A quantitative and qualitative assessment of terpenes in the manufacturing of Cannabis-infused and highly hopped SA craft beers

by

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Declaration of independent work

I, Puleng Rose Zacharia (student number _________), hereby declare that this research project submitted to the Central University of Technology, Free State, for the degree of Master of Health Science in Environmental Health is my own independent and original work. This research project was conducted at the Central University of Technology, Free State under the supervision of Pro~~f. O de Smidt and co-supervised by M~~s. LB Mogotsi.

Date: 31 October 2025

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Signature of candidate

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I certify that the above statement is correct.

Date: 31 October 2025

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Abstract

The increasing global interest in functional beverages has extended to beer, where bioactive plant compounds are being harnessed to provide perceived health benefits alongside sensory appeal. Within this context, hops (*Humulus lupulus*) and *Cannabis sativa*, two members of the Cannabaceae family, share significant chemical and aromatic similarities through their terpene content. This study explored the quantitative and qualitative assessment of terpenes in the manufacture of *Cannabis*-infused and highly hopped South African craft beers. The work was motivated by the absence of verified data on the survival, retention, and potential bioactive contribution of terpenes in the final product, despite widespread claims of their presence in such beers.

The study aimed to determine whether terpenes originating from hops and *Cannabis* are retained after brewing, at concentrations that may contribute to health or sensory benefits. The specific objectives were to: (1) analyse and compare terpenes between raw materials and finished commercial beers; (2) assess the chemical composition of these beers using validated chromatographic methods; (3) brew experimental beers incorporating hop and *Cannabis* extracts to enhance terpene retention; and (4) evaluate the sensory acceptability of the resulting beers.

Commercial samples of highly hopped and cannabis-infused beers, as well as their corresponding raw materials (hops, hop oils, *Cannabis* terpene concentrate, and CBD oil), were characterised using Gas Chromatography coupled with Flame Ionisation Detection (GC-FID), Gas Chromatography-Mass Spectrometry (GC-MS), and High-Performance Liquid Chromatography (HPLC). These methods enabled the detection, separation, and quantification of volatile terpenes and cannabinoids across different matrices. The compounds detected in the raw materials were not retained in the finished beers. Lager 1 in which shelled hemp seeds were used, only terpinolene was detected in the final beer. Lager 2 in which an CBD oil with content CBN, Delta-9-THC, THC-V and total potential THC at levels 0.004, 0.005, 0.001 and 0.005% respectively, was used contained none of the compounds in the finished beer. Pale ale 1 in

which commercial *Cannabis* terpene extract was used that contained 9 terpenes namely α -Humulene (157.622 mg/g), α -Pinene (64.453 mg/g), β -Caryophyllene (202.573 mg/g), β -Myrcene (151.144 mg/g), β -Pinene (36.156 mg/g), limonene (54.502 mg/g), linalool (19.981 mg/g), ocimene (37.426 mg/g), and terpinolene (58.745 mg/g). The finished beer contained only terpinolene (0.249 mg/g). Analysis of highly hopped beers from the same breweries also yielded similar results. Raw materials (hops) contained high levels of terpenes, but only terpinolene was detected in 2 of the 3 finished beers.

Experimental brewing trials were then conducted using hop oils distilled from up-cycled South African hop waste and *Cannabis* terpene extract. Controlled fermentation and late-stage hop oil additions (0.03 g/7 L) were applied to minimise terpene volatilisation losses. Three pilot brews (PZB-01, PZB-02, PZB-03) were produced, representing hop-oil and cannabis extract treatments, and were evaluated through sensory sessions with trained beer judges/tasters (n = 22) as well as analysed using GC-FID.

Sensory analysis of experimental beers attributed medium low aroma and flavour to fruity, hoppy apple, pear, orange, lemon and earthy when the median of test results was considered, with little differences among the 3 beers. Overall acceptability of PZB-02 (*Cannabis* terpene concentrate and PZB-03 (African Queen hop oil) was high (score of 8 on hedonic scale). These results indicated that the concentration of oils used required optimization and could be increased. Interestingly, the GC-FID analysis of the experimental beers again only detected the presences of terpinolene in PZB-01 (0.301±0.022 mg/g), PZB-02 (0.355±0.006 mg/g) and PZB-03 (0.362±0.026 mg/g) in the finished beers. Terpinolene is a structural isomer of limonene and presents as fresh, pine, herbal, woody and resinous. Its aroma profile may explain the comparable sensory results while no other terpenes were detected in the finished beer.

Terpene retention primarily influences sensory quality rather than bioactivity of beer. The results provide a scientific basis for future formulation of functional or sensory-enhanced beers and support the potential of up-cycled South African hop extracts as sustainable flavouring agents in the craft brewing sector.

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Chapter 1

Introduction

1.1. Background

Consumer preference for healthier and sustainably sourced food products has been the driving force behind product innovation, spanning the food and beverage industry, with the latter demonstrating that these functional beverages are not merely for refreshment and hydration but are expected to deliver certain health benefits like improved immunity, digestive health and cognitive assistance (Gupta *et al*., 2023). Thus, consumers are looking for more than just great taste and good nutrition in their foods; they want them to contribute positively to their overall well-being and to be produced in an environmentally friendly way. The growing concern about well-being and demand for foods that cater to this need is evident not only by the increase of such foods in stores but also by the increase in scientific publications to this effect (Figure 1.1).

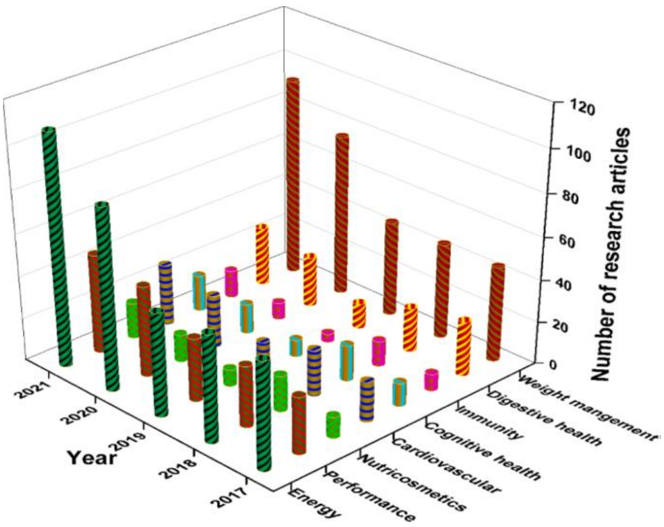

Figure 1.1: Total Number of research articles found in the SciVerse Scopus database between 2017 and 2021 that include the terms "Functional beverage" or "Functional drink" and "defined category" in title, keywords and abstract (Gupta et al., 2023).

This quest for functional foods is the driving force behind the move toward nutraceuticals in beverages and, by extension, beer. Beer is often a drink of choice in social gatherings and celebrations or a drink of choice for relaxation. Moreover, craft beer transcends any commercial beer in terms of its complex flavour profile rendering it not only a good choice for enjoyment but a decadent meal accompaniment. Many European countries are defined by their beer identities and have been for hundreds of years. For example, Germany is famous for lagers, pilsners, dunkels, bocks and weissbiers; Belgium is renowned for blondes, dubbels, tripels and quads; and England is known for bitters, porters and stouts. In the west, America has led the hoppy craft beer revolution since the 70s, and they're known for hop-forward pale ales, bitter IPAs and most recently, the juicy New England IPA (NEIPA). Africa is best known for opaque beers emanating from the use of the indigenous starch sources, but of late, the craft beer revolution has led to the participation of African countries in clear beers. Even though it initially started with imported raw materials, the use of indigenous plants has slowly infiltrated the market. Consequently, the vast variety of craft beer-style offerings has not only catered to the diverse tastes and preferences of consumers, but it also opened the industry to academic interest and research on the influence of the various raw materials, quality, stability, and nutraceutical benefits.

Craft beer popularity in South Africa (SA) has prompted brewers to transform the old beer styles through innovative exploration of alternative starch sources, bittering plants, and the incorporation of indigenous plants. For years, the South African Breweries (SAB) have dominated the beer market in South Africa and have been the biggest importers of international raw materials. The European malts and hops were the initial ingredients in SAB beers and over time, locally grown malts and hops were introduced in SA. These proudly South African ingredients, such as barley grown and malted in Caledon, and hops grown in George, Western Cape, have proven to be contenders in the beer market, not only for commercial production but craft beer as well.

South African hops, although highly sought after for their unique flavour and bitterness, constitute just under 1% of global production due largely to the tough growing conditions. Hop breeding, dating from the

1970s and to date, 11 farms produce hops for use by local and international breweries (de Smidt *et al*., 2025). Despite the harsh growing conditions, for example, cold weather and insufficient day-lengths during the growing season, not to mention limited land for hop farming, these hops continue to make their mark in the brewing industry.

The traditional bittering plant, hops, has been at the centre of investigation in the quest for niche beer products leading to experimentation with different varieties, addition at different brewing stages, or even the use of different hop plant matter i.e. whole hop cones, hop pellets, hop extracts, hop essential oils (Duarte *et al*., 2024). The various forms of hop production have been central in developing various beers with the once forgotten hop cones making a comeback in the craft industry. Although hop pellets are more popular as they offer more stability and uniformity at a cost-effective price, hop extracts and hop essential oils are being explored for use in beers to create more niche products and to significantly reduce beer losses compared with using pellets for late hopping (BarthHaas.com).

Indigenous plants related to hops have also found uses in beverages, such as A*zadirachta indica (*Agu *et al.,* 2023*)* and *Cannabis* (Ascrizzi *et al.,* 2020). Although previously restricted, *Cannabis* has found uses in foods, sweets, and drinks for its reputation for easing issues relating to stress, anxiety, nausea, and insomnia, and enhancing brain clarity and creativity (Nuutinen, 2018). *Cannabis* species include *C. sativa*, *C. indica* and *C. ruderalis* (Figure 1.2*)* and these subspecies have different appearances as well as chemical compositions hence the application in diverse industries*.* Adhikary *et al*. (2021) asserted that *C. sativa* plants are often tall, thin, and have delicate leaves, growing natively in sunny, hot countries like Mexico and South Africa. In contrast, *C. indica* plants often have thicker, shorter, and broader leaves; they come from chilly, mountainous regions like the Himalayan foothills. The least-known *Cannabis* subspecies, *C. ruderalis* species is believed to have been a result of cross-pollination between *sativa* and *indica*. Unlike the other two species, it can bloom on its own without being affected by the day length/light-dark cycle, making it perfect for growth in areas with low light levels, like Russia.

With a long history of use in traditional and modern medicines (Masyita *et al*., 2022; Nuutinen, 2018), these two plants from the *Cannabaceae* family of plants have sparked scientific interest based on their shared chemical composition (terpenes) and bioactive application in functional foods.

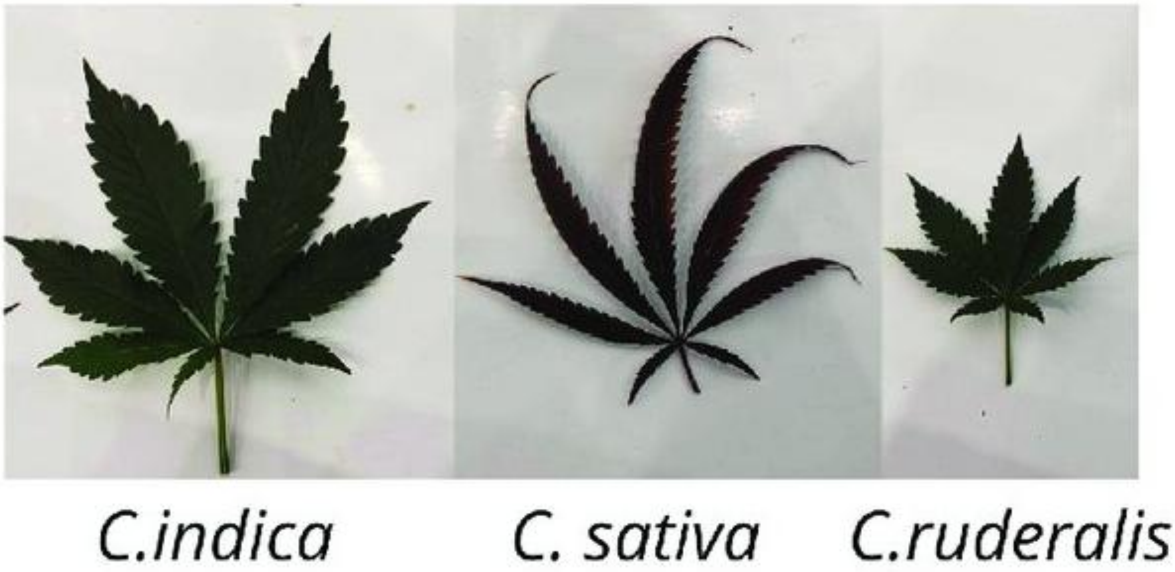

Figure 1.2: Morphology of different Cannabis species

1.2. Problem statement

Claims on the health benefits of terpenes found in hops and *Cannabis* have led to the use of these plants in craft beer, yet, for one, there is no definitive information on whether these terpenes are retained in the final product.

1.3. Aims

This study was aimed at exploring the relationship between terpenes found in hops and *Cannabis,* their mode of addition and retention in South African craft beers, and to investigate whether the levels are significant enough to elicit the bioactive health benefits.

1.4. Objectives

To realise the aims of the study, the following objectives were put forth:

1. To collect samples of hoppy and cannabis-infused beers, analyse and compare levels between the raw materials and finished beers.
2. To chemically analyse these hoppy and cannabis-infused beers alongside their raw materials for comparison.
3. To manufacture our own beers using terpene extracts and hop extract to try to get a high terpene content in the final product.
4. To perform sensory analysis (using certified beer judges) to investigate the integrity and drinkability of those beers.

1.5. Novelty

The hop extract employed in this study was made from up-cycled hop matter collected from the South African Breweries (SAB) hop varieties. This product was made from distilled hop waste matter i.e., leaves, stalks, and branches that would normally be discarded after the hop inflorescence was collected for pelleting.

1.6. Hypothesis

Firstly, the hop and *Cannabis* terpenes can survive the brewing process and thus be found in the final craft beers. Secondly, these terpenes are retained at a level that is regarded to be functionally significant, offering health advantages to the consumer. Finally, it is possible to modify existing craft beer recipes to include a terpene concentration that is high enough to be considered positive for one's health using hop extract and *Cannabis* terpene concentrate.

Chapter 2

Literature Review

2.1. Introduction

The rise of functional foods and beverages has made it one of the fastest-growing segments in the food industry. This is because of the focus on fortification of food products to improve bioavailability of bioactive compounds for general wellbeing, and the functional drinks segment is no different (Gupta *et al*., 2023). By extension, beers have also been fortified. Light-to-moderate consumption of alcoholic beverages, including beer, can provide various advantages to human health due to the presence of protein, B vitamins, certain minerals, phenolics (antioxidants), ethanol, dietary fibers, and even prebiotic compounds (Sohrabvandi *et al*., 2012; Shumye Gebre *et al*., 2024; Madilo *et al*., 2024). As of 2019, South Africa was the 12th largest beer producer in the world (Bailey, 2019), but due to the alcohol ban during the COVID-19 lockdown (2020 – 2022), production in this sector was severely affected, especially the craft industry. However, this did not in any way stop innovation as more people took to home brewing while the craft brewers came up with new ideas to make their brews better. The SA craft brewing exemplifies innovation, integrating traditional ingredients with emphasised health benefits like *Humulus lupulus* (hops) and novel ones such as *Cannabis*, thus driving innovation in the direction of functional and bioactive beers. It has been demonstrated that both plants contain a myriad of compounds that are beneficial to health (cannabinoids and terpenes) therefore, analysis and quantification of these bioactive molecules is necessary for the development and growth of the sector in this direction. Also, because these compounds occur on trichomes of *Cannabis* and flower cones of hops, their presence in subsequent beers is to be expected.

2.2. The evolution of beer

Beer, an alcoholic beverage, is traditionally brewed from water, a sugar source, a bittering agent, and yeast. This ancient art of brewing originated in different civilisations and cultures, so much so that there is no precise and unanimous agreement on its origins. Archaeological artefacts place its existence to around 11,000BC, with the timespan for its existence differing over a wide range of geographical areas, from as far back as "The Neolithic Revolution" to the early horison in South America. Historical evidence of the Sumerians places it around 9000 BC, and in China evidence of rice-fermented beverages dates back 7000 BC, whereas in Egypt, Northern Africa, about 3500 BC, in Europe, 3000 BC (Callejo *et al*., 2019). It is for these reasons that the approach by different cultures and civilisations produced a variety of fermented drinks and beers using varying raw materials, giving them unique characteristics and names.

The most important ingredient is the sugar source as yeasts require sugar for alcohol production. The sugar source supplies fermentable sugars, namely, maltose and glucose via enzymatic breakdown of starches; while water dissolves flavour compounds and supports yeast fermentation, converting sugars into alcohol and carbon dioxide. With barley dominating in European countries, alternative starch sources such as sorghum, millet and cassava were mainly used in Africa, reflecting regional innovation (Shumye Gebre *et al*., 2024). In China, rice was the main ingredient for fermented beverages (Callejo *et al*., 2019), and it still is a central ingredient to this day. The extensive study and benefits of malted barley have resulted in this grain being an integral part of the brewing process to this day and with the introduction of smoking, various malts have been discovered. Examples include black malt, chocolate malt, Cara Munich malts and crystal malts, all originating from malted barley that is indirectly heated at different temperatures and times to create different flavoured malts.

The use of bittering plants in beer was not only to add bitter flavour but also to add distinctive flavours to the beer to showcase its origins. The discovery of hops (*Humulus lupulus*) was the turning point in brewing as not only was it essential to the development of bitterness, but it was also essential in ensuring microbial stability as it brought about longevity to highly hopped beers. Extensive study of the role that hops play in beer revealed that hops contain alpha acids which react with malt proteins to aid in clarification of the beer (trub formation) (Priest and Stewart, 2006; Thesseling *et al*., 2019) but also to inhibit the growth of spoilage bacteria. Hop experimentation was born, and breeding led to the discovery of three types of hops: bitter hops, flavour hops, and dual-purpose hops, i.e., they could impart the bitterness to beer while also contributing significant aromatic profiles to beer. These aroma compounds were later identified as terpenes. In addition, bittering hops are added during wort boiling as heat is important to the isomerisation of the alpha acids to form bittering acids, whereas flavour hops do not require any heat for their flavour compounds to be released (Figure 2.1). Dual-purpose hops mean that even in addition to the hot side of the brewing process, they release the aromatic compounds thus imparting bitterness and flavour to the beer.

