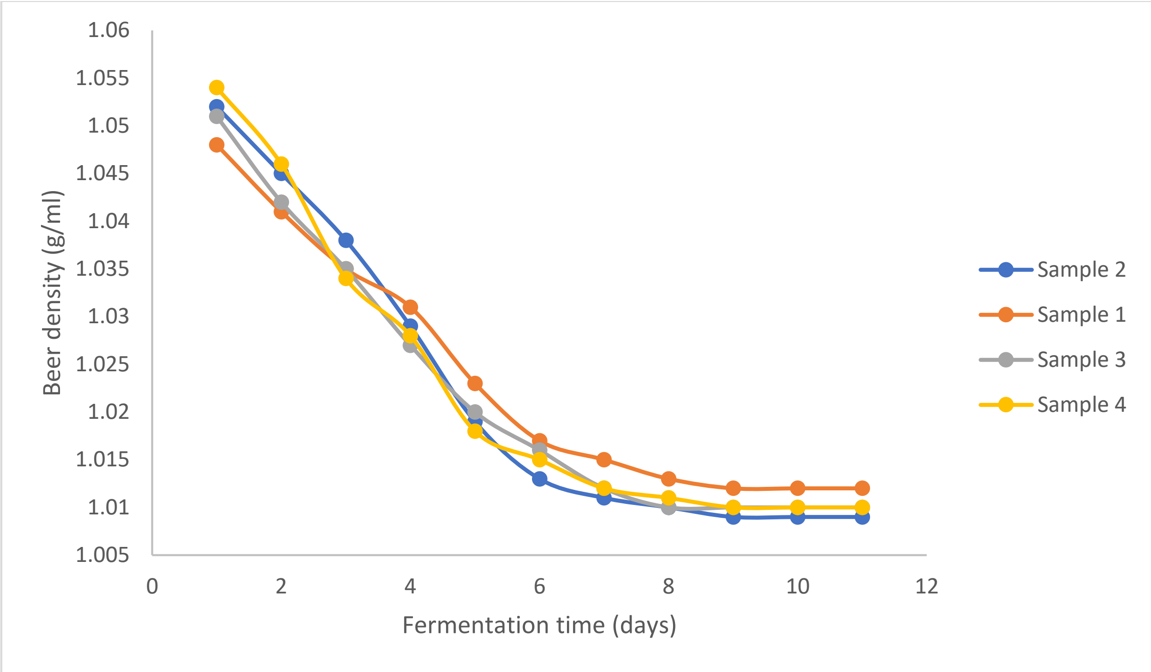

Figure 12. Decline in beer density with fermentation progression

A graph of decline in specific gravity during fermentation was measured at intervals of 1 day, starting from the day OG was measured and till the final day where the FG values were constant (Figure 12).

The consistent final gravity values for all the samples state that the fermentation has been completed to the full extent. It was noted that the OG value of the 1st sample had a minute difference over the other samples,whereas FG reading for all the samples are almost the same values (maximum difference of ≈.003 g/ml) for all the samples due consistent levels of fermentation completion.

5.2.3. Apparent attenuation:

The (AA) Apparent attenuation known to be the decrease of a property in a substance. This decrease occurs when the fermentation takes place that converts the sugars into alcohol and CO_2 (Palmer, 2009). AA was determined to monitor and verify the quality of beer, sugar to alcohol conversion in the beer samples. It is vital as we can analyze how effectively the fermentation has been completed. They were calculated with the help of the OG and FG values that were tabulated earlier. The table given below exhibits apparent attenuation (%) for all the four different samples on the extent of fermentation completion.

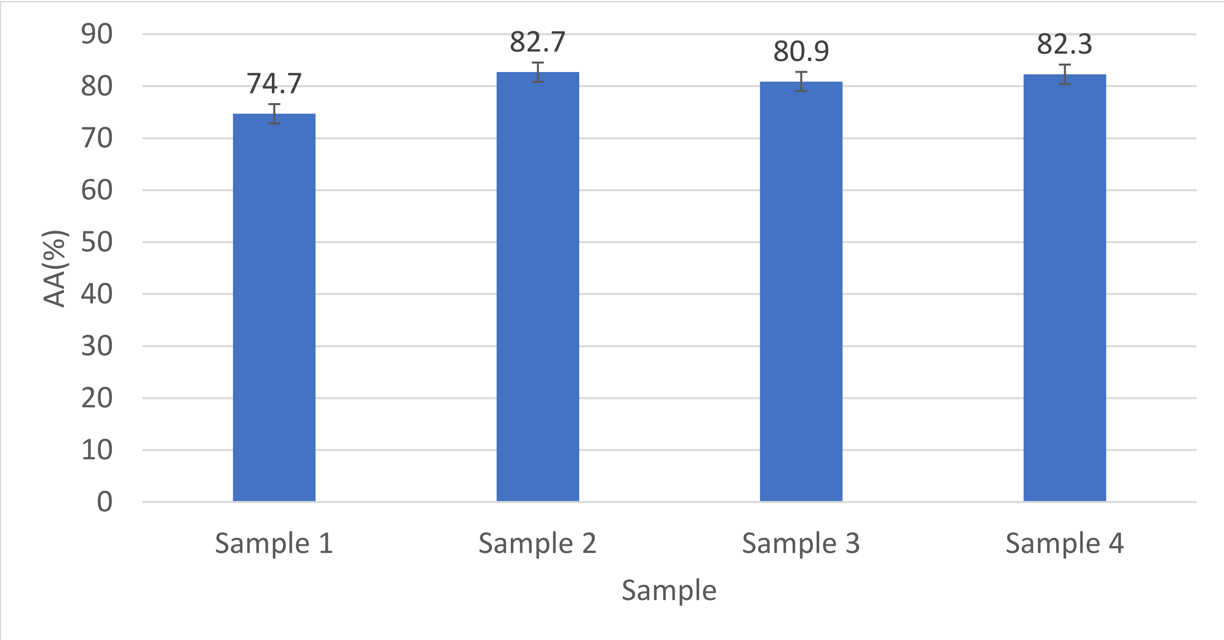

Figure 13. Apparent attenuation of beer samples

When analyzed, it is seen that in all 4 samples, the extent of fermentation completion is good, this is inferred due to the fact that AA is around 75% as it is common for all beers (Palmer, 2009). Although it is noted that sample 1 is found to be the least fermented, it maybe due to a few inadequacies like shortage in mashing time, inefficient cooling process etc. might have not released adequate amount of sugars for effective fermentation to have taken place.

On an overall scale, most samples have a more than average level of attenuation, which is an indicator that the beers wouldn't be overpoweringly sweet which was later backed up in the sensory section (as the sweetness factor was scored to be 4.5 on a 0-10 point scale).

5.2.4. Diastatic power and its correlation with malt color

The overall diastatic power of the mash was predicted by summing up the diastatic power for each ingredient times its weight divided by the total grain weight. To get this number, the diastatic power for each grain is multiplied times the weight of that grain, add the numbers up for all of your grains, and divide by the total grain weight (Smith, 2010) as follows :

Lintner for batch = Σ (Lintner for grain * weight of grain) / (total batch grain weight)

Since the modified German Pilsner Malt has the diastatic power of 110 °L, diastatic power of job's tears (pearl millet) is 22°L (Badau et al., 2006)and broomcorn millet is 10.38°L(Muoria et al., 1998). These values were used in predicting the overall diastatic power of the mash which was found to be 53°L.

As a general rule of thumb, the mash should average 70 Linter or above to obtain effective starch breakdown (Smith,2010).

Even though the prediction explains that our mash might not possess an effective starch degrading quality by the usage of enzymes (alpha-amylase, beta-amylase, limit dextrinase, and alpha-glucosidase), the German pilsners malt's high diastatic power and its quantity in the grain bill tends to balance out for any DP shortcoming.

The driving force for DP appears to be beta amylase, which usually correlates better with DP than the other starch-degrading enzymes and has the highest activity of all starch-degrading enzymes in malt. Also our DP value prediction is evident that our malts might need to be germinated more to effectively increase the production of said required enzymes for a good mash.

From this we can infer that for complete conversion of starch to sugars, high levels of barley malt DP are especially important when adding substantial amounts of unmalted adjunct to the mash tun during brewing.

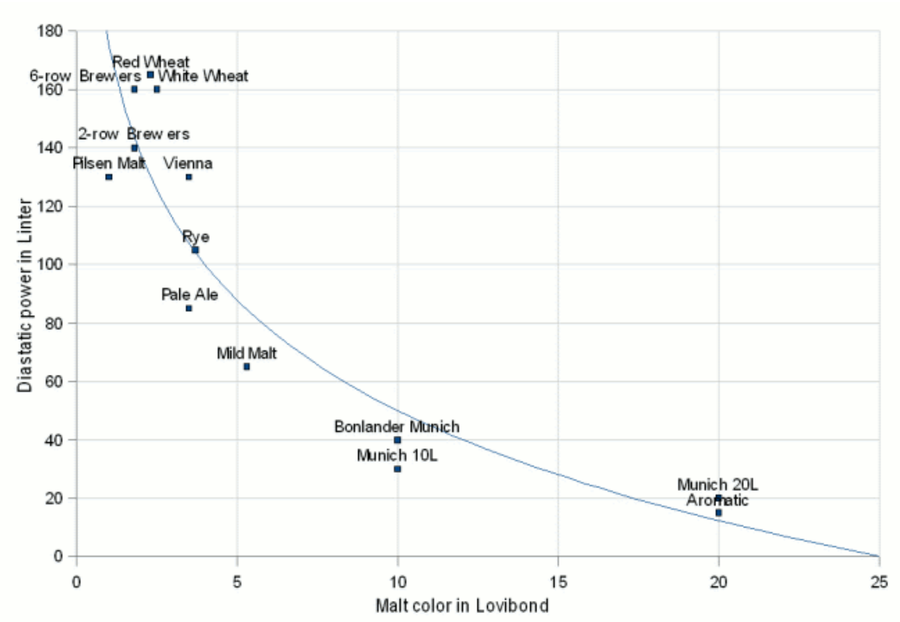

Figure 14. Correlation between the diastatic power of malts and their color (Kaiser, 2008)

There is also a relationship between diastatic power and color as exhibited in Figure 14. Various malt types in accordance to their diastatic power are plotted against the color of the malt in °L (Lovibond units). From the trend of the graph we can infer that the diastatic power decreases as malt color increases. Our recreated recipe diastatic power prediction was compared with this reference graph in order to find if the color of our mash coincides with this graph.