2.3. The craft beer revolution

Civilisations merged their brewing practices to keep processes simple, straightforward, and to ensure that each batch produced in one place resembled one produced in a different country. A need for standardised processes was born and with the industrial revolution, mass-production of beer was easy to navigate. Not only was equipment made to handle big batches of brewing, but refrigeration and automation ensured that the recipes were so refined that with time, single style beers took over the beer industry, and a beer born in Europe would taste the same as one produced in America, and vice versa.

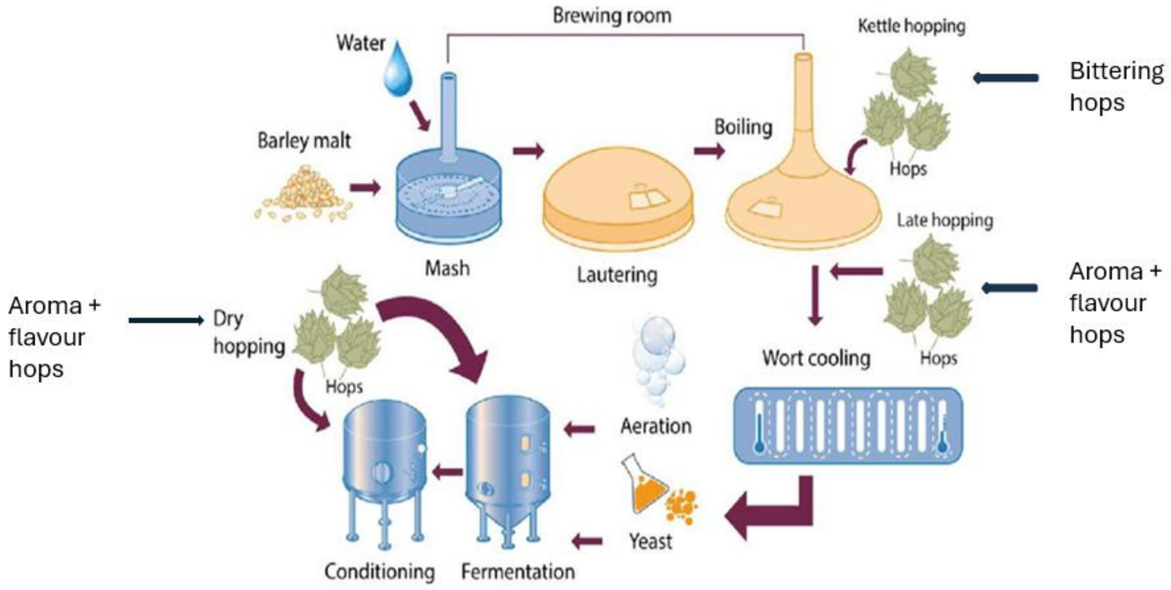

Figure 2.1: An overview of the brewing process, from raw ingredients to finished green beer ready for packaging (Gomes *et al.,* 2022).

Beers can taste different if brewing parameters were to be adjusted, even if the ingredients are similar, giving rise to over 120 different beer styles as per the Beer Judge Certification Program (BJCP). Various brewing parameters, such as the variety of barley and the malting process, pH, the variety of hops added during wort boiling, fermentation conditions, including yeast strains, pitching rate, temperature, pressure, aeration and stirring as well as storage and aging conditions, can influence the type and quality of beer (Sohrabvandi, *et al*., 2012). As a result, brewers can design various beer recipes with the same ingredients, thus forming the basis of over 120 formally classified beer styles.

As with all things, change to the brewing process was inevitable. The consumer preference for different products drove brewers to examine some of the discarded indigenous knowledge to create niche products. This gradual, but steady change in consumers' drinking patterns spurred the craft beer revolution, leading to the craft beer boom in America in the 1970s. In fact, it can be traced to the 1960s, when a microbrewery in America, "Anchor Steam Beer Company", "formulated the first American India

Pale Ale (IPA) and the re-introduction of non-traditional beer styles like porters, wheat beers and spiced holiday beers" (Jaeger *et al*., 2020). This was in contrast to the beers made by the big, commercial breweries at the time, who had a near monopoly on the beer market and created nearly entirely light-coloured lagers. In Africa, the craft industry experimentation has in recent years moved toward the use of native starch sources, including sorghum, cassava, millet, local fruit, and vegetables (Collins *et al*., 2023; Madilo *et al*., 2024; Akpoghelie *et al*., 2024), which were known for producing opaque beers. In recent years, the use of indigenous plants in beer brewing has gained huge importance

In contrast to mainstream beer, the craft beer industry's scope for experimentation is not limited as volumes brewed are a fraction of what mainstream breweries produce. Initially, volumes were the distinguishing factor between craft and mainstream beer, along with local production for local consumption due to constraints in refrigeration and transportation. These limitations in size and volume led to the following classifications: nanobrewery (refers to a facility with minimum production quantity); microbreweries (the place of sale of beer: production is sold outside); brewpub (beer is sold on the same floor of production); contract brewing company (brewing companies that outsource their production to other already established breweries); regional craft brewery (over 50% or more of their volume production focuses on all-malt beers and/or their malt flagship) (Callejo *et al*., 2019); independent brewery (not more than 25% of the business is owned by another member of the alcohol industry who is not a craft brewer and using traditional or innovative ingredients in its fermentation process) (Alfeo *et al*., 2020). Consumer preference for a "unique" drinking experience and flavourful beers has been the driving force for craft brewers (Faganel and Rižnar, 2023); hence, the need for constant innovation to maintain/grow their market share, however small.

Furthermore, extensive innovation in the craft industry has resulted in huge strides being made in the raw materials industry to provide them with new products to work with. The hop industry (including South Africa), has been privy to this experimentation, resulting in the growth of more hop varieties, and production of various hop products for use in the beer and beverage industries. Selective breeding for the production of local hop varieties, such as African Queen and Southern Passion and medicinal plants which includes *Cannabis,* and elderflower, ensured the craft sector's agility in enhancing flavour experimentation, such as cannabis-infused beers and highly hopped styles, where terpenes and their derived compounds drive aroma and taste (Barrus *et al*., 2018; van Wyk *et al*., 2018). These advancements underscore the dynamic evolution of the craft beer industry, where innovation in brewing has catalysed significant growth and diversification within the hop and raw materials sectors

2.4. Cannabis infusion in beer

Cannabis infusion in food products gained popularity for its perceived nutraceutical benefits, particularly, giving rise to the term '*edibles'* to refer to any food product (and beverage) made from *Cannabis* extract (Blake and Nahtigal, 2019). Also true to their recreational use, *Cannabis* and alcoholic beverages are said to stimulate reward pathways in the users; it was only a matter of time before the two collided, especially for adults aged 18 and above (Anderson, 2018). In 2018, Poison City Brewing manufactured South Africa's first cannabis-infused beer, opening doors for other craft brewers. This pioneering move not only marked a significant milestone in South Africa's brewing history but also signalled a broader shift toward innovative, cannabis-infused beverages that cater to evolving consumer preferences and wellness trends.

2.5. The South African legislation on Cannabis uses in foods

Production and selling of any cannabis and cannabis-related foodstuff is governed by the Department of Health under the Foodstuffs, Cosmetics and Disinfectants Act (Act no.54 of 1972). Legalisation of *Cannabis* and Cannabidiol (CBD) in 2017 made an allowance only for the cultivation of CBD plants, not THC. The South African Health Products Regulatory Authority (SAHPRA) released the Medicines and Related Substances Act, 1965 (Act 101 of 1965) to this effect, stating that "a processed product containing the naturally occurring trace amounts of THC (≤ 0,001 %) and CBD (≤ 0,0075 %) is specifically excluded from the Schedules, when the product does not contain whole *Cannabis* seeds and does not make any medicinal claim. If such substances align with the definition and annexures identifying health supplements, they may also be considered as health supplements" (SAHPRA, 2019). This meant that for as long as any cannabis products, including edibles, do not contain more than 0.0075% CBD, then a manufacturer could make the product without having to obtain a special cannabis license.

The guidelines regarding *Cannabis* infusion in foodstuffs have undergone several revisions in 2019, 2020, 2024 and 2025. On 7 March 2025, the Ministry of Health published the Foodstuffs, Cosmetics and Disinfectants Act expressly prohibiting the manufacture, selling and importing of any foodstuff containing *Cannabis*, hemp seed or any component derived from this plant (Gazette & Notice, 2025). This regulation was revised following industry backlash, and it has since been amended to indicate that hemp seeds & seed oil are not scheduled substances and remain lawful under food regulations including food containing same and CBD-infused foodstuffs under 600 mg CBD per pack and <0.001% THC as per SAHPRA's 2019 CBD notice. The government's concerns regarding safety and unrestricted access to these products now requires that the manufacturers properly label all products, clearly indicating THC and CBD content to prevent confusion and misuse.

2.6. Hops and Cannabis: a match made in craft beer

Despite having been around for centuries, hops have quite a complex chemical composition, making it an important beer ingredient for researchers and brewers alike. It is this extensive research over the years that has uncovered the relationship between hops and cannabis. Together, these plants have a wide range of applications in academia, agriculture, pharmaceuticals and industry (Kovalchuk *et al*., 2020).

Descriptively, *Humulus lupulus* is a fluorescent plant of the *Cannabaceae* family (Figure 2.2), which first gained popularity for its use in beer due to its preservative and bittering properties, but with time and plant breeding, use of hops for flavour became popular. These strong flavour characteristics were later attributed to terpenes (Almaguer *et al*., 2014).

Another genus present in this family of plants is *Cannabis sativa* L., a significant and sometimes contentious plant with an extensive application history in agriculture, medicine, industry, and recreational settings. It can be cultivated for medicinal use (selected for its high cannabinoids) and grown under strict conditions. While the variety that is grown for fibre is referred to as *hemp* (low cannabinoids), and can be grown anywhere there is arable land, even grown on land in need of bioremediation (Kovalchuk *et al.,* 2020). Although about 100 cannabinoids are produced by the *Cannabis* plant, THC and CBD are two of the most abundant cannabinoids present in the *Cannabis* plant. THC is psychoactive in nature and is the cannabinoid most sought after by recreational users for the "euphoric" high. On the other hand, CBD is non-psychoactive in nature, and is the key cannabinoid targeted for medical applications (SAHPRA, 2019).

Whole hop cones comprise several components, such as bitter acids (alpha and beta acids), polyphenols and the essential oil fraction comprised of terpenes, thiols, esters and sulphur compounds (Figure 2.3). The brewing value of hops is primarily attributed to the precursors of the flavour and bitter-active compounds found in the resins secreted by the lupulin glands. The hop essential oils are also important to the brewer as they contain terpenes which provide flavour and aroma characteristics to the beer (Almaguer *et al*., 2014).

The unpollinated female in both plants is what is considered important as the female *Cannabis* will bear flowers while the hop female bears cones. The right time to harvest lies in the physical, sensory and texture of the plant and these intrinsic signs of ripeness are indicative of which plant has an acceptable content of essential oils. Through selection and breeding, the plants with the richest production of resins and oils are grown, as this oil fraction contains the essential oils, terpenes, alpha acids, and many other components that are beneficial in various industries.

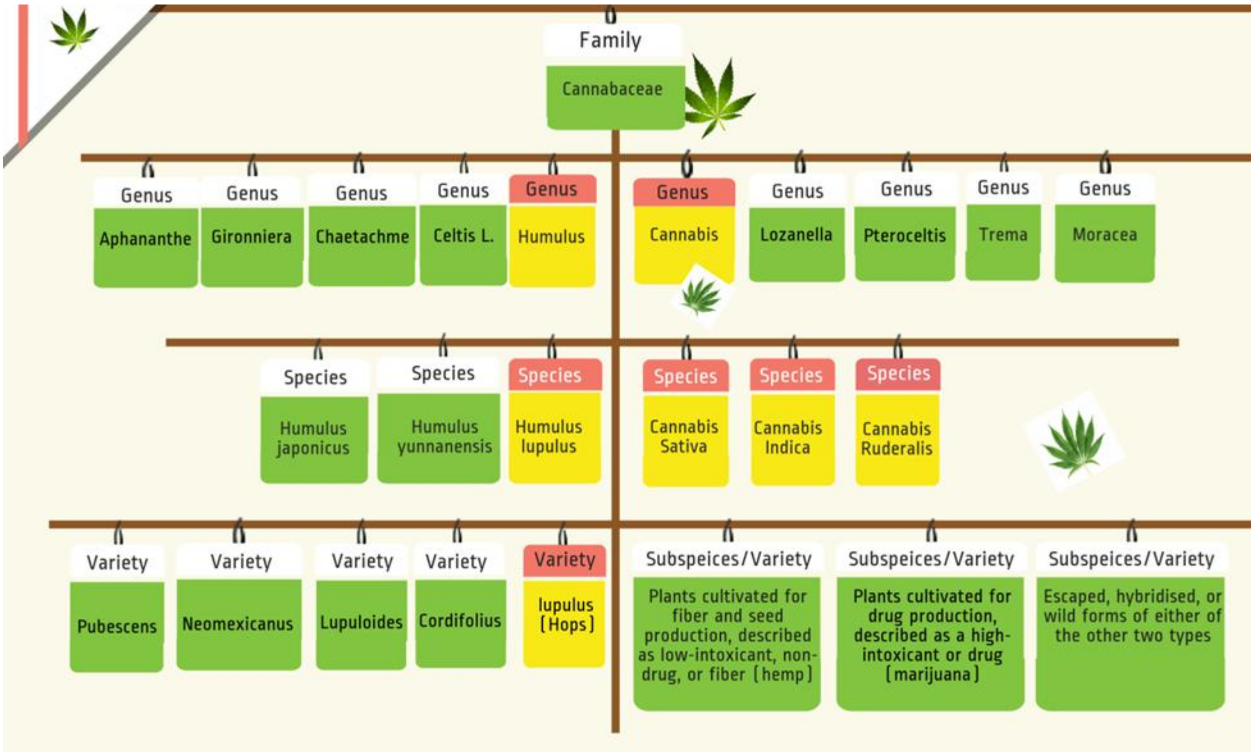

Figure 2.2: Phylogenetic relationship of hops and *Cannabis* plants showing common ancestry

Cannabis has various chemical components, including phenolic compounds, terpenes, and cannabinoids, and over the years, it has received attention because of the perceived pharmaceutical and nutraceutical value. Apart from cannabidiol (CBD), other commonly occurring cannabinoids are tetrahydrocannabinolic acid (THCA), cannabindiolic acid (CBDA), and cannabinol (CBN). The relationship between hops and the cannabinoid content of *Cannabis* has thus been a focus for academic, medical and food-related studies (Del Prado-Audelo *et al.,* 2021a).

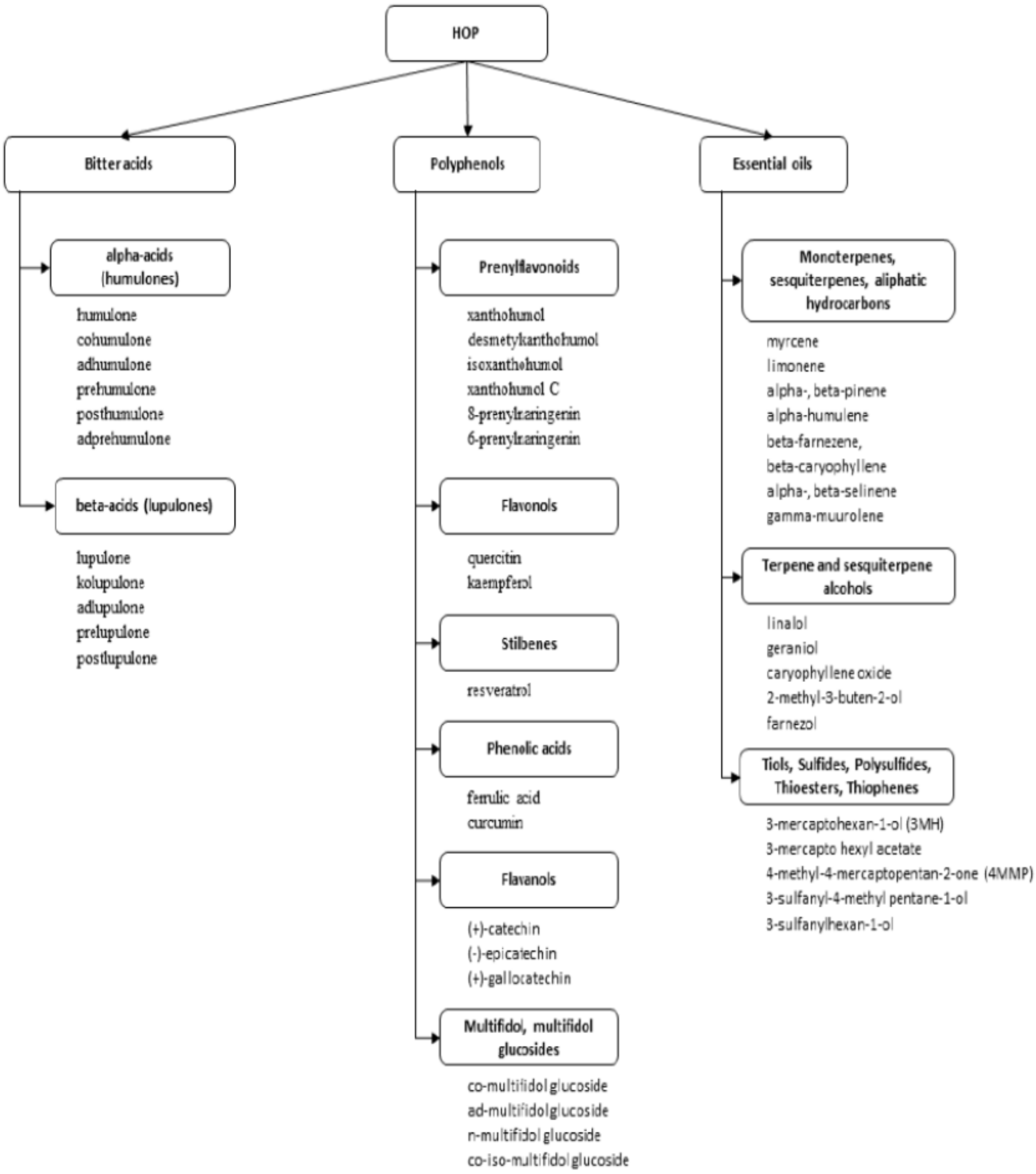

Figure 2.3: Chemical composition of hops

The *Cannabis* plant can be cultivated to contain varying concentrations of cannabinoids (Figure 2.4), such as THC and CBD, depending on the intended use. The high THC-containing *Cannabis* plant, generally utilised for recreational purposes, is commonly referred to as marijuana/weed (SAHPRA, 2019), while the low-THC-containing *Cannabis* plant, cultivated to produce fibre (included in such products as bricks, ceiling boards and textiles) or seeds is commonly referred to as hemp (Kovalchuk *et al.,* 2020).