After cross referencing with table 11. which shows our brews had an overall color of 7.56 EBU and the diastatic value of our mash which was ≈53°L. ,its evident that the values coincide proving that the resultant beer has achieved an accurate color. This is now an additional method for cross referencing the recipe with the final product for production accuracy.

5.2.5. Color

In order to analyze the color of the beer samples, initially the absorbance of beer for light path of ½ (A½) by multiplying absorbance by ratio of ½ into thickness of beer column in which the cuvette was used. The absorbance at 700 nm was ≤0.039 times absorbance at 430 nm which indicated that the beer was “free of turbidity” and the color of beer was determined from its absorbance at 430 nm.

Table 11. Absorbance values at 430 nm, SRM and EBC values of beer samples

Sample	Average absorbance at 430nm	SRM (Standard reference method)	EBC (European brewery convention
Sample 1	0.294	3.73	7.34
Sample 2	0.304	3.86	7.60
Sample 3	0.302	3.83	7.54
Sample 4 (Sample without hops)	0.303	3.84	7.56
Sample 5 (Sample with hops)	0.311	3.95	7.78

These values are then averaged out to get a final absorbance (430nm) value which is utilized to calculate the SRM (Standard reference method) units. The SRM units of the four samples averaged from the ranges of 3.73 – 3.86 (ochre yellowish color range between blonde ale and Weissbier) Since we require to obtain the EBC (European brewery convention) values, the SRM units are then calculated into EBC which is then compared to a standard color chart that provides the color of the beer. The EBC units ranged from 7.3 to 7.6 which ranged the same color band when referred to the chart. This reference also matched with the beer sample thus verifying its color.

SRM/Lovibond	Example	Beer color	EBC
2	Pale lager, Witbier, Pilsener, Berliner Weisse		4
3	Maibock, Blonde Ale		6
4	Weissbier		8
6	American Pale Ale, India Pale Ale		12
8	Weissbier, Saison		16
10	English Bitter, ESB		20
13	Biere de Garde, Double IPA		26
17	Dark lager, Vienna lager, Marzen, Amber Ale		33
20	Brown Ale, Bock, Dunkel, Dunkelweizen		39
24	Irish Dry Stout, Doppelbock, Porter		47
29	Stout		57
35	Foreign Stout, Baltic Porter		69
40+	Imperial Stout		79

Figure 15. SRM & EBC Color reference scale (Mosher, 2017)

(a)

(b)

(c)

(d)

Figure 16. Beer type color comparisons (a) Weissbeer (b) Blonde Ale (c) Ancient brew 108 (without hops) (d) Ancient brew 101(with hops)

As compared in Figure 16, the ancient brews exhibit similar color to certain pale colored beer types (weissbeers,maibocks and blonde ales), as mentioned in the EBC color reference. All these brews exhibit the pale-yellowish color when helt to the light. The main common factor with all these brews is that most of them have German Pilsner malt as the primary malt or as a supporting malt in the recipes. This could be one of the main contributors in providing these types of beers their signature colors.

Although these brews contain similar color profiles, there are minute differences when observed closely. Weissbeers are a little darker than both the recreated ancient brews which explains its EBC value and blonde ales are more pale as per prediction, thus confirming their EBC values for respective color. Apart from pilsner malt, even the adjuncts contribute to the pale tone for ancient brews. Also, as mentioned in the literature review, hops provide a minor color difference which can be noted among the two ancient beer samples shown in the figure above. The sample with hops (101) exhibits a mild darker tone compared to the sample without hops (108) which explains the previous sample's (101) slightly higher EBC value.

5.2.6. pH

pH is an indicator of acidity, fermentation completion and product consistency. As explained in detail in the methodology, pH was analyzed via pH meter and the readings are given in the table.

pH was analyzed for all the 4 samples that were produced to observe if any changes resulted in the final product due to different ingredient proportions or change in methodology amongst the samples etc.

The bars in the chart are compared to infer that the pH value for the 1st sample is barely higher compared to the other samples and as inferred through the error bars, this change is insignificant. The minute changes maybe due to the variations in mashing parameters or also due to alcohol content, amount of volatiles etc.