While several nations have permitted limited hemp farming for commercial and agricultural purposes, the import and export of *Cannabis* is heavily regulated.

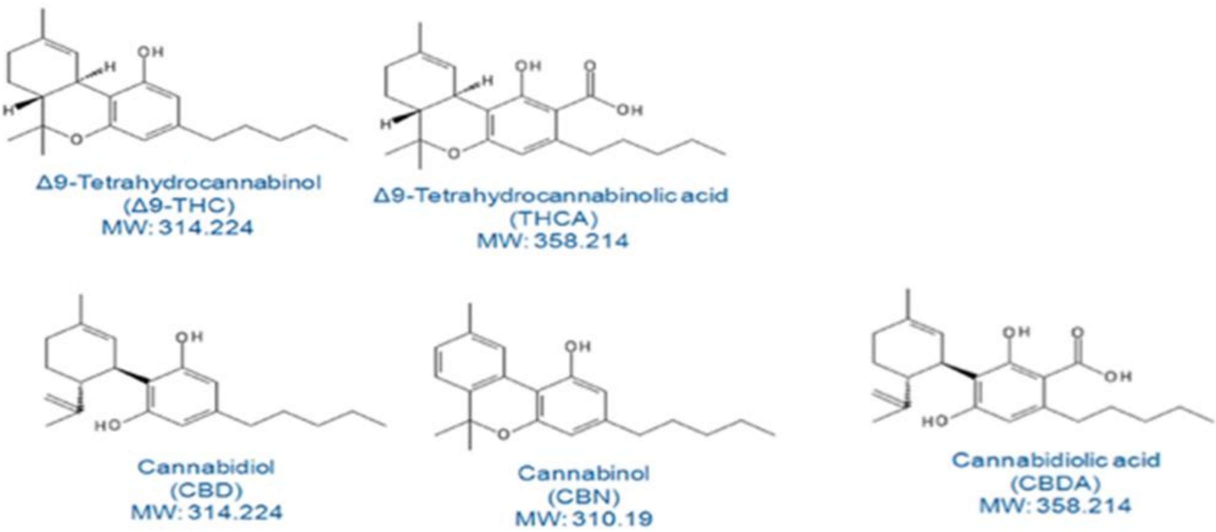

Figure 2.4: Phyto-cannabinoid composition of *Cannabis*

2.7. Hops and *Cannabis* terpenes

Terpenes are a widespread class of biologically active molecules in plants and are found to play a role in the aroma and flavour of hops and *Cannabis* alike. They are secondary metabolites formed due to the enzymatic reactions of primary metabolites (amino acids, sugars, vitamins, etc.) and "consist of five carbon isoprene units which are assembled in thousands of ways (Radwan *et al*., 2021; Wang *et al*., 2023. They are divided into monoterpenes, sesquiterpenes, diterpenes, sesquiterpenes, and triterpenes (Figure 2.5) (Del Prado-Audelo *et* al., 2021). In nature, terpenes are produced by almost every plant, and some animals, for interaction with other organisms, for instance, to attract pollinators or repel herbivores (Perveen, 2018). As with *Cannabis* and *Humulus lupulus*, most of these terpenes are found in the essential oil fraction of plant oils (Nuutinen, 2018).

1. **Monoterpenes**: They have a chemical structure based on two isoprene units ($C_{10}H_{16}$) and can have different arrangements such as acyclic, monocyclic, and bicyclic (Del Prado-Audelo et al., 2021b). Monoterpenes play a vital role in the pharmaceutical industry and are known for their unique fragrance. Blends of oils containing monoterpenes are widely used in cosmetics and perfumes to create captivating scents. These compounds also possess powerful antibacterial properties and exhibit physiological activity (Perveen, 2018).
2. **Sesquiterpenes**: They consist of three isoprene units ($C_{15}H_{24}$) and often have simple to complex structured mono- and polycyclic (bicyclic, and tricyclic) rings ((Perveen, 2018); Del Prado-Audelo *et al*., 2021). Numerous latex-producing plants are rich in sesquiterpenes, and they are known for their powerful antimicrobial and anti-insecticidal properties (Perveen, 2018).
3. **Diterpenes** are made up of four isoprene units with a molecular formula $C_{20}H_{32}$. This family of chemicals has been reported to demonstrate significant biological activity, including anti-inflammatory, antibacterial, anticancer, and antifungal properties (Perveen, 2018; Nuutinen, 2018)
4. **Sesterpenes** consist of 25 carbon atoms with 5 isoprene units and a molecular formula $C_{25}H_{40}$ (Nuutinen, 2018)**.** These substances are said to have potent anti-inflammatory, anti-cancer, antibacterial, and antifungal properties and are physiologically active (Perveen, 2018)**.**
5. **Triterpenes**, usually contain 30 carbon atoms consisting of 6 isoprene units, $C_{30}H_{48}$ (Nuutinen, 2018). Triterpenes have a wide distribution and can have more than 40 different carbon skeletons as they can be oxidised into alcohols, aldehydes, and carboxylic acids, which make them complex and differentiate them biologically. This is because they have numerous active sites for glycosylation, transforming them into another large family of compounds known as saponins (Perveen, 2018).

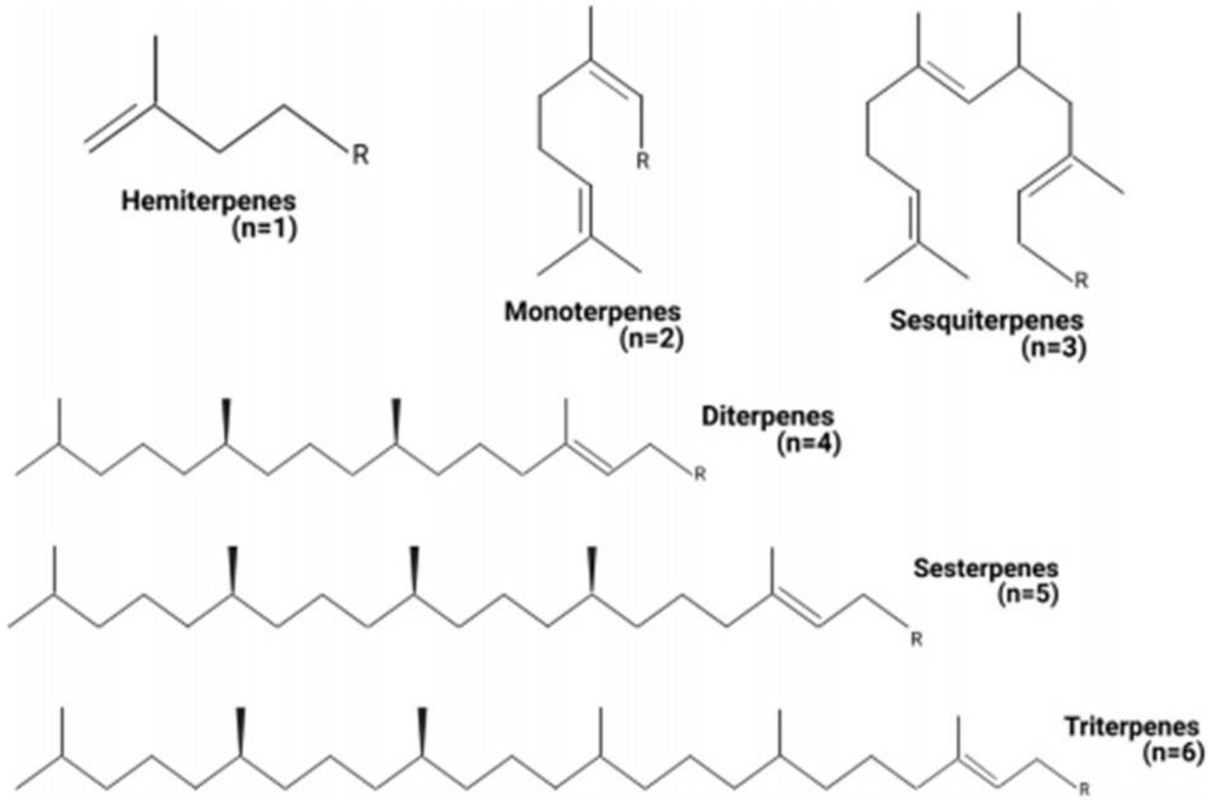

Figure 2.5: Terpene classification based on the number of isoprene units (Del Prado-Audelo *et al*., 2021)

2.8. The bioactive potential of hops and *Cannabis* terpenes

Nuutinen (2018) illustrated that both *Cannabis* and hops have been used in traditional medicine for centuries, owing to some of their medicinal properties or even the synergistic effect with some modern medicines. Numerous animal and clinical trials with purified terpenes have shown the significant effect of these molecules in promoting healing, preventing and treating certain ailments such as cancer, diabetes, depression, neurological disorders, bacterial infections to mention a few. The low toxicity and promising benefits of these terpenes have resulted in their use beyond biomedicine and cosmetic applications; they are now being used as food additives. Linalool has been linked with anti-anxiety and sedative properties; myrcene has been found to exhibit neuroprotection where it was shown to suppress the formation of thiobarbituric acid reactive substances (TBARS) (the oxidation results of fats and fatty acid oxidation), thus protecting the brain, heart and other tissues from oxidative damage while limonene has been shown to act as a strong antidepressant by inhibiting the secretion of stress hormones in the body etc (de Smidt *et al.,* 2025; Masyita *et al*., 2022; Nuutinen, 2018).

These terpenes have, for millennia, been shown to exhibit potential practical applications and have been reported to ameliorate various symptoms of disease. For example, purified versions of these components were used for the treatment of inflammatory diseases (Del Prado-Audelo *et al*., 2021b), insomnia, menstrual irregularities, irritation, nervous tension, delirium, anxiety and digestive disorders (Nuutinen, 2018). Indian medical texts have proposed the use of cannabis to stimulate digestion and act as an analgesic and nervous system stimulant, as well as for its sedative, spasmolytic, diuretic, aphrodisiac, anti-parasitic and anti-viral actions, in the treatment of glaucoma and in skin care (Nuutinen, 2018). Prized for their many therapeutic uses and high medicinal value, pure terpenes and cannabinoids/*Cannabis* extracts are now pharmaceutically available to treat a variety of illnesses. including nausea and vomiting brought on by chemotherapy for cancer, appetite loss, and cachexia (Ibrahim et al., 2019a). Most notably, they are significantly active against illnesses (Del Prado-Audelo *et al*., 2021a) (Ibrahim *et al*., 2019a)

2.9. Methodologies for assessing terpenes and cannabinoids

This growing trend of legalising and commercialising hops and *Cannabis* products has created an increased demand for accurate and reliable methods to quantify chemical composition in these plants. This has led to standardisation, testing and publication of various testing methods including High Performance Liquid Chromatography (HPLC), Gas Chromatography (GC), Gas Chromatography coupled with Mass Spectrometry (GC-MS), and Flame Ionisation Detection (GC-FID).

2.9.1. GC-MS analyses

GC-MS is a powerful analytical technique that combines the separation capabilities of gas chromatography with the molecular identification power of mass spectrometry, rendering this combination a precise analysis of complex mixtures (Sneddon *et al*., 2007; Ibrahim *et al*., 2019). The integration of GC and MS enables the detailed analysis of complex mixtures, providing both qualitative and quantitative data essential for various applications, with the characterisation of the terpene fraction representing a highly effective technique in hop research. It is usually the preferred method for analysing minor volatile compounds in hops and beers (Duarte *et al*., 2020).

The GC-MS process is described in the following steps:

Separation of compounds: Gas chromatography (GC) is used to separate volatile components in a mixture based on their interactions with the stationary phase inside a column and a mobile gas phase. It is crucial to separate individual components in complex mixtures before they are introduced into the mass spectrometer, and this process involves several key steps as follows:

- Sample introduction: A liquid sample was injected into the chromatograph, where it was rapidly vaporised.
- Carrier gas flow: An inert gas, such as helium or nitrogen, transports the vaporised sample through the chromatographic column.
- Column separation: The column contains a stationary phase that interacts variably with different compounds based on their volatility and polarity. Consequently, substances with lower boiling points or weaker interactions with the stationary phase move more quickly through the column.
- Detection: As each compound exits the column at different times, it is detected and quantified. The time required for a compound to exit the column is known as the retention time.

Identification and quantification: Once the compounds are separated by GC, they enter the mass spectrometer for identification and quantification through the following stages:

- Ionisation: Neutral molecules are ionised to generate charged fragments. A common method is Electron Ionisation (EI), in which molecules are bombarded with high-energy electrons, causing them to fragment into ions.
- Mass analyser: The generated ions are separated based on their mass-to-charge (m/z) ratios. Quadrupole mass analysers, which use oscillating electric fields to filter ions with specific m/z ratios, are commonly employed in GC-MS systems.
- Detection: The separated ions are detected, typically by an electron multiplier, producing a mass spectrum that displays the intensity of the ions as a function of their m/z ratios.
- Data analysis: The resulting mass spectra were compared against known spectral libraries, allowing for the identification and quantification of the compounds present in the sample.

2.9.2. GC-FID analyses

GC-FID combines gas chromatography (GC) with flame ionisation detection (FID) to separate and quantify volatile compounds such as terpenes due to their high volatility. The key components of a GC-FID system include:

- Injector: Introduces the sample into the system, often using a split/splitless injection mode.
- Column: A capillary column coated with a stationary phase separates terpenes based on their volatility and polarity.
- Oven: Controls the temperature programme to optimise separation.
- Flame Ionisation Detector (FID): Ionises organic compounds in a hydrogen-air flame, producing a signal proportional to the concentration of each compound.

Challenges and considerations for GC analysis. Matrix Complexity: *Cannabis* oils and hops contain numerous compounds that can co-elute with terpenes, requiring careful method optimisation. Terpene degradation is also a factor as terpenes are sensitive to heat and oxidation, necessitating careful handling and storage. Finally, the lack of commercially available standards for some terpenes can complicate quantification.

2.9.3. HPLC analyses

High-Performance Liquid Chromatography (HPLC) is a widely used analytical technique for the quantification and identification of cannabinoids in various matrices, including *Cannabis* oils, seeds, and cannabis-infused beers. It was used by the National Analytical Forensic Services (NAFS) for quantification of cannabinoids in the *Cannabis* and cannabis-infused beers. HPLC is a form of column chromatography that uses a liquid mobile phase to separate compounds based on their interaction with a stationary phase (King, 2019).

The first step involved in HPLC analysis is sample preparation, which is critical for accurate cannabinoid quantification, especially in complex matrices like *Cannabis* oils, seeds, and beers. *Cannabis* oils are typically diluted with a solvent (e.g., ethanol or methanol) and filtered to remove particulates, whereas the *Cannabis* seeds are ground and extracted using solvents such as ethanol or hexane. The extract is then centrifuged and filtered. As for cannabis-infused beers, they are first degassed to remove carbon dioxide, and cannabinoids are extracted using liquid-liquid extraction or solid-phase extraction (SPE) (De Backer *et al.,* 2009).

Sample preparation is followed by analysis, where the sample is first injected into the mobile phase and then pumped at a constant flow rate through the column. In the column, there is a stationary phase where separation occurs before the different constituents are measured by the detector as the sample exits the machine. Ultraviolet (UV) or diode array detection (DAD) is typically used to detect cannabinoids, which exhibit strong absorbance in the UV range (200–220 nm).

Challenges and considerations for HPLC. The most common limitations of HPLC are due to matrix interference caused by the complexity of cannabinoid samples with terpenes (King, 2019) or the degradation of cannabinoids during storage and analysis due to their highly unstable nature (De Backer *et al*., 2009).

2.10. The use of essential oils in beer production

It is one thing to infuse hops in beer during normal beer production, but the use of hop oils that are steam-distilled from fresh hops is another thing entirely. Beverages infused with plant extracts are subject to solubility issues (Wang *et al*., 2023b), which may present an obstacle to creating a user friendly bioactive beverage. Strong flavours of the isolates may be undesirable as the 'entourage effect' with other molecules in the plant. This would be easy to mask in other beverages like fruit beverages or iced tea using artificial flavours or sugar derivatives. This is not the case in beer production; therefore, the successful infusion of the *Cannabi*s terpene concentrates and hop oil extract would be the first of its kind in the South African beer industry. To determine the retention rate, the resulting experimental beers will undergo rigorous analytical analysis as well as sensory analysis to ensure palatability.

2.11. Sensory analysis

Sensory analysis is a measurement discipline closely associated with precision, accuracy, and sensitivity, aiming to prevent misleading or incorrect positive results. Objective sensory tests are typically conducted by trained panellists and yield measurable data on a product's sensory attributes. These tests are further classified into two categories: discrimination tests, which identify sensory differences between samples, and descriptive tests, which detail the nature and intensity of those differences. In contrast, subjective tests focus on consumer perceptions such as acceptability, preference, and overall liking. These are usually performed by untrained individuals and are commonly referred to as affective or consumer tests (Sharif *et al.,* 2017). Sensory science indicates that chemical and physical attributes of foods and beverages stimulate different sensory nerves on and in the mouth (Wolinska-Kennard *et al.,* 2025), eliciting a response that's either sweet, salty, sour, bitter or umami. Conversely, with beer tasting, sensory attributes are classified as aroma, appearance, flavour and mouthfeel to focus on perceptions derived from the ingredients, not the ingredients or processes themselves. An overall acceptability describes the core characteristics of the beer style by focusing on the elements that set it apart from others (BJCP.org) (Mitchell *et al.,* 2023).

Beer judging is carried out by using standardised BJCP scoresheets, one for judge training and competitions and the other more simplified version for use by anyone be it professional competitions, homebrewers, beer connoisseurs, enthusiasts and consumers alike (Appendix A and B). Analysis of the main components of the judging wheel revealed that smell or aroma refers to the sensory perception of volatile chemical compounds through olfactory receptors in the nasal cavity (Wolinska-Kennard *et al.,* 2025). This is a result of flavour-active volatiles from hops, yeast metabolism by-products, and malt.

Secondly, appearance refers to how the beer looks, considering clarity, colour, and carbonation (Norman, 2019). Colour is imparted by the malt, clarity by interaction of hop acids and malt protein to trap CO_2 within the beer, and carbonation a factor of how much CO_2 was pumped into the beer (for force carbonated beers) or CO_2 that developed in the beer (because of bottle carbonation). Carbonation has the greatest impact on how beer looks as this can be the difference between a flat beer (little carbonation) or a lively beer (high carbonation).

Thirdly, flavour is generally interpreted as a sum of multiple senses like taste, smell, and mouthfeel (Wolinska-Kennard *et al.,* 2025). This is true for beer tasting as well, where this feature incorporates all the five tastes sweet, bitter, sour, salty and umami (Norman, 2019). These attributes measure the interaction between the beer ingredients, yeast health and fermentation products, and serving conditions. In a beer judging exercise, this is the section that carries the most points due to the intricacies of the factors analysed.

Fourthly, mouthfeel refers to the physical, tactile, and textural sensations experienced in the mouth during the consumption of food or beverages, resulting from the interaction between the food's chemical compounds and the taste buds (Wolinska-Kennard *et al*., 2025). In the context of beer, these sensations include carbonation, alcohol warmth, mouth-coating effects, astringency, viscosity, and overall body (Norman, 2019).

Lastly, overall acceptability serves as a detailed, consumer-friendly explanation that helps describe and distinguish the style for someone who isn't a beer enthusiast or certified judge (BJCP.org). This means that the technical know-how is not the focus, what is most important is that the consumer describe what they think of the beer (personal preference) and how likely they are to buy/drink it again.

2.12. Conclusion

Cannabis and hops have been used in traditional medicine for millennia, and research into their mode of action revealed that the bioactive compounds of these plants are found in the essential oil fraction; mainly terpenes and cannabinoids in *Cannabis*; terpenes, alpha acids and humulones in hops. This has been the backbone for the addition/infusion of these plants in functional beverages in the US, Canada and other first-world countries. The expectation is that these bioactive compounds can be retained throughout the brewing process and thus confer their beneficial properties to beer.

Chapter 3

Characterisation of commercially available beers and raw ingredients

3.1 Introduction

Historically, craft beer was defined as the unfiltered and unpasteurised beer produced by small-scale breweries, differently from what was referred to as commercial beers. However, over the years, this definition has evolved significantly with the growth of micro and nano-breweries, pasteurisation to ensure stability in bottles and cans. This has now led to a widely-accepted definition that a brewery can be regarded as craft if it is legally, economically, and independently owned (Alfeo *et al*., 2020). The development and growth of the South African craft beer industry is similar to that experienced in European countries in the 1970s and 1980s, albeit on a smaller scale (Collins *et al*., 2023). The application of indigenous raw materials in beers to create more localised beer identities has been the backbone of the craft beer revolution, seeing movement from total dependence on imported raw materials i.e. malts and hops to the development of SA growth of barley and hop breeding.

The evolution of craft beer and consumer-driven growth of the beverage industry has led to the mushrooming of functional foods, driving scientific research towards healthier options. The SA craft brewing exemplifies innovation, integrating traditional ingredients like *Humulus lupulus* and novel plants like *Cannabis* in various beer styles. Various explorations on modes of addition have been undertaken to add *Cannabis* or hemp to produce unique products following the legalisation of cultivation and consumption of CBD in South Africa in 2018. As only CBD is legal, the choice of infusion of *Cannabis* in foods and beverages is done using the high CBD/low THC plants, otherwise referred to scientifically as hemp. According to Radwan *et al*. (2021) (Radwan *et al*., 2021) *Cannabis* was observed to contain a wide range of chemical components, including terpenes, cannabinoids, and phenolic chemicals, some of which occur in both hops and *Cannabis*.

Terpenes, volatile hydrocarbons abundant in hops, are central to beer's sensory profile. Brewing parameters, namely, malt variety, hop addition timing, fermentation conditions (e.g., yeast strain, temperature), and aging, modulate terpene expression, in over 100 classified beer styles as available in at BJCP.org.; Sohrabvandi *et al*., (2012). Although often used interchangeably, terpenes are characterised by their simple hydrocarbon structure, while terpenoids refer to a modified class of terpenes that have variable functional groups in various positions (Masyita *et al*., 2022). Due to numerous variations and subcategories within these classifications, both terms are often used interchangeably; therefore for this study, the term terpene was used to refer to both simple and oxidised forms.

More than 120 terpenes, primarily mono- and sesquiterpenes, as well as 120 cannabinoids, have been found in *C. sativa* (Radwan *et al*., 2021) while hops contain bioactive compounds such as bitter acids, polyphenols, terpenes, flavonoids and alkaloids (Przybys and Skomra, 2020). Since hops and *Cannabis* both belong to the taxonomy family Cannabaceae, they contain similar secondary metabolites which may exhibit related physiological traits, thus the application of both plants in foods and beverages has, in recent years, risen due to the consumer's demand for biologically active foodstuffs.

In this chapter, we sought to determine the concentrations of terpenes in hops, hoppy beers, *Cannabis* raw materials and cannabis-infused beers. In addition, to determine cannabinoids in *Cannabis* and cannabis-infused beers as well as to assess their retention rates during the brewing process.

3.2. Materials and methods

3.2.1. Sampling

Beers (hop-forward and cannabis-infused) were collected from four breweries, along with the hops used in producing these beers, and the *Cannabis* matter. These beers were chosen from the commercial micro-breweries that were also producing cannabis-infused beers.

3.2.2. Hoppy beer selection

Modern craft brewing in South Africa, like many countries around the world is hugely influenced by America (Collins *et al*., 2023b), with adaptations often made to suit each region or by the availability of ingredients. This has thus made the Indian Pale Ale (IPA) and American Pale Ale (APA) the most brewed, highly hopped beers. The American version of beers are often more bitter than the English versions, showcasing the American hops which are known for their citrus, piney and resiny notes. They have a high alpha acid content (AA) and thus strong bittering potential (measured in International Bittering Units or IBU). This was evident in the beers that the test breweries produced, with the highest IBUs being the Double IPA and IPAs.

An American IPA is classified under the BJCP category 21A (BJCP.org, 2021). It is described as a hoppy and bitter, moderately strong, pale American ale. The alcohol range is 5.5 – 7.5 % ABV and the IBU range is 40 – 70 (medium to high bitterness). The balance is hop-forward, with a clean fermentation profile, dryish finish, and clean, supporting malt allowing a creative range of American or New World hop characteristics to shine through. This prominent to intense hop aroma often features citrus, floral, pine, resin, spice, tropical fruit, stone fruit, berry, or melon flavours (BJCP, 2021). In short, this can be described as an aggressively hoppy beer with a bitter aftertaste with supportive malt.

A double IPA (DIPA) is classified under BJCP category 22A (Mitchell *et al*., 2023). Alcohol by volume (ABV) range for this style is 7.5 – 10 % (high alcohol) and IBU range is 60 – 120 (high bitterness). It is described as an intensely hoppy, fairly strong pale ale without the big, rich, complex maltiness. A long, lingering bitterness is common in the aftertaste but should not be harsh (Norman, 2019). It differs from a classic IPA in that it has a more complex profile due to a higher malt content, higher alcohol content and used more hops early in the brewing process.

The first IPA was hopped with Chinook for bittering and flavour (12 – 14% AA) and Cascade, mostly for flavouring (4.5 – 7% AA). The second beer was a single-hop IPA with Columbus (14 -18% AA). All these hops are of American origin.

3.2.3. Cannabis beer selection

The choice of beer style for different *Cannabis* matter is determined by the flavour profile of the *Cannabis*, the hops used in that beer to ensure alignment and synergy of the flavour profile of the volatiles of both plants. Light beers with a light hop regime will require subtle *Cannabis* matter to avoid overpowering the beer, whereas flavourful beers can accommodate the intense flavour of certain *Cannabis* if it complements the flavours of the beer and the hops used.

Three cannabis-infused beers were selected for analysis: two lagers and a pale ale. Lager 1 was one of the first cannabis-infused beers in South Africa, making use of only hemp seeds in the mash whereas Lager 2 only had CBD oil, which was added after fermentation (commonly known as dry hopping i.e. addition of flavour active material to beer after fermentation). The third beer, the pale ale, had a combination of hemp seeds in the mash, and purified *Cannabis* terpene concentrate added after fermentation.

The two beers with *Cannabis* matter added after fermentation (lager 2 and pale ale) were treated in this manner to ensure maximum retention of the hemp volatiles in the beer as addition during active fermentation could lead to loss of volatiles with the escaping carbon dioxide. Thus, addition after fermentation was done to not only enhance the *"dank" Cannabis* profile in the beer but also to complement the hops used in these beers and to ensure that the consumer could taste the hemp.

The hemp seeds and CBD oil profiles were unknown as they were obtained from experimental *Cannabis* farms. The *Cannabis* terpene concentrate on the other hand was a commercial product imported from Canada, and it is widely sold in the cannabis industry. It is declared by the manufacturer to be extracted from a *Cannabis* plant that is dominant in β-caryophyllene, myrcene, and terpinolene.

3.2.4. Analysis

In South Africa, the capacity of institutions to conduct *Cannabis* and cannabinoid testing is subject to rigorous regulation, given the relative novelty of this field of study. Accreditation from regulatory bodies entails substantial costs, particularly for smaller laboratories. Testing was done at the National Analytical Forensic Services (NAFS) and Versuchs- und Lehranstalt für Brauerei in Berlin (VLB), selected independent, but highly regulated laboratories for both *Cannabis* and hop matter, as well as the beers they were infused in.

3.2.4.1. HPLC analysis

The samples were analysed by NAFS, as it was one of the first labs in South Africa to gain accreditation from the South African Health Products Regulatory Authority (SAHPRA) to perform *Cannabis* testing on foodstuffs. In this instance, HPLC was used, method number TM006.3 (Potency Cannabis HPLC) (211207-004-002). The cannabinoids investigated were CBC, CBD, CBD-A, CBD-V, CBG, CBG-A, CBN, Delta-9-THC, THC-A, THC-V, total potential CBD, and total potential THC.

3.2.4.2. GC-MS analysis

The method used for terpene analysis was a headspace-trap GC-MS method (TM003.5 (Terpenes) (211207-004-002). It was used for the detection and quantification of 21 terpenes, including α-bisabolol, α -humulene, α -pinene, α -terpinene, β -caryophyllene, β -myrcene, β -pinene, camphene, cis-nerolidol, delt-3-carene, gamma-terpinene, geraniol, guaiol, isopulegol, limonene, linalool, ocimene, para-cymene, terpinolene, trans-Nerolidol and total nerolidol.

3.2.4.3. GC-FID analysis

GC-FID was carried out by VLB-Berlin to test for terpenes in the Cannabis (CBD oil and *Cannabis* terpene concentrate) and hop oils from three South African hop varieties (African Queen, Southern Sublime and Southern Passion). The method used was GC-FID (Analytica EBC, 2006,7.12) and the 16 terpenes tested for were as follows: α -pinene, β -pinene, myrcene, limonene, cis-linalool oxide, trans-linalool oxide, linalool, β -caryophyllene, farnesene, α -humulene, α-terpineol, geranyl acetate, citronellol, nerol, geraniol, and caryophyllene oxide.

3.3 Results

3.3.1. HPLC analyses

cannabis-infused beers were procured along with *Cannabis* matter that was added during the brewing process. In this case, more than one type of *Cannabis* matter was employed by different breweries i.e. *Cannabis* seeds (hemp seeds), *Cannabis* oil and a *Cannabis* terpene concentrate. Cannabinoid testing was performed for these samples where HPLC was employed. The five cannabinoids assessed included cannabichromene (CBC), cannabidiol (CBD), cannabigerol CBG, cannabinol (CBN) and delta-9-tetrahydrocannabinol (δ-9-THC); and their total decarboxylation products: cannabidiolic acid (CBD-A), cannabidivarin (CBD-V), cannabigerol acid (CBG-A), tetrahydrocannabinol acid (THC-A), and tetrahydrocannabivarin (THC-V), total potential CBD and total potential THC.

3.3.2. Commercially available beers brewed with cannabis products

3.3.2.1. Lager 1

This was the first cannabis beer that was commercially produced in South Africa and the *Cannabis* matter used was de-shelled hemp seeds from a non-THC containing *Cannabis* strain. The hemp seeds were added during mashing of the brewing process. No cannabinoids were detected in the seeds as well as the beer.

3.3.2.2. Lager 2

In the production of this beer, a CBD oil was added after fermentation was complete, i.e., dry hopping. The cannabinoid analytical results revealed that the CBD oil contained: CBN, Delta-9-THC, THC-V and total potential THC at levels 0.004, 0.005, 0.001 and 0.005% respectively (Figure 3.1.), however, none of these were detected in the beer.

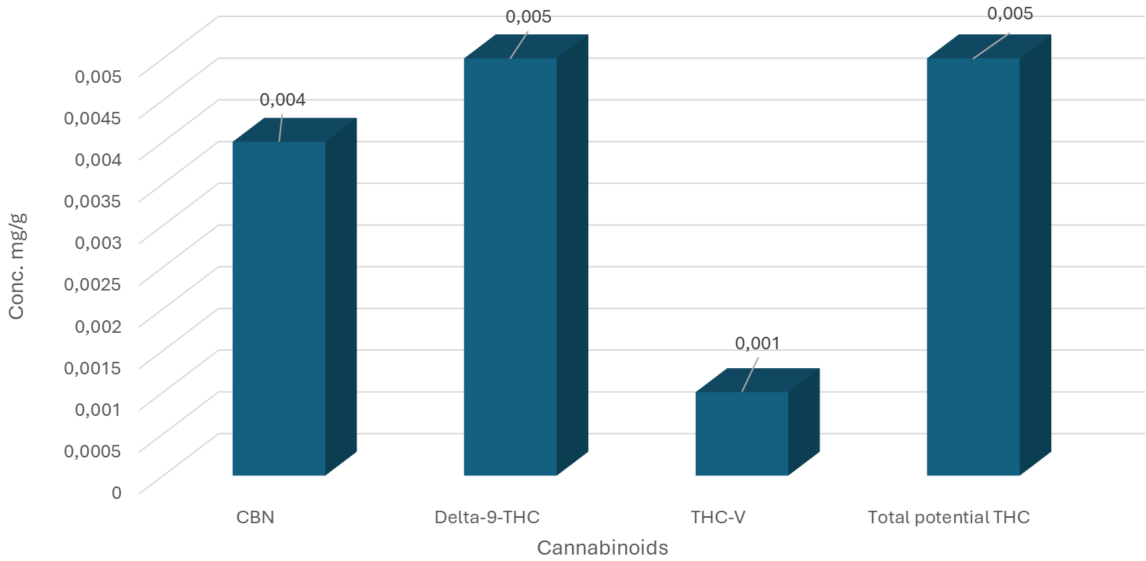

Figure 3.1: Cannabinoids concentration of CBD oil used in the brewing of Lager 2

3.3.2.3. Pale Ale 1

Cannabis seeds, de-shelled, were added during the mashing stages of this pale ale and the purified *Cannabis* terpene concentrate added post-fermentation i.e., dry hopping. The analytical results showed that cannabinoids were found only in the terpene concentrate at 0.037 % of CBD (and total potential CBD), but none were detected in the seeds or the beer.

3.3.2.4. CBD session IPA

Cannabinoids detected in this beer were THC, and total potential THC was at 0.002%.

3.3.2. GC-MS analyses

This method was used in the analysis of terpenes in hops used in the cannabis-infused and hoppy beers (IPA 1 & 2, and the double IPA), as well as the *Cannabis* matter for beers in section 3.3.1 above.

3.3.2.1. Lager 1

The South African hops used in this lager were Southern Aroma and Southern Passion, and they presented with the terpenes α-Humulene (0,718; 0,623 mg/g), β-Caryophyllene (0,324; 0,16 mg/g) and β-Myrcene (0,452; 0,063 mg/g). None of these terpenes were detected in the beer, only terpinolene was detected at 0.292 mg/g.

3.3.2.1. Lager 2

This beer was also hopped using the South African hop (African Queen) commonly used for bittering and flavour development. The hops presented the following terpene concentration: α -Humulene (1.196 mg/g), β -Caryophyllene (0.553 mg/g), β -Myrcene (0.657 mg/g), and limonene (0.545 mg/g). None of these terpenes were detected in the beer except terpinolene at 0.466 mg/g. Terpene analysis of the CBD oil presented Delta-3-Carene at 0.415 mg/g, but this was also not detected in the beer.

3.3.2.3. Pale Ale 1

The hops used in this beer were the classic American hops: Columbus, a dual-purpose hop used for bittering and flavour often showcasing earthy, peppery, spicy, and floral notes. Its terpene profile was α -Humulene (0.757 mg/g), β -Caryophyllene (0.322 mg/g), β -Myrcene (0.580 mg/g) and limonene (0.135 mg/g). These terpenes were not detected in the beer except Terpinolene at 0.249 mg/g. Interestingly, the *Cannabis* terpene concentrate was also added to this beer after fermentation, during dry-hopping with a terpene profile showing nine terpenes (Figure 3.2) as follows: α -Humulene (157.622 mg/g), α -Pinene (64.453 mg/g), β -Caryophyllene (202.573 mg/g), β -Myrcene (151.144 mg/g), β -Pinene (36.156 mg/g), limonene (54.502 mg/g), linalool (19.981 mg/g), ocimene (37.426 mg/g), and terpinolene (58.745

mg/g), yet only terpinolene was detected in the beer at 0.249 mg/g. Terpene analysis of the hemp seeds yielded no terpene results. The terpinolene concentration had dropped from 58.7 mg/g in the concentrate to 0.249 mg/g in the beer.

3.3.2.2. CBD session IPA

No terpenes, including terpinolene, were detected in this beer.

3.3.2.5. IPA 1

This American IPA was hopped with Columbus, which showed the terpene concentration of α -Humulene (0.757 mg/g), β -Caryophyllene (0.322 mg/g), β -Myrcene (0.580 mg/g), and Limonene (0.135 mg/g), yet the only terpene detected was Terpinolene at 0.431 mg/g.

3.3.2.6. IPA 2

The hops used in IPA 2 were Cascade and Chinook. The terpenes detected were α-humulene and β-caryophyllene at 0.669 mg/g and 0.334 mg/g respectively, but these terpenes were not detected in the beer. Only terpinolene was detected at 0.497 mg/g.