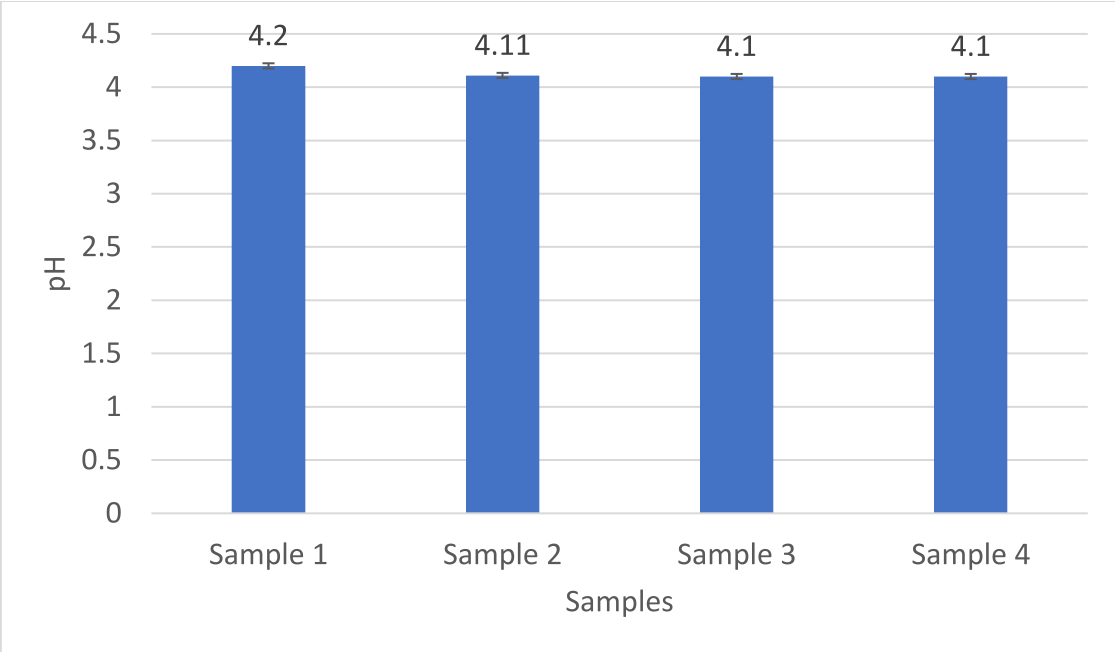

Figure 17. pH values for beer samples

The first sample has a lower mashing time compared to the other samples which means that the precipitation of the phosphates and the amino acids obtained from the malts has not been completed yet giving the 1st sample a slight pH increase than the other samples. This also indirectly explains the importance of completion of mashing, which not only aids in the sensory properties but also the nutrition profile in the finished beer product.

By analyzing the graph, it is evident that the values average to 4.15 for the recreated samples. These approximately similar values exhibit that the fermentation progression was consistent throughout all the samples.

Also,its commonly advised to check the completion of mashing as mentioned above as it can affect fermentation products thus varying the pH in the end product. This can have a small impact on the beer's final taste.It is now seen that the recreated ancient beer provided a pH which is similar to barley wine which has a pH of 4.4 (François et al., 2006).

Since there are no known publications where the pH of ancient beers were analyzed, it is not confirmed that these pH values are the standard for ancient beers but when compared with commercial beers, it proved to be less acidic and this was be reasoned due to the absence of hops in this recreated beer.

Table 12. Physicochemical characteristics

Parameters	Method	Result
Alcohol Content	Gas Chromatography & Refractometer-based method	Sample 108 – 4.1% ABV Sample 101 – 4.1% ABV
Color	UV Spectrophotometer	Avg. Absorbance for both samples @430nm ≈0.3 SRM: 10 x 1.27 x Abs430 Avg. SRM = 3.8 units EBC: SRM x 1.97 Avg. EBC =7.56 units
Original Gravity (OG)	Refractometer	≈ 1.050 g/ml
Final gravity (FG)	Hydrometer	≈ 1.010 g/ml
Apparent attenuation (AA)	Hydrometer	Avg. OG = 1.050 g/ml Avg. FG = 1.010 g/ml Avg %AA for all samples= [(OG-FG) / (OG-1)] x 100 ≈80%
Diastatic power	-	≈53°L
pH	pH meter	≈ 4.1 ± 0.01

5.3. Focus group session:

5.3.1. Focus Group:

The Focus group consisted of 10 members who were of legal age for consumption of alcohol. The table below shows the demographics of the focus group participants.