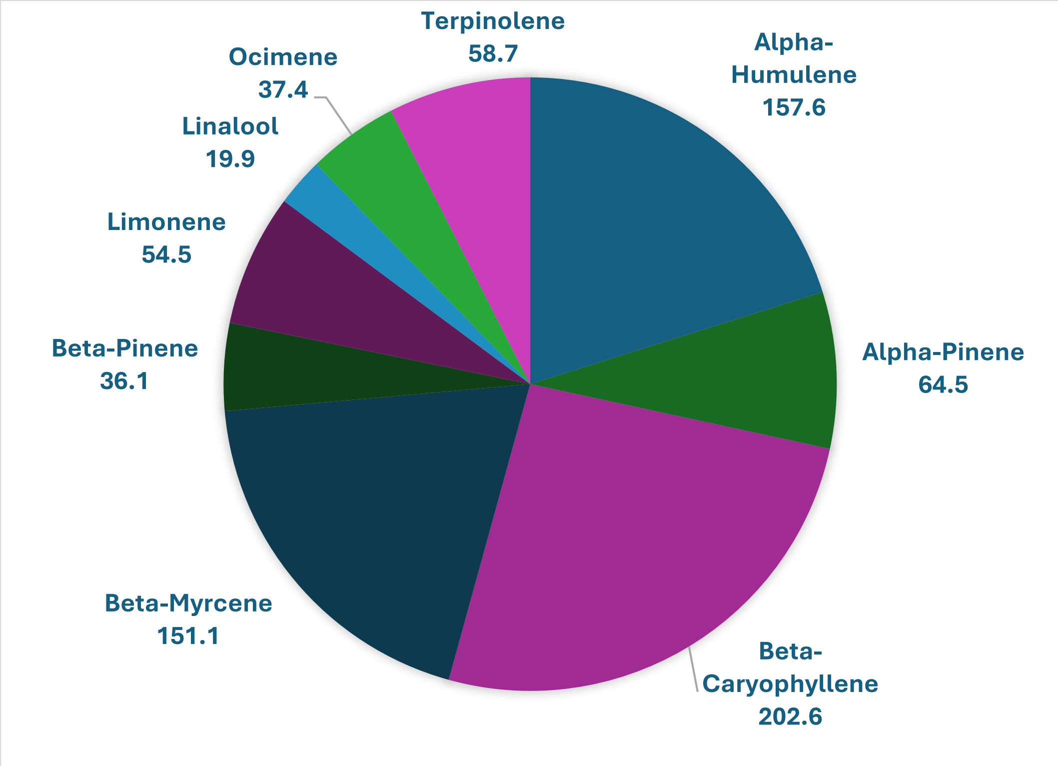

Figure 3.2: Terpenes detected in the commercial *Cannabis* terpene concentrated (values are mg/g) used in Pale Ale 1.

3.3.2.7. Double IPA (DIPA)

The third hoppy beer was a double IPA, brewed with the following hops: Columbus, Summit, Chinook Centennial and Centennial Cryo. These hops all contained α-humulene, β-caryophyllene, β-myrcene and Limonene (Figure 3.3). Nevertheless, none of these terpenes were detected in the beer, and this time around no terpinolene was detected in the beer.

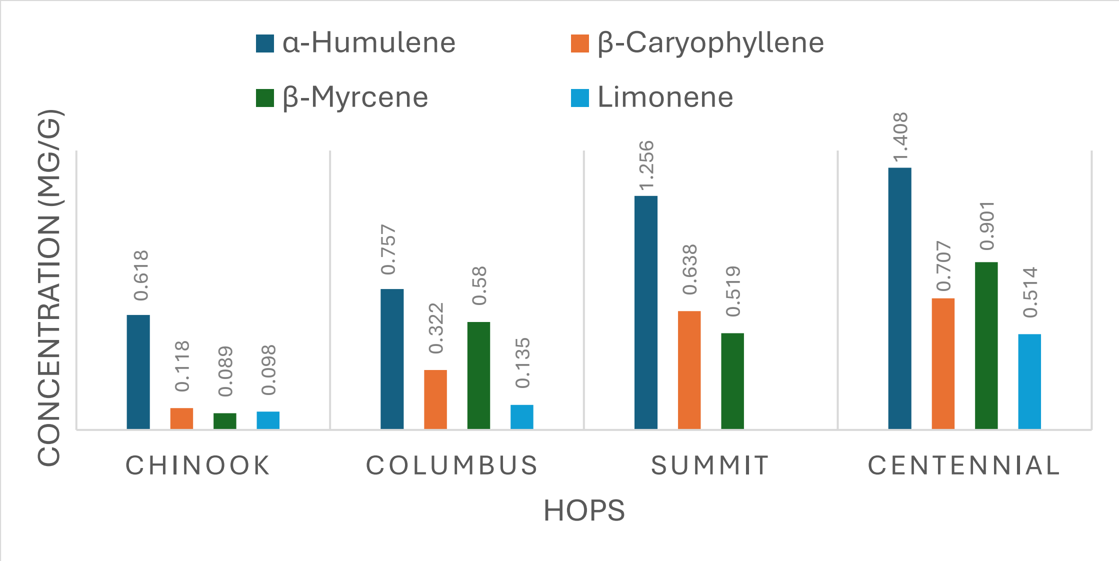

Figure 3.3: Terpene concentration of hops used in the double IPA (DIP

3.4. Discussion

There are over 120 terpenes that are commonly present in hops and *Cannabis* plants, with β-myrcene, α-pinene, β-pinene, limonene, (E)-β-ocimene, β-caryophyllene, α-humulene, (E)-nerolidol, and linalool being the highest in concentration. Concentrations of other compounds for which standards are not available, are usually estimated based on a response factor obtained from the calibration curves of compounds with similar chemical structures (Giovannoni *et al*., 2023). Of these, four terpenes were the most occurring in hops irrespective of origin, namely, α-humulene, β-caryophyllene, β-myrcene and limonene (Móricz *et al*., 2023), and this is evident in the hop analytical data presented in summary form in Figure 3.4..

However, all these terpenes were not retained in the corresponding beers, with only terpinolene being detected even when it was not found in the hops. It has been indicated that "terpenes concentration in beer is directly linked to the choice of hop variety used (Steyer *et al*., 2017). However, the absence of these terpenes in the beer contradicted to this notion. In fact, the contradictory data could be attributed to a possible loss of terpenes either during beer processing, or upon storage or even transformed into other compounds which were not analysed. Another possible reason could be that the levels might have decreased so significantly to levels that were undetectable using GC-MS, justifying the use of an alternative method with higher sensitivity. This suggests that the results and the unit of measurements especially for GC-MS (mg/g) did not provide a clear picture of the bioactive compounds. As a result, the need for another analytical method was necessary to validate the above findings, necessitating the need for GC-FID analysis.

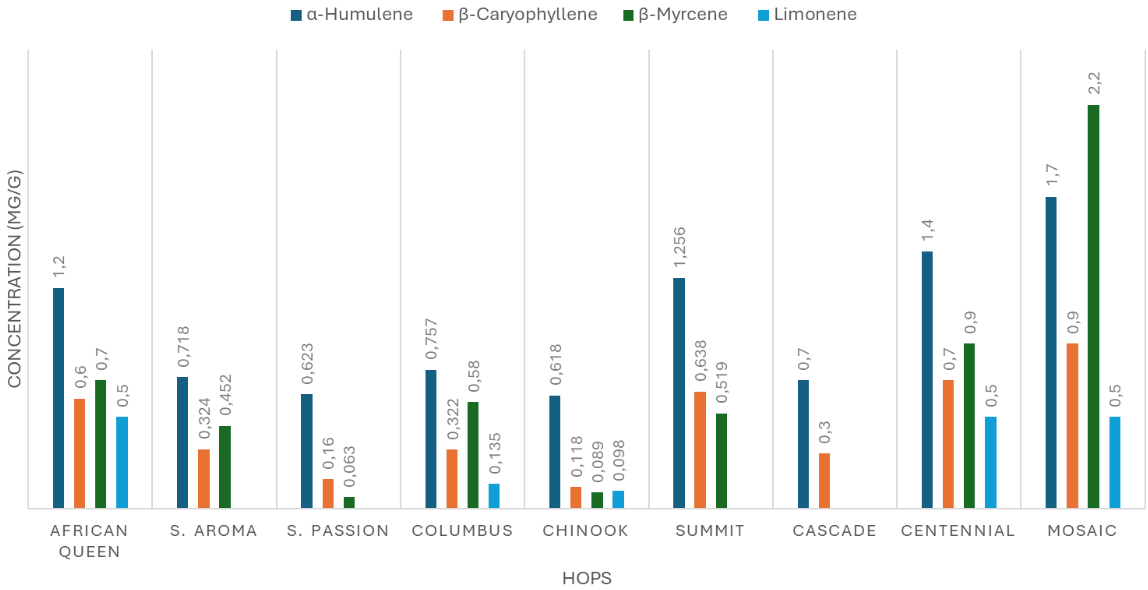

Figure 3.4: Comparative terpene concentrations from different hop varieties

Furthermore, the detection of terpinolene in most of these beers (5 out of 7 beers) even when terpinolene was not detected in the raw ingredients, highlighted that terpinolene might have been formed from the breakdown of terpenes. This phenomenon known as biotransformation, is currently being widely researched by hop breeders and brewers worldwide in the quest to understand the volatile composition of beers and how yeasts affect the terpene concentration (Lallemand, 2025); (Fermentis, 2023). In brief, the fermentation process is a highly complex process with substrates being changed and end-products also being transformed or incorporated into various molecules. The bioactive compounds in the starting material may not remain intact through this process or can be transformed into completely different molecules.

Cannabis and hop matter were evaluated using the Gas Chromatography-Flame Ionisation Detection (GC-FID) for terpene analysis at the VLB laboratories (Berlin). The samples analysed were hop oils (African Queen, Southern Sublime and Southern Passion), *Cannabis* matter (CBD oil and terpene concentrate). These hop oils are steam distilled from the South African hops from the upcycled vegetative hop biomass (de Smidt *et al*., 2025).

No beer samples were analysed at this point, as the breweries had either discontinued these beer styles or other breweries had shut down due to the impact of COVID 19 restrictions on alcohol production or trade. The beers that could still be found in the market were not ideal for analysis as they were beyond the expiration dates.

This method aimed at detecting 16 terpenes: α-pinene, β-pinene, myrcene, limonene, cis-linalool oxide, trans-linalool oxide, linalool, β-caryophyllene, farnesene, α-humulene, α-terpineol, geranyl acetate, citronellol, nerol, geraniol and caryophyllene oxide. The comparison of terpene concentrations of the CBD oil vs terpene concentrate (Figure 3.5) shows that both samples contained all the terpenes tested for except for α-pinene which is not detected in the CBD oil. The terpene concentrate has higher concentrations of β-pinene, limonene, linalool, β-caryophyllene and caryophyllene oxide whereas the α-terpineol concentration seems to be the same. The CBD oil has higher concentrations of myrcene, farnesene and α-humulene.

In total, GC-MS data showed nine terpenes detected in the terpene concentrate, while GC-FID was able to detect 10. Terpenes detected by both methods includedα-pinene, β-pinene, β-myrcene, Limonene, Linalool, β-Caryophyllene, α-humulene. The differences observed were in ocimene (GC-MS), farnesene and caryophyllene oxide (GC-FID). Different forms were observed where GC-MS detected β -myrcene and terpinolene while GC-FID detected myrcene and α-terpineol, respectively.

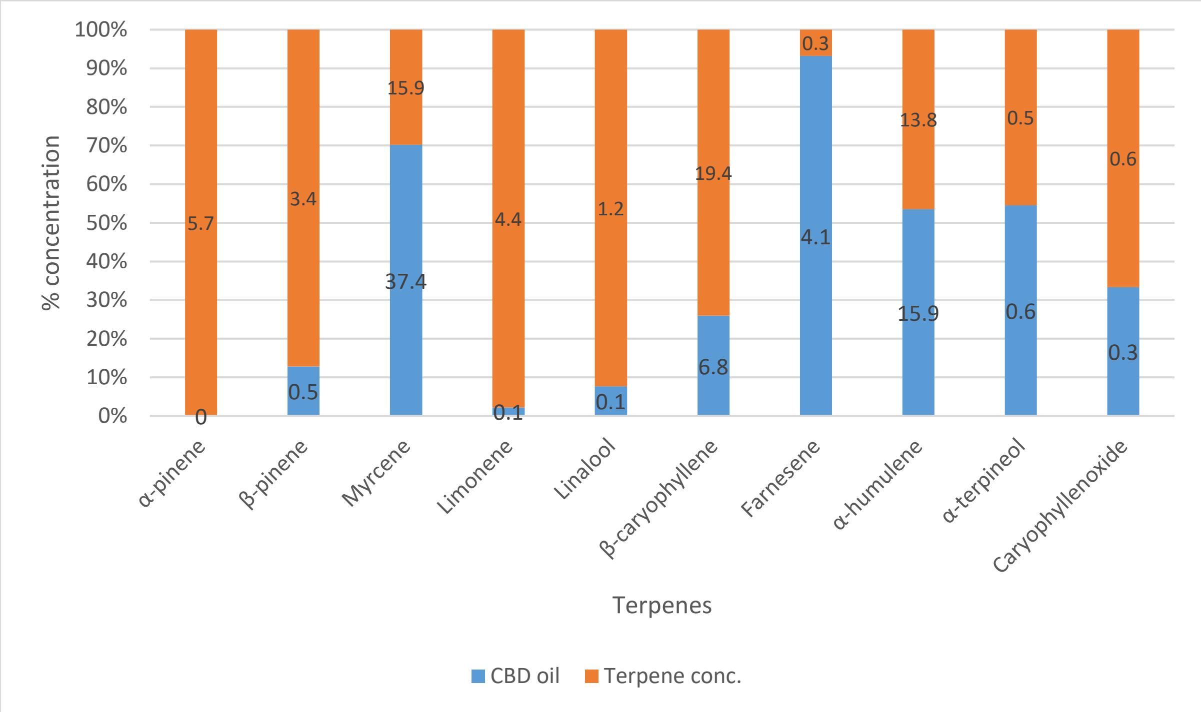

Figure 3.5: Comparison of the CBD oil and -terpene concentrate analysed by GC-FID

3.5. Conclusion

Overall, the cannabinoids detected in the different *Cannabis* raw ingredients shows that most of the cannabinoids were detected in the oils and not in the hemp seeds or the terpene concentrate. Considering that the seeds were obtained from CBD *Cannabis* strains, one would have expected them to contain some, even traces of CBD-forming molecules. Moreover, for protection of their intellectual property (IP), the brewers were not open to sharing information on the addition rates of their raw materials, or sources of the *Cannabis* material; therefore, standardisation of the process could not be determined.

As the beers sampled were made with different varieties of hops and *Cannabis* material, to get a standardised view of the terpene retention rate, it is thus imperative to conduct test brews where the same form of hops and *Cannabis* matter is used. It would be imperative to use an analysis method that measures the percentage of the bioactive compounds in the samples, as this indicates what percentage of the oil the specific compound was. To mitigate the chance of loss during active fermentation, “dry-hopping” (addition of hops or oil post primary fermentation) should be considered as well as the use of yeast strains that give little to no biotransformation.

Chapter 4

Characterisation of experimental beers brewed with cannabis and hop oils

4.1. Introduction

4.1.1 Hops and hop processing

Hop cones are processed into different forms after harvest depending on the intended use and the leaves, bracts and stems of the plant are often discarded. The most common form of hops are pellets, where cones are crushed, mixed and pelletised for uniformity. Other forms include whole hop cones, hop oils and hop extracts.

4.1.2. Hop oils

There has recently been a rise in the production of hop essential oils for use in hop-forward beers to improve batch-to-batch consistency, improve hop flavour and reduce beer losses (Duarte *et al*., 2024). This practice has also been used in the US and Europe to reduce waste during hop harvest by not only relying on hop cones for oil but also from the hop vegetative mass that is often discarded after harvest. It was adopted in South Africa in 2022 for trials on the SAB hops, and when this proved successful, the work was performed on more varieties using the 2023 and 2024 crops, presenting the opportunity to reduce waste and increase hop oil output per hectare.

Steam distillation of hop waste matter ensures that valuable compounds from the whole of the hop plant are extracted (Van Opstaele *et al*., 2012) proving that this vegetative biomass contained an abundance of compounds that are useful in an array of industries. This is primarily because of the oxygenated fraction of hop oils (de Smidt *et al*., 2025). During boiling, nearly all hop oil constituents volatilise, and even with late kettle additions, typically only the less volatile oxygenated compounds are retained in the beer and this is due to the insoluble nature of most terpenes. As a result, there are many views on how to successfully use them in beer, with *"dry hopping"* the preferred method for imparting hop flavour and aroma. Different authors suggested dispersing the oil into a carrier before adding to beer at 0.05 - 0.3 g/hL (i.e. 0.003 g/L) (BarthHaas.com); others extracted individual terpenes with CO_2 and added them to wort at 0.4 µL/mL (i.e 4 µL/L) (Dietz *et al*., 2021) allowing a 24-48 hrs contact time before analysis. Other approaches involved experiments separating the hop oil fractions into three phases: hop oil, water-soluble aqueous and residual aqueous which were added at 0.3 mL/L and 50 mL/L (Wang *et al*., 2023a). The varying techniques were influenced by the manufacturer's specifications of different oils and for this reason, for the experimental beer brewed for this study, Preserve Botanica specifications were adhered to (2 drops per 20 L, which translated to 0.09 g). Following analysis of the hop oils distilled from SA hop varieties, we then selected two varieties for test brews, African Queen and Southern Passion, and a commercial *Cannabis* terpene concentrate, to investigate their chemical and sensory attributes.

4.1.3. Sensory analysis of beer

A trained sensory panel undergoes rigorous training to participate in sensory analysis, and the same applies in the beer industry where beer judges undergo a series of taste training and exams (written and practical tasting) to ensure standardisation in judging (BJCP, 2021). Following success in the examinations, active participation in judging sessions becomes crucial for accumulating judging points. This ongoing involvement not only reinforces the judge's experience and exposure but also helps maintain and refine their judging skills. Judges who achieve a score between 60 and 69 on the judging exam, or those scoring 70 or above but possessing fewer than five experience points, are awarded the Recognised rank. The Certified rank is granted to judges who scored 70 or higher and have accumulated at least five experience points. To qualify for National status, beer judges must attain a score of 80 or above on the beer judging exam and earn ten judging points, after which they become eligible to sit for the BJCP Beer Written Proficiency Exam required for advancement to National or Master Beer Judge ranks (BJCP.org, 2021). National beer judge rank is earned with a composite score of 80-89 and 20 experience points (with at least 10 points from judging). As of 2025, there are three National judges in South Africa.

The aim for this chapter was to investigate and quantify the essential oil terpenes retained in the beer by means of GC-FID analysis and to investigate the sensorial influence of the hop oils and *Cannabis* terpene concentrate on flavour and aroma properties of the American Pale Ale beer. Two hop oils from African Queen and Southern Passion varieties, as well as a commercial *Cannabis* terpene concentrate, were used to enhance the hop flavour in beer through "dry-hopping" a practice commonly adopted by brewers in hop-forward beers.

4.2. Materials and methods

4.2.1 Beer style and vitals

The beer style selected for experimental brewing was category 18 subcategory B (18B): American Pale Ale (APA) as outlined in the Beer Judge Certification Programme style guidelines (BJCP, 2021). This beer style is described as an average strength, hop forward, pale American craft beer with sufficient supporting malt to make beer balanced and drinkable. It has a clean hop presence showcasing the American or new word hop varieties with a wide range of characteristic. The beer vital statistics are shown in Table 4.1.

4.2.2 Ingredients and hot side conditions

An experimental brew of 50 L was prepared by using 5 kg of Marris Otter pale malt (Crisp Malting, UK), 6 kg SAB Pale malt, 1 kg of Weyermann Munich malt, 500 g Weizenmalz Hell Pale Wheat malt and 500 g Weyermann Caramunich 2. A 60 L, single vessel DEMACRAFT microbrewery (DEMATECH) with circulation and temperature control was used for wort preparation. Mashing was performed at 66°C with a volume of 45 L at pH 5.25, held for 1 hour to ensure proper enzymatic conversion of starch and proteins (Thesseling *et al*., 2019; Nehra *et al*., 2024). During 15-minute intervals, Demacraft temperature readings were noted, and a sample was drawn for analysis of pH (using a benchtop pH metre); gravity (SG and Brix) using a refractometer (RSG-100ATC). At the end of mashing, grain (spent grain) was separated from the wort and 8 L of water at pH 5.3 was used for sparging (rinsing of grain bed with water) to dilute the wort gravity from 1.070 to 1.048.

Spent grain was discarded and the final wort volume of 53 L was boiled for 1 hour, at the start of which 160 g Southern Aroma hop variety was used for bittering (Thesseling *et al*., 2019) to yield calculated bitterness of 42 IBU. Wort was cooled with a heat exchange column to 20°C and transferred to two 25 L jacketed, temperature-controlled Grainfather conical fermenters. The Grainfather glycol chiller was used for temperature control during fermentation. The yeast SafAle US-05 known for its neutral fermentation profile, ability to produce well-balanced, clean and crispy ales, (Fermentis by Lesaffre, France) was used for fermentation. It is an ideal yeast to use to get a clear fermentation characteristics as it lacks the biotransformation enzyme β-lyase (Fermentis, 2025), ensuring that the aroma profile of the hops remains unchanged during fermentation. This dry yeast was pitched by sprinkling directly onto the wort at 11 g/20 L.

Municipality water used throughout the brewing process was passed through a carbon and sand filtration system, before use in mashing and sparging. The starting pH was 7.43, and this was adjusted to 5.2 for mash water and 5.33 for sparge water. One litre of the water was collected just before use, stored in the fridge at 4°C before delivery (in an ice box with crushed ice) to an accredited water testing laboratory for analysis. The water was profiled for Ca^{2+}, Mg^{2+}, HCO_3 (alkalinity), Na^+, Cl^-, SO_4^{2-} and residual alkalinity (RA).

4.2.3 Fermentation conditions (cold side)

Fermentation was performed at 20°C for 10 days according to the yeast suppliers' instructions. Gravity, temperature, pH and alcohol content were measured daily at 12-hour intervals and within 24 hrs intervals during the diacetyl rest and yeast settling/flocculation. Temperature was recorded as displayed on the

Fermenter LCD screen. Two portions of 50 mL (2x 50 mL) were collected using sterile centrifuge tubes, centrifuged to settle out the yeast and other solids, the supernatant poured off for analysis. One sample was stored in light-resistant centrifuge tubes, stored at 4°C and analysed for diacetyl which was carried out with a Thermo Scientific Trace 1310 gas chromatograph fitted with a flame ionization detector (FID), an SGE BP5MS analytical column of 60 m x 0.25 mm x 0.25 µm and connected to a Thermo Scientific ISQ 7000 single quadrupole mass spectrometer (MS). Carrier gas was hydrogen at 200 kPa. The injector was held at 150°C, FID at 290°C, transfer line at 280°C and the ion source at 200°C. Specific ion monitoring at 86 m/z was performed. The initial oven temperature was 40°C held for 5 minutes, raised at 25°C/minute to 200°C. An external standard curve was constructed with deionized water and 2,3-butanedione (diacetyl) reference material from 0.05 to 1.1 mg/L. Instrument control and data analysis was with Thermo Xcalibur 4.0 software and the 2017 NIST library.

The remaining sample was analysed for gravity, pH and ABV. Gravity was measured using the digital refractometer (HI96841) and confirmed using the handheld refractometer (RSG-100ATC). Percentage alcohol by volume (ABV) was measured using the Alex 500 extract and ethanol analyser (Anton Paar, Germany) following centrifugation of the sample, pH was measured on the Jenway pH meter. When gravity was 0.005 points from the target final gravity (FG) of 1.015, the temperature was increased by 1°C every 24 hours for 3 days to illuminate the majority of diacetyl in the finished beer (Krogerus & Gibson, 2013). When the FG stabilised, the yeast was removed from the bottom tap in the conical fermenter and the temperature was lowered to 4°C for 3 days.

The remainder of the yeast was removed, and the finished beer was transferred from the top tap of the conical fermenter to two washed, sanitised and CO_2 purged 8 L Kegland Oxibar PET Kegs (fitted with a PCO38-Tapping Head Assembly with Ball Lock Posts, Dip Tube and PRV). The kegs were filled with half of each of the two fermenters to ensure consistency in the final batches and stored upright in the chest fridge at 4°C. A diagram of the brewing process is presented as Figure 4.1).

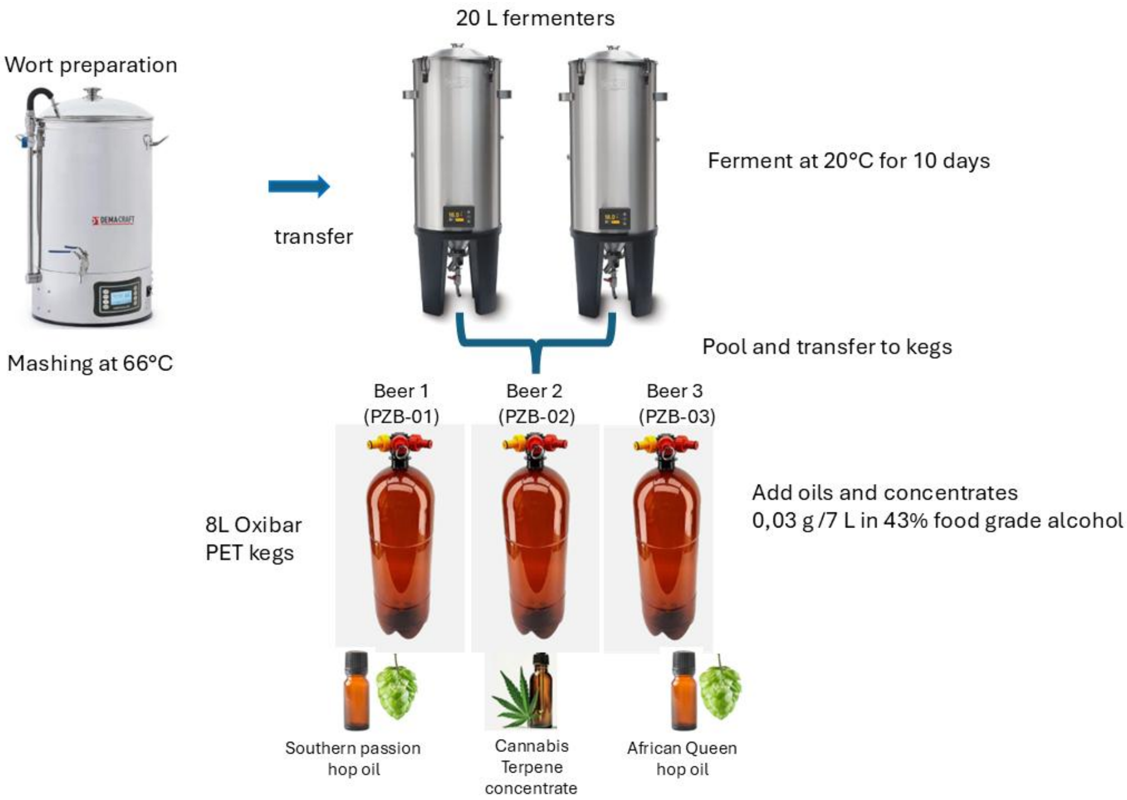

Figure 4.1: Diagram showing the brewing process, packaging and hop oil and cannabis terpene extract additions.

4.2.4 Hop oil additions

The hop and terpene oils were first dissolved in filter sterilised 43% food-grade ethanol to prepare dosing solutions for the finished beer. A volume of 34 µL (equivalent to 0.03 g) of oil was measured using a micropipette and added to 1 mL of ethanol in a sterile tube, resulting in a total mixture mass of 0.967 g. These ethanol-oil solutions were vigorously mixed by shaking before introduction into the respective kegs, followed by the transfer of beer to promote mixing. The final oil concentration in each keg was 34 µL per 7 L of beer. The kegs were stored overnight under refrigeration at 4˚C. Each keg was assigned a unique identifier: PZB-01, PZB-02, and PZB-03, corresponding respectively to the order of dry hopping with Southern Passion hop oil, *Cannabis*-derived terpene concentrate, and African Queen hop oil. To minimise oxidation, each keg was purged with carbon dioxide (CO_2) prior to the addition of both the oil and beer.

Once filled, the kegs were purged again and gently agitated to facilitate thorough mixing of the oils into the beer. The kegs were left stationary for 24 hrs at 4°C.

After 24 hours, and prior to carbonation, 50 mL samples were collected into light-resistant centrifuge tubes for terpene analysis. The beers were then force-carbonated at 20 PSI while being gently mixed for three minutes. Following carbonation, the pressure was reduced to a serving level of 10 PSI, and the kegs were returned to refrigeration until sensory analysis was conducted.

4.2.5 Sensory evaluation of experimental beers

Trained beer judges/tasters from the beer industry were invited to partake in judging of the beers. These tasters' backgrounds and experience in brewing ranges from both the commercial and craft brewing industries. The panel consisted of 22 trained tasters, 18 male and 4 female. Beers were assigned codes and served in the order PZB-01, PZB-02 and PZB-03. They were served as unlabelled and unknown samples. The beers were kept chilled, connected to CO_2 at a serving pressure of 10 PSI and served in a clear, 250 mL Gilder cognac glass (Figure 4.2).

Figure 4.2: Beer tasting glass used for sensory sessions. The shape is specifically designed to capture volatiles for better aroma perception.

The beer scoresheet used for this study was designed on a Google form (Appendix A) and its terminology was adapted from the BJCP scoresheets (Appendices B & C) and included only the aroma, flavour and overall acceptability sections. The aromatics and flavour characteristics selected were derived from the beer flavour wheel (Norman, 2019) as well as the aromatics corresponding to the terpenes detected in these oils as detected via GC-FID in the previous chapter. The terpenes included caryophyllene (herbal and woody), β-pinene, myrcene (green, citrus, fresh herbaceous), and humulene (earthy, woody, herbal, and black pepper). The oxygenated compounds included linalool (floral, fresh, coriander), geraniol (floral, rose-like, citrus), nerolidol, farnesol, α-terpineol (lilac-like, piney), citronellol (rose-like, citrus), and caryophyllene oxide (Ao *et al*., 2025; Kaminski *et al*., 2025). This scale was designed as 6 tick boxes and the scale direction went from left to right with increasing intensities, Not detected, 1 (low), 2 (medium/low), 3 (medium), 4 (medium/high), 5 (high). The overall acceptability part of the beer scoresheet was adapted to be a hedonic scale often used in sensory science to show preference on a scale of 1 – 9 interpreted as follows: 1= dislike extremely, 2= dislike very much, 3 = dislike moderately, 4 = dislike slightly, 5 = neither dislike nor like, 6 = like slightly, 7 = like moderately, 8 = like very much; and 9 = like extremely. At the end, the judges also had to pick which was their favourite and least favourite beer.

Sensory results from all the tasters were reported for each experimental beer in spider plots. The median of each attribute for aroma and flavour as well as the combined score out of 110 (the maximum intensity score possible per attribute) was presented as bar charts for comparison.

4.2.6. GC-FID Analysis of experimental beers

Beer samples (50 mL) were collected into brown light-resistant, centrifuged and the terpene content were analysed using Gas Chromatography-Mass Flame Ionisation Detection (GC-FID) (method number TM003.5) at a South African Health Products Regularity Authority (SAHPRA) facility called PET Labs Pharmaceuticals (Johannesburg, SA). The method detected and quantified 21 terpenes namely α-bisabolol, α -humulene, α -pinene, α -terpinene, β -caryophyllene, β -myrcene, β -pinene, camphene, cis-nerolidol, delt-3-carene, gamma-terpinene, geraniol, guaiol, isopulegol, limonene, linalool, ocimene, para-cymene, terpinolene, trans-Nerolidol and total nerolidol.

4.3. Results and Discussion

4.3.1 Beer style, vitals and ingredients

The BJCP style guidelines are internationally recognised guidelines for beer competitions and offer overall impression, aroma, appearance, flavour and mouthfeel expected in beers entered into specific categories. For this study 18B: American Pale Ale (APA) was selected because this category has a specific focus on hop character, and the malt profile is uncomplicated and serves as background and balance. Brew water for mashing and sparging contained 42.96±0.2 ppm Ca^{2+}, 27.7±0.5 ppm Mg^{2+}, 38.94±0.85 ppm Na^{+}, 44.65±1.05 ppm Cl^{-}, 23.7±0.1 ppm SO_4^{2-} and residual alkalinity (RA) of 34.75±6.45. The vital statistics guidelines which describe the ranges allowed for 18B in terms of alcohol content, bitterness, gravity and colour are presented in Table 4.1 as well as the obtained parameters for the base beers from the two independent fermenters which was considered independent duplicates. As is evident from the data presented in Table 4.1 that the produced base beers grouped within the allowed parameters for category 18B: APA with adequate repeatability.

Table 4.1: Vitals statistics for category 18B: American Pale Ale (APA) as well as values obtained for the base beers from each fermenter.

Vitals	Range	Results
% Alcohol by volume (ABV)	4.5 – 6.2 %	5.54±0 %
International Bittering Units (IBU)	30 – 50	≈ 42.
Original gravity (OG)	1.045 – 1.060	1.048±0
Final gravity (FG)	1.010 – 1.015	1.006±0
Colour - standard research method (SRM)	5.0 – 10.00	≈ 6

4.3.2 Fermentation conditions for base beer and hop oil additions

The fermentation profiles of base beers in both fermenters are presented in Figure 4.3. The temperature was maintained at 20±0.27°C for the first 5 days of fermentation and increased 1°C per day for 3 days to reduce residual diacetyl which may have a prominent buttery aroma and influence the mouthfeel of the finished beer (Krogerus & Gibson, 2013). Thereafter, the temperature was decreased over 2 days to allow for yeast flocculation and removal. The gravity (fermented sugar content) decreased rapidly during the first 4 days of fermentation with the concomitant production of alcohol. The discrepancy in ABV% determined at days 1, 5.5 and 9 can be attributed to equipment sensitivity, especially at lower alcohol concentrations, since the same differences were not noted in the gravity measurements. After 10 days the finished beer was pooled in a separate vessel and 7 L was transferred to 3 separate PET kegs. The oils and concentrates were added to each keg at a concentration specified by the manufacturer (0.03 g/7 L) and carbonated for sensory evaluation.

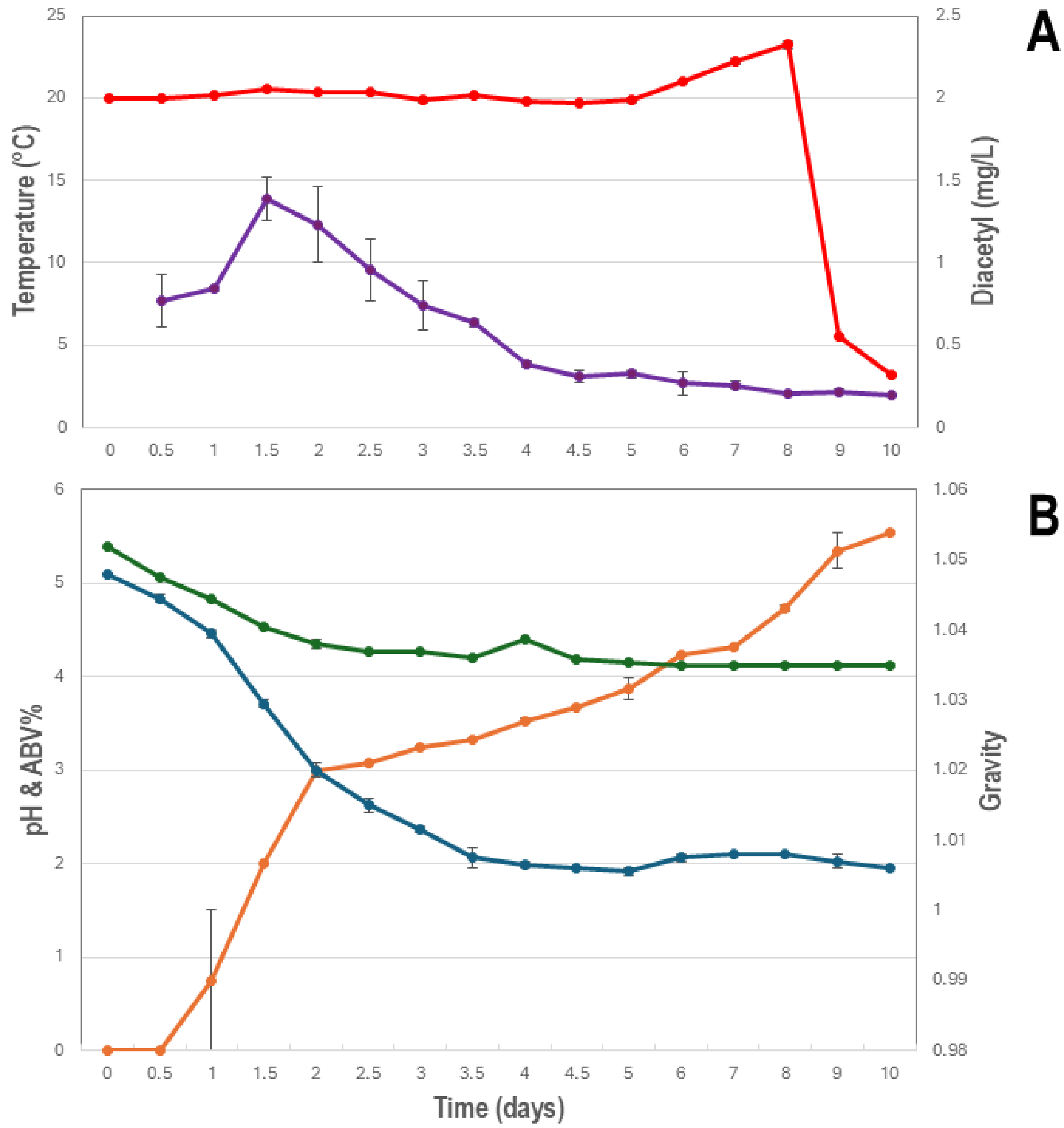

Figure 4.3: Fermentation profiles of base beers. Samples were collected from both fermenters every 12 hours for 10 days. (A) represents the temperature (red) and diacetyl (purple) profile. (B) represents gravity decrease (blue), pH decrease (green) and alcohol production (orange). The fermenters were considered as independent duplicates and the data is presented as averages with standard deviations as error bars.