Table 13. Focus Group panellists (Beer consumers) demographics (n=10)

	Beginners (occasional average beer consumers)	Intermediates (experience in beer brewing and consumption)
Gender	5 Males 3 Females	1 Male and 1 Female
Age	Ages ranging from 21-31	Ages ranging from 30-38
Ethnic groups	4 Kiwis 3 Indians 2 Asians (1 Chinese & 1 Malaysian) 1 American	2 Kiwis
Additional Information	Primarily Massey Students and Graduates	Homebrewers (5+ years)

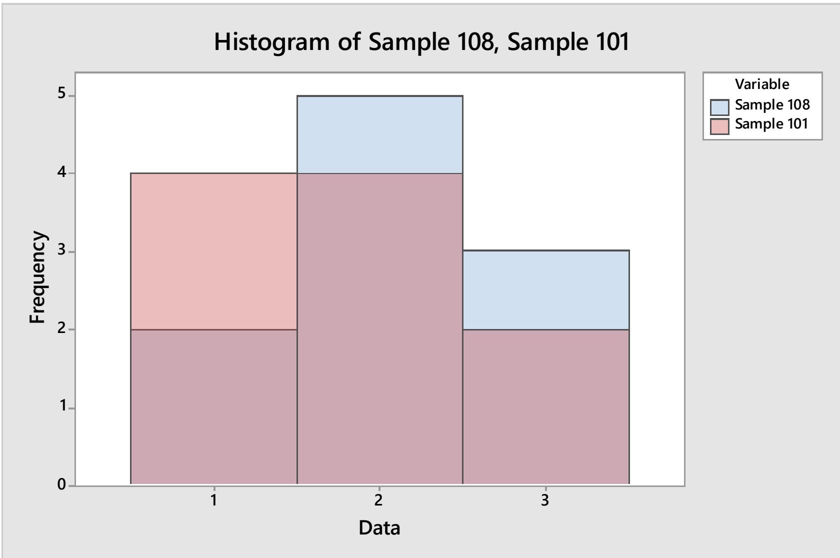

Figure 18. Histogram of likelihood of sample consumption (1=likely, 2=neutral and 3 =unlikely)

The figure depicted above shows that the distribution of consumer responses based on likelihood of ancient beer consumption were similar in certain aspects. It can be observed that both samples had a similar "neutral and unlikely to consume" trend with a slight increase for sample 108. The contrast factor was that the “likely” consumption response which is clearly evident that sample ancient beer with hops was favoured more to be consumed than ancient beer without hops.

In order to obtain a comprehensive result for the consumer responses obtained through the focus group, a summarised table of general comments and individual quotes was created . In this table, both the positive and negative descriptors of sensory attributes (samples 108 and 101) were listed. Apart from these comments and quotes, also a summary of consumers' overall reaction towards the ancient beer concept was stated. The resultant tabulation is exhibited below (Table 14).

Table 14. Summarised comments from the focus group for ancient beer samples

			Sample 108 (without hops)	Sample 101 (with hops)
Common General descriptors	Positive	Appearance	1)Golden brown colour 2) Clarity (non hazy) 3) Non viscous consistency of beer	1) Commercial beer-like consistency 2) Aesthetic brown complexion
		Aroma	1)Butterscotch notes 2) Strong grainy aroma 3)Malty scent 4) Identical to commercial beer	1) Malty notes 2) Hoppy scent 3)Faint grainy notes
		Taste	1) Sweet notes 2) Moderate caramelized taste 3) Moderate sourness 4) Pleasant aftertaste	1) Commercial beer-like taste 2) Better aftertaste than sample 108 3) Balanced sweetness with bitterness
	Negative	Appearance	1) Mild yellowish tint 2) Less carbonation	1) Consistency too runny

				2) Severe lack of fizziness
		Aroma	1) Overpowering maltiness	None
		Taste	1) Flat with no fizziness 2) Intense rancidity 3) Aftertaste gets bitter after a while	1)Flat taste 2)Too much bitterness 3)Overpowering sourness at times.
Individual quotes		Appearance	"Mango'ish colour" "Not a lot of foam on top like store bought beers" "Very smooth in consistency"	"Aesthetic heineken looking beer" "Foam disappears very quickly"
		Aroma	"Salivation provoking scent" "Can taste fruity notes"	"Very strong hoppy scent right off the top"
		Taste	"Better than commercial beer due to sweetness" "Needs to be a little stronger"	"Would taste a lot beer-like if artificially carbonated" "Would prefer if it as much as normal beer if it tasted stronger"

Summary : The majority of the participants came to a consensus that both the samples of ancient beer had a pleasing commercial beer-like appearance when it came down to "dark golden-brown colour" and "moderate foam retention". The aroma was pleasing for majority of the consumers with highlights of " fruity","grainy" and "malty" scents, although these were only for sample 108. For sample 101, the consumers related to commercial beer-like (hoppy) aroma. However, the group was divided in their opinions on taste as the balance of overall taste was “moderately satisfactory” due to inconsistent aftertastes and stronger notes of either sourness, bitterness or lack of carbonation that resulted in a flat beer.