4.3.3 Sensory evaluation of test brews

Sensory science plays a vital role in the beverage industry. It supports product marketing strategies by providing insights into consumers' preferences and choices, and it also contributes to product understanding and the development of new beverages (Marques *et al.*, 2022). The approach used for assessing the experimental beers brewed can be considered a modified version of flash profiling where a restricted number of terms in the beverage ranking were introduced to provide quantitative information about the attribute's intensity (Liu *et al.*, 2018).

4.3.3.1. PZB-01 (Southern Passion oil)

Most tasters observed that the malt profile's aromas and flavours were intensely dominant, which initially suppressed the hop aromatics. However, as the beer warmed, the hop characteristics became more pronounced. Additional aromas identified included papaya, a tea-like scent, and strong woody and resinous notes, which were prominent at first but diminished over time. Other nuances such as green watermelon, a slight horse blanket note, honeyed caramel, and a fruity breakfast punch were also detected.

The spider plots in Figure 4.4 shows that PZB-01 presented a broad, diverse aroma spectrum, with strong fruity, floral, and woody components. The fruit complexity presented as pear, banana, and black currant attributes, contributing to a complex aroma. It also expresses floral notes (lavender, lilac, rose-like) and herbaceous tones, adding aromatic complexity.

4.3.3.2. PZB-02 (*Cannabis* terpene concentrate)

The spider plot Figure 4.5. shows strong citrus, floral, and hoppy characters, alongside moderate grassy and fruity undertones in beer PZB-02. The flavour spider plot showed that PZB-02 expressed more hop-driven, floral, citrusy, and resinous complexity. The overall acceptability presented in Figure 4.5, indicated a generally favourable panel response.

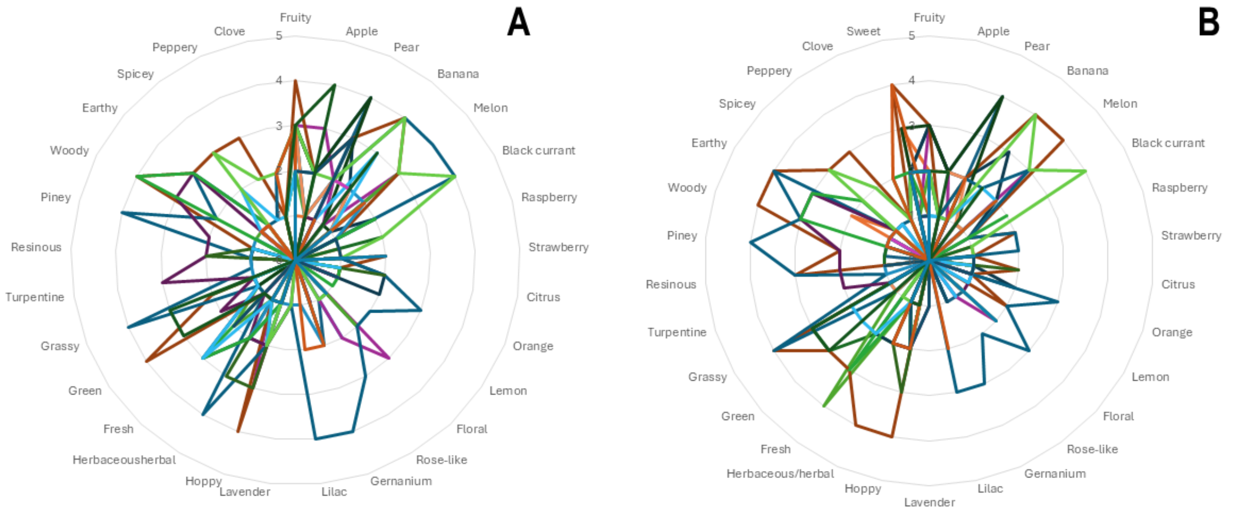

Figure 4.4: Sensory results of the aroma (A) and flavour profiles (B) of experimental beer PZB-01 which contained Southern Passion oil. The scales represent 0 – not detected to 5- high (intensity of each attribute). The graphs reflect input from all tasters (n=22).

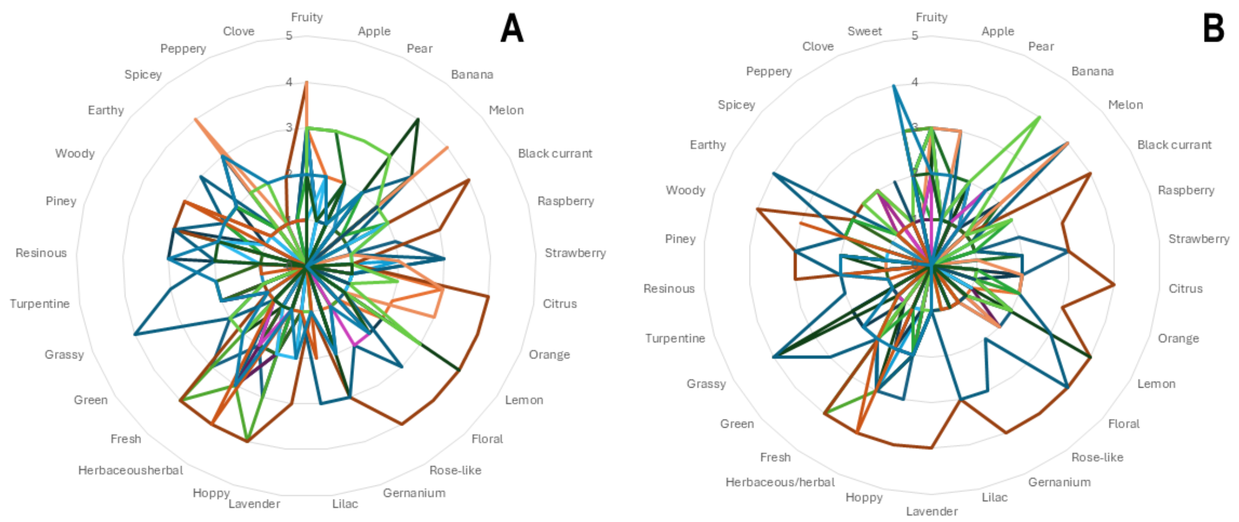

Figure 4.5: Sensory results of the aroma (A) and flavour profiles (B) of experimental beer PZB-02 which contained commercial *Cannabis* terpene extract. The scales represent 0 – not detected to 5- high (intensity of each attribute). The graphs reflect input from all tasters (n=22).

The median score for PZB-02 was approximately 5.5, while the mean score closely aligned with the median, suggesting a symmetrical distribution of ratings. Most panellists rated the sample between 5 and 7, reflecting moderate to high acceptance. The lower bound of the data (around 3) suggested that a few participants found the sample only marginally acceptable, whereas the highest ratings reached 8, indicating strong approval from some assessors. Overall, PZB-02 received consistent and generally positive evaluations, implying that it was well-liked, though with slight variation in individual preferences (Figure 4.6.).

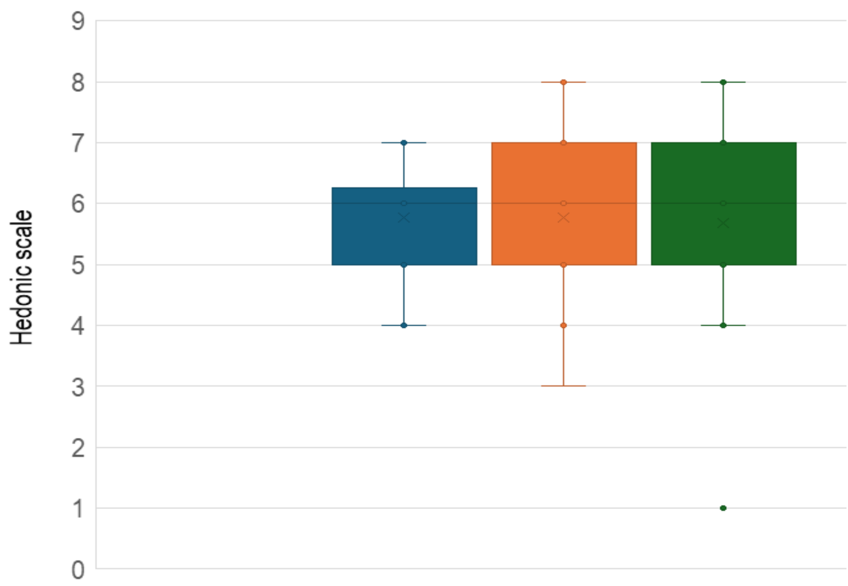

Figure 4.6: Overall acceptability of experimental beers PZB-01, PZB-02 and PZB-03 measured by the Hedonic scale, 0 = dislike extremely to 9 = like extremely.

4.3.3.3. PZB–03 (African Queen oil)

Tasters noted the following aroma and flavour profiles: vanilla-like sweetness, hop aroma was very soft, presenting as resin, apricot and guava. One taster noted strong yeast aroma and two noted the solventy and high alcohol presence. The aroma radar plot Figure 4.7 revealed a concentrated intensity along the fruity axis, reinforcing a clear sensory impression dominated by fruit esters. This may suggest that sample PZB-03 exhibits a distinctly fruit-forward aroma profile, marked by high intensity in the general fruity and hoppy descriptors, with supporting notes of apple, pear, and citrus. Secondary attributes include herbaceous, fresh, and green tones introducing a mild vegetal complexity followed by a limited aromatics such as woody, resinous, and earthy. In contrast, floral descriptors and spicy notes were either minimal or not perceived, indicating a limited aromatic contribution.

The aroma and flavour of PZB-03 were both distinctly fruit-forward, though they differed in balance. The aroma showed a mix of fruity esters with lighter accents of subtle herbal-green and woody undertones that added depth.

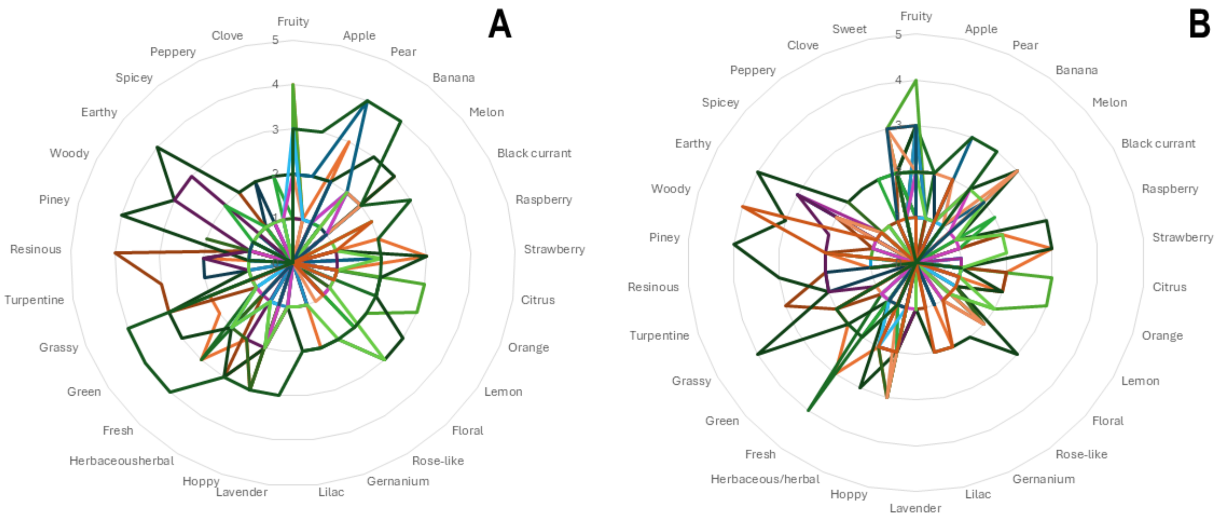

Figure 4.7: Sensory results of the aroma (A) and flavour profiles of experimental beer PZB-03 which contained African Queen hop oil. The scales represent 0 – not detected to 5- high (intensity of each attribute). The graphs reflect input from all tasters (n=22).

In contrast, the flavour profile was led primarily by fruity and some sweetness with only faint traces of pear or citrus and little to no herbal, floral, or spicy expression. In essence, the aroma presents greater complexity while the flavour delivers a simpler, cleaner impression centred on fruit character. The two profiles are harmonious but indicate that the beer's aromatic intensity and diversity are higher than its palate expression.

Regarding flavour, the fruity descriptor exhibited the highest overall intensity, forming a distinct peak on the radar plot and indicating a pronounced fruit-forward character. Within this category, secondary notes such as apple and pear were present at medium intensity, while other sub-notes which included banana, melon, and berries were either faint or not detected. In addition to the dominant fruity profile, a subtle herbal/green undertone was discernible, complemented by delicate hints of resinous, woody, and earthy attributes. Furthermore, floral and spicy notes were minimal.

The tasters' additional comments included earthy, woody notes with resin, and higher alcohol perceived. As it warmed, the beer became slightly spicy, presenting subtle but enjoyable fruitiness, giving a cider-like impression. One taster called this a Christmas cake due to notes of benzaldehyde that were detected.

4.3.3.4. Overall acceptability

Overall acceptability of each beer is represented in Figure 4.6 and Table 4.2. Preference was devided between PZB-02 (n=9) and PZB-03 (n=8), which indicated that the *Cannabis* terpene concentrate and beer containing African Queen hop oil were found to be more pleasant than the Southern Passion (PZB-01) beer.

Table 4.2: Comparison of the three beer samples

Sample	Mean	SD	Median	Range	Interpretation
PZB-01	4.8	1.0	5	3–7	Slightly liked to neutral
PZB-02	5.6	1.3	6	3–8	Moderately liked
PZB-03	6.4	1.1	6	4–8	Liked moderately to very much

PZB-01 had less perception of bitterness than the other two beers and strong grassy notes. In addition, it had more of the green flavour. On the other hand, PZB-02 had a better overall balance and was a favourite for most judges. Although, those who did not pick it as their favourite attributed the dislike to a dank flavour profile that remain on the tongue after swallowing. PZB-03's mouthfeel was heavier, and the beer had hints of vanilla, toffee and coffee. This beer was the second most favourite. The most distinct aroma and flavour profiles for PZB-02 and PZB-03 are summarised in Table 4.3.

Table 4.3: Summary of the aroma and flavour profiles for PZB-02 and PZB-03.

Attribute	PZB-03	PZB-02	Key Difference
Fruity	Dominant (apple, pear)	Broader fruit mix (lemon, banana, black currant)	Broadened complexity in flavour
Floral	Mild	Strong (rose-like, geranium)	Intensified in flavour
Hoppy/Herbal	Moderate	Strong	More hop presence when tasted
Resinous/Piney	Subtle	Pronounced	Hop bitterness emphasised
Spicy/Earthy	Mild	Moderate	Adds depth in flavour
Fresh/Green	Low	Noticeable	Reflects hop freshness

Even though the analysis from 22 tasters were complex and varying, when the median for each beer was considered both the intensity of the listed aroma and flavour attributes were low, but differences could be observed among the 3 experimental beers (Figure 4.8 & Table 4.3)

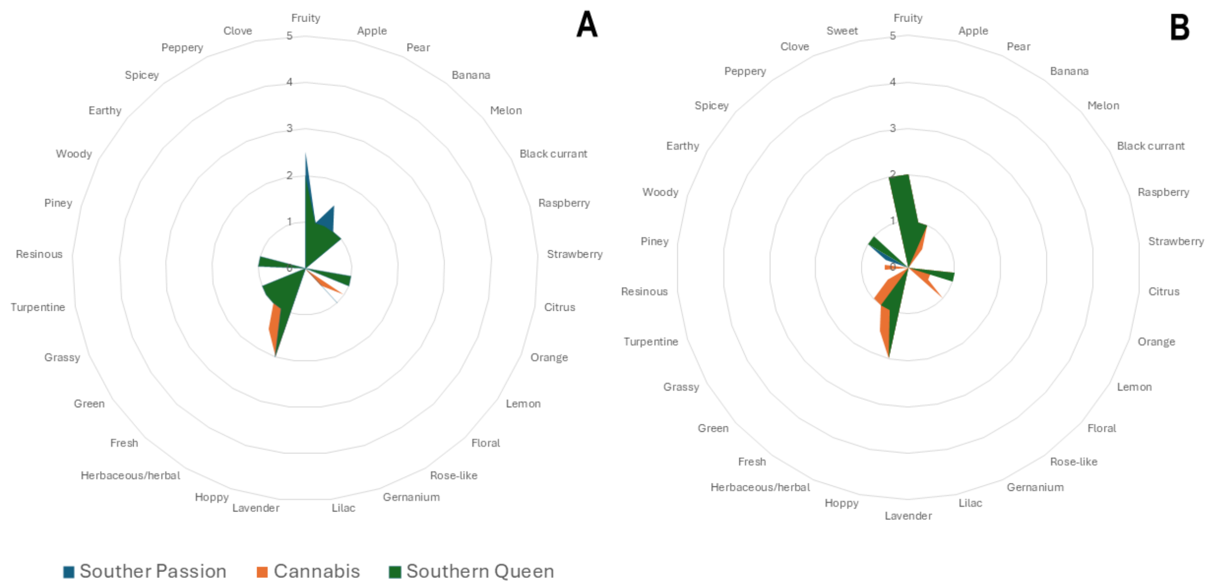

Figure 4.8: Sensory results of the aroma (A) and flavour (B) profiles of all 3 experimental beers PZB-01-03. The scales represent 0 – not detected to 5- high (intensity of each attribute). The graphs reflect the medians from inputs from all tasters (n=22).