Table 15. Responses for common questions regarding the Ancient beer product concept

Participant number	Product satisfaction (Very dissatisfied / Moderately dissatisfied / Neither satisfied nor dissatisfied /Moderately satisfied/ Highly satisfied)	Product recommendation (Not at all likely to recommend / Not very Likely to recommend /Unsure/ Likely to recommend / Extremely likely to recommend)
1	Very dissatisfied	Not at all likely to recommend
2	Moderately satisfied	Not very likely to recommend
3	Moderately satisfied	Likely to recommend
4	Neither satisfied nor dissatisfied	Unsure
5	Moderately dissatisfied	Not very likely to recommend
6	Moderately satisfied	Likely to recommend
7	Highly satisfied	Extremely likely to recommend
8	Moderately satisfied	Not very likely to recommend
9	Moderately satisfied	Likely to recommend
10	Very dissatisfied	Not at all likely to recommend

From Table 15, it can be seen that most of the panelists were “moderately satisfied” with the ancient beer product concept overall and in terms of recommendation, it was most probably that the product was going to be either “Not very likely to be recommended” . However, its note-worthy that these responses cannot be generalised to the population of beer consumers as these responses were obtained from a focus group and the number of panelists were relatively less in numbers. A consumer sensory test with large group of consumers will be required to understand consumer perception of the sensory attrinutes of these samples.

Panellists' comments on the sensory attributes of the samples are summarised in Table 16.

Table 16. Table representing the most frequent comments for each each attribute of ancient beer samples

Sensory Characteristic	Sample number	Most frequent comments
Clarity	108	No cloudiness (non-hazy)
	101	Brighter than sample 108
Foam Retention	108	Less fizzy (low carbonation)
	101	Moderate carbonation
Floral (Smell)	108	No obvious floral aroma
	101	Mild floral aroma detected
Fruity (Smell)	108	Faint citrus aroma
	101	Similar to sample 108
Hoppy (Smell)	108	No obvious hoppy aroma
	101	Strong hoppy aroma detected
Caramelised (Smell)	108	Heavy caramelized scent
	101	Mild caramelized aroma
Sweet (Taste)	108	Moderate sugary aftertaste
	101	Slight hint of sweetness
Bitterness (Taste)	108	Hoppy aftertaste
	101	Heavy bitterness noted during and after consumption
Sourness (Taste)	108	Moderate tangy taste
	101	Similar citrus taste to sample 108
Phenolic (Taste)	108	No notable phenolic taste
	101	Similar to sample 108
Grainy (Taste)	108	Mild nutty flavour
	101	Faint Starchy taste

Sample 108 = sample without hops.

Sample 101= sample with hops

Using information from Tables 15 and 16 as well as the raw data from the focus group session, general observation by the panellists in terms consensus were predominantly related to the following attributes: appearance (clarity and foam retention), aroma (floral and fruity, caramelized, and hoppy) and taste. Summaries of each of each attribute are as follows:

Appearance

Clarity: On overall, the participants of the study agreed that the sample with hops (Sample 101) was comparitively more brighter and clearer than the sample without hops (Sample 108).

Foam retention: The focus group results were analysed to arrive at a consensus that while both samples had an under-average foam retention, sample 101 had a slightly more carbonated appearance than the other sample.

Aroma

Floral and Fruity: From the focus group results, both of these aroma attributes were observed to be present in moderate amounts in both the samples. The participants agreed that both attributes were not obviously noticeable except for a mild citrus aroma that was present in both the samples.

Caramelized: Altogether, the focus group participants came to a consensus that sample 108 had a strong caramelized aroma compared to sample 101. This was found to be due to the lack of hops in sample 108, that prevented masking of sugary aroma.

Hoppy: This attribute was identified with ease by most of the participants as it possessed a strong notable aroma. Due to this, it was agreed upon that sample 101 possessed a more hoppy aroma than sample 108 due to the obvious presence of hops.

Taste/flavour

It was agreed upon by the participants of the study, that noticeable flavors were present in both samples due to the grains and hops in the brew. Except for the phenolic taste, others were stronger and similar for both samples excluding bitterness. Sample 101 was more bitter due to the inclusion of hops. From this, it was noted that the ancient beer had an overall nuanced taste characteristics than aroma and appearance.

Under these observations, it was evident that

1) Hoppy (aroma)
2) Bitterness (Taste)

were significant attributes that separated both the samples more compared to the other attributes. These two attributes were especially dominant in sample 101 than sample 108. This is an evidence of hop addition that differentiated the characteristics of sample 101.

In spite of the results obtained, findings are still not generalisable due to the entire population of interest i.e., these results cannot be generalized and taken to be representative of all beer consumers due to the nature of the approached used. Decisions could still be made but this will be limited due to the high degree of uncertainty and risk because of the sample size used in this study. So, it is safe to assume that the results obtained are strictly for contrast observations and not for any decision making.

Post observing the results, it is determined from the focus group that both samples of beer are preferred more or less equally by the consumers for regular consumption and also through the recorded responses, it is found that the ancient beer concept on an average has "moderately satisfied" the panelists.

6. Conclusion

Overview

The ancient beer recipe obtained from archaeology articles were utilized alongside contemporary beer brewing methods that resulted in a novel beer that had similarities with modern beer types. As stated in the research aims chapter, the recipe was treated from a technological perspective in order to analyze the product in detail and determine whether it can be developed further.