4.3.3 GC-FID analysis of experimental beers

Among the 21 terpenes analysed, only terpinolene ($C_{10}H_{16}$) was detected in all three beers at concentrations 0.301±0.022 mg/g (PZB-01, Southern Passion oil), 0.355±0.006 mg/g (PZB-02, *Cannabis* terpene concentrate) and 0.362±0.026 mg/g (PZB-03, African Queen oil) consistent with the findings from the commercial beer samples discussed in Chapter 3. Terpinolene (4-isopropylidene-1-methylcyclohexene) is a structural isomer of (+)-limonene (Figure 4.9) a monocyclic monoterpene compound containing a cyclohexene ring (Sowndhararajan *et al*., 2015). Its profile presents as fresh, pine, herbal, woody and resinous. It enhances the hop freshness character, enhancing perceived complexity, especially when co-present with myrcene, humulene, and oxygenated terpenes (linalool, geraniol) (Isaacson *et al*., 2025). Its aroma threshold in water is ≈ 100–200 µg/L (approx. 0.1–0.2 mg/L), even though it dissolves poorly in water, it extracts into ethanol or fatty phases and is, therefore, better retained in beer if added on the cold side of the brewing process or "dry-hopping" (post fermentation addition). Upon ageing, both terpinolene and limonene can oxidise to carveol, carvone, α-terpineol.

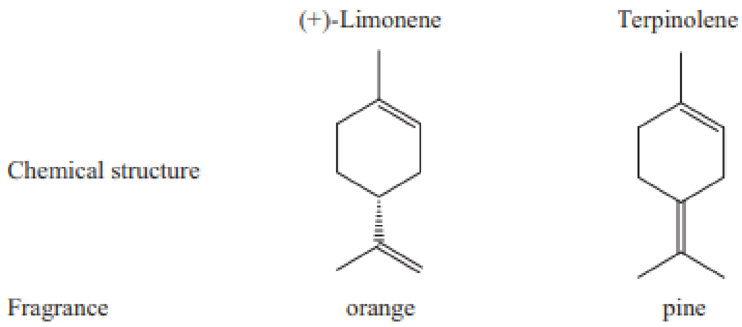

Figure 4.9: Schematic representation of limonene and terpinolene showing structural and aromatic differences

Although the presence of terpinolene can account for the perception of pine, herbal, woody and resinous aroma and flavours by the tasters, it did not explain the fruity, sweet, hoppy, citrus and lemon attributes highlighted in Figure 4.8. Sensory data diversity could be supported by the presence of other volatile compounds in the beer contributed from the hop oils such as ketones, acids, alcohols, aldehydes, esters that were present in the hop oils in very low fractions but have similar aroma attributes to the terpenes. These include herbal, spicy, fruity, woody, grassy, green, etc. (de Smidt *et al*., 2025; Ou *et al*., 2024).

4.4. Conclusions

The recent rise in the production of hop essential oils represents a significant advancement in brewing practices, particularly for hop-forward beers. This innovation enhances batch-to-batch consistency and to improves hop flavour retention. Internationally, the practice has gained traction in the United States and Europe, where it also contributes to sustainability by utilising hop vegetative biomass traditionally discarded during harvest, for oil extraction. Upcycling of South Africa hop waste offers a viable strategy to reduce agricultural waste and increase hop oil yield per hectare.

The beers were successfully manufactured using the 65 L Demacraft system and fermented in two temperature-controlled Grainfather fermenters. When fermentation was complete, the bright beer was split into three PET Oxibar before dosing with the hop and cannabis oils. The findings based on the sensory qualities or properties revealed that the most preferred beers were PZB-03 (African Queen oil) and PZB-02 (*Cannabis* terpene concentrate). The steam-distilled hop oils significantly influenced beer flavour, as shown by differences between batches, particularly hop beers. However, terpene profiles alone failed to predict the sensory outcomes, with many judge-identified flavours undetected by GC-FID. As established by (Isaacson *et al*., 2025), chemical composition on its own is inadequate for predicting aroma profile.

For future research, it would be crucial to have the non-dry-hopped beer for sensory for calibration purposes. Considering the heavy malt profile of the American Pale Ale, a standard lager experimental beer could be a useful tool to judge how different beer styles express the dry-hopped terpene profile.

Chapter 5

Concluding remarks

The evolving consumer demand for healthier and sustainably sourced food and beverage products has become a pivotal driver of innovation across the industry. In particular, functional beverages, have transcended their traditional roles of refreshment and hydration, now expected to deliver tangible health benefits such as enhanced immunity, digestive support, and cognitive function (Gupta *et al*., 2023). This shift reflects a broader consumer expectation: food and drink must not only taste good and nourish but also contribute positively to overall well-being and environmental sustainability. The proliferation of such products in retail spaces and the growing body of scientific literature underscore this trend.

In response, the brewing industry has embraced experimentation, especially with hops, traditionally regarded as mostly bittering agent, to explore various forms such as whole cones, pellets, extracts, and essential oils to craft niche beer products (Duarte *et al*., 2024). While pellets remain popular for their stability and cost-effectiveness, extracts and essential oils offer opportunities to reduce beer losses and enhance product uniqueness (BarthHaas.com, 2025). Furthermore, indigenous plants related to hops, including *Azadirachta indica* and *Cannabis*, have gained attention for their bioactive properties and potential applications in functional beverages (Agu *et al*., 2023; Ascrizzi *et al*., 2020). Ultimately, the convergence of consumer health consciousness, sustainability concerns, and botanical innovation is reshaping the future of food and beverage development, paving the way for products that are not only functional but also culturally and environmentally resonant.

This study highlighted that the edition of functional ingredients such as cannabis should be confirmed by laboratory analysis. Functional components in cannabis-infused products were confirmed to contain only the terpene terpinolene, similar to highly hopped beers. Hop oils extracted from South African hop varieties were chemically diverse and contained similar terpene profiles to a commercial *Cannabis* terpene extract used in experiment brewing trials and sensory evaluation. Sensory analysis by a panel of trained judges demonstrated a difference in perceived aroma and flavour complexity for the two hop varieties African Queen and Southern Passion as well as the *Cannabis* terpene extract. Overall scores however, were low, indicating a need for optimizing the dosing rates. Chemical analysis of the experimental beers indicated the presence of only the same single terpene detected in the initial commercially available beers, namely terpinolene. Even though the presence of this single terpene can account for the aroma and flavour profiles described by the tasters, its sole presence in the final product remains unexplained.

Future research should include reconsidering the base beer style. A lighter style such as a international pale lager may be more suited for the purpose of comparative tasting. The malt profile of the American Pale ale used as base beer in this study may have distracted tasters from the hop aroma and flavour.

Secondly, the dosage of the different oils requires further optimisation if the terpenes detected in the raw ingredients are to carry through into the beer. Without the terpenes in the beer, this suggests that the hop oils and terpene concentrate addition at this stage serves to enhance the aroma and flavour profile of the beers.

Lastly, the chemical analysis of experimental beers should be more comprehensive than targeting terpenes only but should include degradation products of terpenes as well. This is evident in the presence of volatiles detectable during sensory analysis but not by targeted GC analysis, indication that other compounds could be responsible for the aroma and flavour contributions. The inclusion of higher alcohols, ketones, esters and aldehydes (e.g. benzaldehyde) would expand our current knowledge of the aroma and flavour imparted to beer by complex hop oils.

Appendices

Appendix A

Example of sensory tool used for evaluation of experimental beer PZB-03. Demographic data was collected with the tool for beer 1 (PZB-01) not with every beer evaluation. "Select your favourite beer" was only included in the tool for beer 3 (PZB-03).

2. Aroma. Determine presence and level of compounds in beer 3. *

Mark only one oval per row.

	Not detected	1 (Low)	2 (Medium/low)	3 (Medium)	4 (medium/High)	5 (High)
Fruity						
Apple						
Pear						
Banana						
Melon						
Black currant						
Raspberry						
Strawberry						
Citrus						
Orange						
Lemon						
Floral						
Rose-like						
Geranium						
Lilac						
Lavender						
Hoppy						
Herbaceous/herbal						
Fresh						
Green						
Grassy						
Turpentine						
Piney						
Woody						

Earthy	⬭	⬭	⬭	⬭	⬭	⬭
Spicey	⬭	⬭	⬭	⬭	⬭	⬭
Peppery	⬭	⬭	⬭	⬭	⬭	⬭
Clove	⬭	⬭	⬭	⬭	⬭	⬭

3. Any additional comments on **aroma** of beer 3. Compounds that are not covered in the list above.

____

____

____

____

____

Please evaluate the hop **flavour** compounds in Beer 3.

4. **Flavour**. Determine presence and level of compounds in beer 3. *

Mark only one oval per row.

	Not detected	1 (Low)	2 (Medium/low)	3 (Medium)	4 (medium/High)	4 (High)
Fruity	◯	◯	◯	◯	◯	◯
Sweet	◯	◯	◯	◯	◯	◯
Apple	◯	◯	◯	◯	◯	◯
Pear	◯	◯	◯	◯	◯	◯
Banana	◯	◯	◯	◯	◯	◯
Melon	◯	◯	◯	◯	◯	◯
Black currant	◯	◯	◯	◯	◯	◯
Raspberry	◯	◯	◯	◯	◯	◯
Strawberry	◯	◯	◯	◯	◯	◯
Citrus	◯	◯	◯	◯	◯	◯
Orange	◯	◯	◯	◯	◯	◯
Lemon	◯	◯	◯	◯	◯	◯
Floral	◯	◯	◯	◯	◯	◯
Rose-like	◯	◯	◯	◯	◯	◯
Gernanium	◯	◯	◯	◯	◯	◯
Lilac	◯	◯	◯	◯	◯	◯
Lavender	◯	◯	◯	◯	◯	◯
Hoppy	◯	◯	◯	◯	◯	◯
Herbaceous/herbal	◯	◯	◯	◯	◯	◯
Fresh	◯	◯	◯	◯	◯	◯
Green	◯	◯	◯	◯	◯	◯
Grassy	◯	◯	◯	◯	◯	◯
Turpentine	◯	◯	◯	◯	◯	◯
Resinous	◯	◯	◯	◯	◯	◯

Piney	◯	◯	◯	◯	◯	◯
Woody	◯	◯	◯	◯	◯	◯
Earthy	◯	◯	◯	◯	◯	◯
Spicey	◯	◯	◯	◯	◯	◯
Peppery	◯	◯	◯	◯	◯	◯
Clove	◯	◯	◯	◯	◯	◯

5. Any additional comments on **flavour** of beer 3. Compounds that are not covered in the list above.

Please evaluate the overall acceptability of Beer 3.

6. Overall acceptability of Beer 3 (PZB-03) *

Mark only one oval.

1	2	3	4	5	6	7	8	9
◯	◯	◯	◯	◯	◯	◯	◯	◯

7. Select your favourite beer *

Mark only one oval.

◯ Beer 1
◯ Beer 2
◯ Beer 3

Appendix B

BEER SCORESHEET

http://www.bjcp.org **AHA/BJCP Sanctioned Competition Program** http://www.homebrewersassociation.org

Judge Name (print) ______________________

Judge BJCP ID ______________________

Judge Email ______________________

Use Avery label # 5160

Category # ______ **Subcategory (a-f)** ______ **Entry #** ______

Subcategory (spell out) ______________________

Special Ingredients: ______________________

Bottle Inspection: ☐ Appropriate size, cap, fill level, label removal, etc.

Comments ______________________

BJCP Rank or Status:

☐ Apprentice ☐ Recognized ☐ Certified
☐ National ☐ Master ☐ Grand Master ___
☐ Honorary Master ☐ Honorary GM ☐ Mead Judge
☐ Provisional Judge ☐ Rank Pending ☐ Cider Judge

Non-BJCP Qualifications:

☐ Professional Brewer ☐ Beer Sommelier ☐ GABF/WBC
☐ Certified Cicerone ☐ Adv. Cicerone ☐ Master Cicerone
☐ Sensory Training ☐ Other ______________

Descriptor Definitions (Mark all that apply):

☐ **Acetaldehyde** – Green apple-like aroma and flavor.

☐ **Alcoholic** – The aroma, flavor, and warming effect of ethanol and higher alcohols. Sometimes described as *hot*.

☐ **Astringent** – Puckering, lingering harshness and/or dryness in the finish/aftertaste; harsh graininess; huskiness.

☐ **Diacetyl** – Artificial butter, butterscotch, or toffee aroma and flavor. Sometimes perceived as a slickness on the tongue.

☐ **DMS (dimethyl sulfide)** – At low levels a sweet, cooked or canned corn-like aroma and flavor.

☐ **Estery** – Aroma and/or flavor of any ester (fruits, fruit flavorings, or roses).

☐ **Grassy** – Aroma/flavor of fresh-cut grass or green leaves.

☐ **Light-Struck** – Similar to the aroma of a skunk.

☐ **Metallic** – Tinny, coiny, copper, iron, or blood-like flavor.

☐ **Musty** – Stale, musty, or moldy aromas/flavors.

☐ **Oxidized** – Any one or combination of stale, winy/vinous, cardboard, papery, or sherry-like aromas and flavors.

☐ **Phenolic** – Spicy (clove, pepper), smoky, plastic, plastic adhesive strip, and/or medicinal (chlorophenolic).

☐ **Solvent** – Aromas and flavors of higher alcohols (fusel alcohols). Similar to acetone or lacquer thinner aromas.

☐ **Sour/Acidic** – Tartness in aroma and flavor. Can be sharp and clean (lactic acid), or vinegar-like (acetic acid).

☐ **Sulfur** – The aroma of rotten eggs or burning matches.

☐ **Vegetal** – Cooked, canned, or rotten vegetable aroma and flavor (cabbage, onion, celery, asparagus, etc.)

☐ **Yeasty** – A bready, sulfury or yeast-like aroma or flavor.

Aroma (as appropriate for style) ______/12
Comment on malt, hops, esters, and other aromatics

Appearance (as appropriate for style) ______/3
Comment on color, clarity, and head (retention, color, and texture)

Flavor (as appropriate for style) ______/20
Comment on malt, hops, fermentation characteristics, balance, finish/aftertaste, and other flavor characteristics

Mouthfeel (as appropriate for style) ______/5
Comment on body, carbonation, warmth, creaminess, astringency, and other palate sensations

Overall Impression ______/10
Comment on overall drinking pleasure associated with entry, give suggestions for improvement

Total ______/50

SCORING GUIDE

Outstanding	(45 - 50):	World-class example of style.
Excellent	(38 - 44):	Exemplifies style well, requires minor fine-tuning.
Very Good	(30 - 37):	Generally within style parameters, some minor flaws.
Good	(21 - 29):	Misses the mark on style and/or minor flaws.
Fair	(14 - 20):	Off flavors/aromas or major style deficiencies. Unpleasant.
Problematic	(00 - 13):	Major off flavors and aromas dominate. Hard to drink.

			Stylistic Accuracy			
Classic Example	☐	☐	☐	☐	☐	**Not to Style**
			Technical Merit			
Flawless	☐	☐	☐	☐	☐	**Significant Flaws**
			Intangibles			
Wonderful	☐	☐	☐	☐	☐	**Lifeless**

Please send any comments to Comp_Director@BJCP.org

Appendix C

BEER SCORESHEET

AHA/BJCP Sanctioned Competition Program

Structured Version

Competition ______ Location ______ Date ______

Judge Name ______
BJCP ID & Rank ______
Email ______

Category# ______ Sub (a-f) ______ Entry # ______
Subcategory (Spell out) ______
Special Ingredients ______

Position in flight ______
Advanced to MINI-BOS
PLACE

FINAL SCORE

The judge team has reviewed their individual scores and have agreed to this final score

Non-BJCP Qualifications

Cicerone Level ______
Pro Where? ______
Industry Describe ______
Judging Years ______

Example:

Flavor (None L M H, Inappropriate)

Malt — Bready w/ subtle toasty notes
Hops — Floral, earthy
Bitterness — Too low for style

When evaluating specialty-type beers, use the "other" line to comment on characteristics unique to the specialty-type beer, such as fruit, spice, acidity, etc.

Common Descriptors

Grainy Cracker Biscuit Bready Toasty
Nutty Caramel Honey Toffee
Chocolate Molasses Vanilla Coffee
Spicy Floral Herbal Earthy
Citrus Pine Resiny Woody Minty
Stonefruit Berry Melon Tropical
Raisin Prune Date Fig Cherry
Banana Berry Bubblegum Orange
Apple Pear Peach Apricot Lemon
Pepper Clove Cinnamon Coriander
Barnyard Horse blanket Leather Goaty
Butter Latex paint Corn Unripe apple
Cardboard Sherry Skunky Baby diaper
Medicinal Smoke Solvent Metallic

Flaws for style (mark L-M-H for all that apply)

Acetaldehyde		Metallic	
Alcoholic / Hot		Musty	
Astringent		Oxidized	
Brettanomyces		Plastic	
Diacetyl		Solvent / Fusel	
DMS		Sour / Acidic	
Estery		Smoky	
Grassy		Spicy	
Light-Struck		Sulfur	
Medicinal		Vegetal	

Scoring Guide		
Outstanding	45-50	World-class example of style
Excellent	38-44	Exemplifies style well, requires minor fine-tuning
Very Good	30-37	Generally within style parameters, minor flaws
Good	21-29	Misses the mark on style and/or moderate flaws
Fair	14-20	Off flavors/aromas or major style deficiencies
Problematic	0-13	Major off flavors and aromas dominate

Bottle Inspection ☐ ok ______

Aroma (None L M H, Inappropriate) /12

Malt ______
Hops ______
Fermentation Character ______
Other ______

Appearance (Inappropriate) /3

Color: Yellow Gold Amber Copper Brown Black — Other ______
Clarity: Brilliant Hazy Opaque
Other: Legs Lacing Particulate
Head — Size: None Small Med Large
Retention: Quick Lasting
Color: White Ivory Beige Tan

Flavor (None L M H, Inappropriate) /20

Malt ______
Hops ______
Bitterness ______
Fermentation Character ______
Balance: Hoppy — Malty ______
Finish/Aftertaste: Dry — Sweet ______
Other ______

Mouthfeel (Inappropriate) /5

Body: Thin M Full
Carbonation: None L M H
Warmth
Creaminess: None L M H
Astringency
Other ______

Overall /10

Classic Example — Not to Style
Flawless — Significant Flaws
Wonderful — Lifeless

Feedback: Provide comments on style, recipe, process, and drinking pleasure. Include helpful suggestions to the brewer.

______

Judge Score /50

Additional resources can be found at these sites: https://www.bjcp.org http://www.homebrewersassociation.org

Chapter 6

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