The contemporary brewing methods that were adopted were modified accordingly to cater to the unique ingredients that were utilized in our project. Also, the physicochemical analysis was carried out to observe vital characteristics such as alcohol content, sugar content, breakdown of sugars, pH, color etc.

The finished product was subjected to an informal sensory analysis via a focus group and also a short sensory questionnaire to find out the panellists view towards modern beer and this product concept. Also, the results obtained from the sensory questionnaire were statistically analyzed to obtain the product's strengths and weaknesses.

In-detail analysis

Multiple samples were originally developed on a trial-error basis to understand the effect of ingredients and the brewing processes on the beer product. In terms of ingredients modification, grains such as broomcorn millet, Job's tears were added along with certain adjuncts like snake gourd root, yam and lilies. Post few experimental trials, two samples were taken into consideration for further analysis.

The trials also considered methodology variations to obtain a more efficient processes that produced good beer. Certain conditions such as adopting double temperature infusion mashing, modifying mashing time to 60 mins & cooling time reduced to 10 mins for better consistency in the beer. Primary fermentation was carried out for 6 days whereas secondary fermentation was extended to a week.

Physicochemical analysis showed that the alcohol content which was 4.1%, similar to the modern-day commercial beer 5% ABV.

The diastatic power exhibited that the recreated beer recipe had enough starch degrading capacity along with exhibiting a relationship with beer color that proved the accuracy of the color analysis performed.

The focus group exhibited that the consumers overall preferred sample 101 (beer with hops) over 108 (beer without hops). The product concept was found to be moderately satisfying and less often recommended from the questionnaire but it is to be noted that the sample size was small and there are certain improvements that can be done on the final product.

Strengths and Limitations

Valuable aspects of this research are Understanding the nature of ingredients present in the ancient recipe.

- Incorporating modern brewing processes into those ingredients.
- Recreation and analysis of the ancient beer in terms of its physicochemical analysis.
- Subjecting the beer to a sensory analysis in order to understand its consumer acceptability and its sensory strengths and weaknesses.

Considering the sensory analysis our product has to be well improved in certain areas like flavor, fizziness, clarity etc., thus opening up to wide range of improvement requirements.

Recommendations

When moving forward with this product concept, it is vital to understand the importance of modifying the brew techniques in order to suit large scale production, thus it is advised to focus on research that would aid in taking this product to a larger scale.

However, this can be done only when the product receives an outstanding reception on a small-scale level in the first place. So, its recommended that certain processes such as carbonation and filtration can be further incorporated to produce a more sensory satisfying beer. It also would be extremely useful if a formal sensory can be performed at a larger scale to further look into the areas that can be improved on.

7. Appendix

7.1. Focus group/sensory response

Questions regarding consumption likeliness, sensory improvements, qualities, similarities about the beer were asked as well. All the answers to these questions are displayed below

Responses for Sample 108

Participants	Likes and Dislikes about the beer	Properties that can be added to the beer	How likely he/she might consume it again (Unlikely/Neutral/More Likely)
1	L: Sweet notes, texture D: Sourness, color(yellowish)	Could add a little more bitterness	Neutral
2	L: Color and sweetness(caramelish) D: Sourness, flat	More carbonation	More Likely
3	L: bright color, Aroma (butterscotch) D: Taste (rancid and bitter)	Needs bitterness	Neutral
4	L: Appearance (clarity and color) D: Taste (doesn’t taste like commercial beer)	Adding more beer like (barley) aroma and taste	Neutral
5	L: Accurate color and texture (especially clarity and thin texture). Also like the grainy aroma D: Non-hoppy bitterness, intense rancidity and flat	Inclusion of hops and carbonation	Unlikely
6	L: Malty aroma and Appearance (pleasing color, texture and clarity) D: Taste and aftertaste(Feels flat and less alcohol)	More fermentation to add ABV	Neutral
7	L: Taste (sweetness and sourness) D: Aftertaste is not good	Would like if it has a more commercial beer taste	Likely
8	L: Smell (Beer like aroma) D: Too bitter and sour	Less bitterness and more fizziness	Unlikely
9	L: Appearance and aroma D: Doesn’t taste like commercial beer	Fizziness	Neutral

10	L: Likes the aftertaste and texture of the beer D: Initial sourness	More commercial taste (bitterness and less sourness)	More likely

Responses for Sample 101

Participants	Likes and Dislikes	Comparison with sample 108	How likely he/she might consume it again (Unlikely/Neutral/More Likely)
1	L: taste, texture D: color(yellowish)	Better aftertaste	Likely
2	L: Color and bitterness D: tastes flat	same	Likely
3	L: Appearance and aroma (butterscotch) D: little sour taste	More beer like smell and taste	Unlikely
4	L: Better aftertaste than 108 D: doesn't taste like proper beer	Better aftertaste than 108	Neutral
5	L: Good texture and appearance. Desirable aroma and mediocre taste D: flat	Similar except for taste	Neutral
6	L: Pleasing appearance and aroma D: aftertaste and texture seem to be moderate	108 had better texture and taste	Unlikely
7	L: Overall taste D: not much except for lack of fizziness	Better texture and taste than 108	Likely
8	L: Sweetness and little bitterness D: Same as 101	Tastes the same	Neutral

9	L: Likes everything except for aftertaste (too bitter) D: Doesn't taste like commercial beer	Tastes similar to 108 except for more beer like qualities	Likely
10	L: Smells better with more sweetness D: Tastes rancid	Sweeter than 108 but same in other qualities	Neutral

7.2. Sensory Evaluation Information Sheet

Researcher Information

Researcher: Barath Kumar	Supervisor: Dr Emilia Nowak
Contact Details: [redacted]	Contact Details: E.Nowak@massey.ac.nz

You are invited to take part in an informal sensory evaluation.

Your participation in this activity will take approximately 30 minutes.

The beverages that you will be tasting contains the following components that can be harmful or cause allergic reactions with certain groups of people. You will be excluded from taking part if you are allergic, or may be adversely affected by any of the following:

- Alcohol
- Sugars and Starches

The type of beverage that you will be tasting is: Beer

The information collected in this study will be used to complete a Thesis project in partial fulfilment of the Masters in Food Technology. No data linked to an individual's identity will be collected.

You are under no obligation to accept this invitation. If you decide to participate, you have the right to:

- Decline to answer any particular question
- Withdraw from the study at anytime
- Ask any questions about the study at any time during participation
- Provide information on the understanding that your name will not be used unless you give permission to the researcher

Signature: _________________________

7.3. Consent Form

Project: Recreation of Ancient Beer

• I have read and understood the information provided to me. Any questions regarding the study have been cleared and I understand that I can ask any further questions at any point of time.

• I understand that I can withdraw myself from this study at any time and can decline to answer any specific questions.

• I have discussed with the researcher regarding any cultural, religious or ethical beliefs that may prevent me from consuming the food product.

• By signing this form, I agree voluntarily to participate in this study under the conditions set out in the Information Sheet. I will also not hold any liability should anything happen to me be it during or after my participation in this study.

Signature: ______________________ Date: _____________________

Full Name: ____

Sensory of Ancient Beer

Instructions

Two types of beers (Sample 108, Sample 101) consisting of slightly different recipes are involved in this sensory.

3 groups of sensory characteristics will be analyzed in this study:

- Appearance
- Aroma
- Taste

The aim of this sensory is to distinguish the differences between 2 ancient beer samples that have similar ingredient bills excepting 1 vital ingredient. This sensory is also performed to gain an insight in consumers' acceptability in ancient beer in general.

Follow the instructions and rate the beer accordingly.

Please rinse your palate with water after each sample.

Questions for Sample 108

Properties/features that you like about the beer

____

Properties/features that you dislike about the beer and why?

____

What properties/features that can be added/removed in this beer?

____

How likely is it you might consume this beer again?

Unlikely /Neutral /More Likely

Numerical descriptive scale for sensory:

Please rate by shading a number from 0-10 depending on the intensity of each sub-sensory characteristic of the ancient beer where:

(0–extremely weak & 10– extremely strong)

1.Visual appearance

1.1 Clarity

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

1.2 Foam retention (Carbonation)

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

2.Smell

2.1. Floral (lavender, sweet blossoms)

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

2.2. Fruity (citrus, berry, melon etc.)

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

2.3. Hoppy

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

2.4. Caramelised (malt, grainy)

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

3.Taste

3.1 Sweet

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

3.2 Bitterness

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

3.3 Sourness

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

3.4 Phenolic (tarry, pepper-like, smoky)

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

3.5 Grainy/Nutty

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

Questions for Sample 101

Properties/features that you like about this beer

____

Properties/features that you dislike about the beer and Why?

____

What properties/features that can be added/removed in this beer?

____

How likely is it you might consume this beer again?

Unlikely /Neutral /More Likely

Numerical descriptive scale for sensory:

Please rate by shading a number from 0-10 depending on the intensity of each sub-sensory characteristic of the ancient beer where:

(0–extremely weak & 10– extremely strong)

1.Visual appearance

1.1 Clarity

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

1.2 Foam retention (Carbonation)

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

2.Smell

2.1. Floral (lavender, sweet blossoms)

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

2.2. Fruity (citrus, berry, melon etc.)

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

2.3. Hoppy

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

2.4. Caramelised (malt, grainy)

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

3.Taste

3.1 Sweet

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

3.2 Bitterness

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

3.3 Sourness

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

3.4 Phenolic (tarry, pepper-like, smoky)

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

3.5 Grainy/Nutty

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

Common questions for regarding both samples 108 and 101

How much were you satisfied with this product?

Very dissatisfied / Moderately Dissatisfied/Neither satisfied nor dissatisfied / Moderately satisfied / Highly satisfied

How much likely would you recommend it to your friend?

Not at all likely to recommend / Not very likely to recommend/Unsure/Likely to recommend / Extemely likely to recommend

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