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# Absinthe: how history influences scientific inquiry

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## Abstract

**Why was the work done:** Absinthe is a spirit (45-74% alcohol by volume) flavoured with botanicals such as wormwood, anise, and fennel seed. It has a distinctly bitter taste and an emerald, green colour. It was first produced in Switzerland during the 1700s, becoming the most popular spirit throughout Europe over the next hundred years. Around the beginning of the 20th century, many European countries and the United States banned absinthe citing concerns over health and safety. As a result of this, there is a paucity of scientific research on absinthe compared to other spirits. This review was conducted to consolidate and evaluate the literature on absinthe together with its history, production, toxicology, and authenticity, and to identify critical gaps in current knowledge.

**What are the main findings:** The review considers the historical and cultural significance of absinthe together with production practices and the principal compounds that contribute to its distinctive flavour. Acknowledgement is given to the perception of absinthe as a hallucinogenic or toxic spirit, alongside the origins of these claims in toxicological research. There is focus on the anecdotally psychoactive ketone thujone, from the perspective of its toxicity in animal studies, concentration in wormwood and absinthe. These insights suggest that both historic and currently produced absinthe contain thujone at levels far below the threshold for acute toxicity. The characteristic phenomenon of absinthe becoming cloudy when water is added (the 'louche effect') is considered based on current understanding. Additionally, the review evaluates contemporary techniques for assessing the authenticity of absinthe, reflecting its history of adulteration by producers.

**Why is the work important:** With the resurgence in popularity following re-legalisation of absinthe in Europe (1988) and the United States (2007), there is renewed interest in understanding this iconic spirit. This review challenges long standing misconceptions about the dangers of absinthe and identifies gaps in current knowledge, suggesting future research that may inform both production practices and regulatory standards. More broadly, it contributes to our understanding of how historical bias can shape scientific inquiry, and highlights absinthe as a case study in the intersection between cultural myth and modern analytical science.

## Keywords

Absinthe, wormwood, grand wormwood, *Artemisia absinthium*, *Artemisia pontica*, thujone, ouzo effect, louche effect

## Early history

Wormwood has been used with other herbs to create bitter medicinal concoctions since antiquity. Predating Pliny the Elder's mention of 'absinthites' by more than a millennium, the *Papyrus Ebers* (circa 1500 BCE) describes the use of wormwood as an ingredient in drinks, potions, poultices, and suppositories for a variety of complaints (Bryan 1930; Adams 2004). Wormwood has a long history of curative and ceremonial uses, appearing in ancient Mesopotamian texts (Sasson 1995), the Torah (Deuteronomy 29:17), and the Bible (Proverbs 5:4; Jeremiah 9:15; Revelation 8:11). Indeed, the name, 'wormwood,' comes from the herb being used to prevent and treat stomach parasites (Conrad 1988; Sasson 1995). The grand wormwood (*Artemisia absinthium*) is a perennial herb of the Asteraceae family and the primary component of absinthe. It is a knee high, shrub like plant with dense hair-covered, greenish silver leaves along ribbed stems that branch in a spiral arrangement. The leaves vary by position with the basal leaves appearing as long and triangular or ovoid with up to three deep clefts (pinnations) and long petioles, while the upper leaves are simple lance shaped leaves. The flowers of the plant form clusters of small, yellow, disc shaped flower heads arranged in loose panicles. Each panicle has female flowers surrounding a central, tube shaped, hermaphroditic flower. From late summer to early autumn, the flowers develop into small achene that are striped and brown (Figure 1; Lachenmeier et al. 2006a; Szopa et al. 2020; North Carolina State Extension 2025).

The drink absinthe originated when wormwood and other herbs were mixed or distilled with alcohol. The word 'absinthe' may originate from the Greek word *apsinthion*, which either refers to wormwood itself or means 'undrinkable' because of its intense bitterness (Conrad 1988). Dr. Pierre Ordinaire and Henriette Henriod are credited with its invention in Switzerland during the late 1700s, with the first absinthe distillery founded in 1805 by Henry-Louis Pernod in Pontarlier, France (Conrad 1988; Baker 2001; Adams 2004; Nathan-Maister 2009). By 1905, the Doubs Valley around Pontarlier, was home to nearly 10,000 people with around a third earning their living cultivating and producing materials for

**Figure 1.**

**Flowers, leaves, and seeds of wormwood (*Artemisia absinthium*).** (Public domain monograph - Wikimedia Commons).

absinthe production, while over 500 were employed by distilleries (Conrad 1988; Nathan-Maister 2009). Throughout the next century, absinthe would become the most popular spirit in Europe, with over 36 million litres being produced in 1910 before being banned and relegated to relative obscurity (Conrad 1988; Adams 2004).

## The rise of absinthe

At the beginning, absinthe was the preferred drink of the elite and idle rich, becoming fashionable for those in lower society. The explosion in popularity began in the 1850's, when cafes and cabarets were places for men to drink the time away. This became so commonplace, that along the boulevards and promenades of Paris, 'five o'clock' was referred to as *'l'heure verte'* (the green hour) (Conrad 1988; Baker 2001; Adams 2004; Nathan-Maister 2009). Absinthe, with its alluring green colour, became the centrepiece of these social gatherings. While driven by the rich, soldiers returning home from the colonies contributed the popularity. As, when stationed abroad, soldiers were given absinthe rations as a treatment for various diseases and they returned to Europe with a fondness for the drink (Conrad 1988; Baker 2001; Adams 2004; Nathan-Maister 2009).

At the same time, outbreaks of phylloxera (insect pest) were causing major losses of grape vines throughout the wine producing areas of Europe (Ordish 1972; Campbell 2004). Consequently, the price of wine increased dramatically while the cost of grain and sugar beet spirits became cheaper due to increases in global trade. By the 1870's, a good wage in France was three francs a day with a bottle of wine costing one franc (100 centimes), a loaf of bread 50 centimes but only 15 centimes for a glass of absinthe (Conrad 1988; Baker 2001, Adams 2004). Further, the industrialisation of France saw large swaths of the population moving to Paris in search of employment in the factories. This resulted in a influx of homeless people with absinthe accessibly priced for peasants and the poor (Huisman et al. 2007). The cafes and cabarets that catered to the rich became social spaces for the working class and absinthe consumption became ordinary. Absinthe became more than just a way to pass time and became woven into social customs and elaborate drinking rituals that heightened its glamour. Accordingly, as the 20th century approached, absinthe was increasingly associated with working class alcoholism and a general decline in society, particularly in France (Conrad 1988; Baker 2001).

Absinthe's appeal was more than being cheap and available. The ceremony with which absinthe was prepared and drunk was unlike any other spirits, and enhanced the mystique of the drink (Nathan-Maister 2009). This fascination persists even among contemporary consumers. The ritual starts by placing a dose of absinthe into a glass over which a flat, perforated spoon is balanced. A sugar cube is placed on top of the spoon and iced water is slowly dripped over the sugar (Figure 2). As the sugar dissolves and mixes with the water, it drips into the absinthe and dilutes it. During dilution, high quality absinthe becomes opalescent, and cloudy white by a phenomenon known as the 'louche' (Nathan-Maister 2009). It is important to add the water gradually, as part of the sensory experience was to savour the release of aromas as essential oils precipitate out at different alcohol concentrations (Nathan-Maister 2009). Ice was never added to absinthe directly. It was customary to start with the chilled drink and allow it to warm up as it was consumed to further appreciate the complexity.

Typically, the proportions were 30 mL of absinthe with about 100 mL of water and a single sugar cube, although this ratio was not strictly prescribed (Nathan-Maister 2009). Additionally, while the sugar softens and improves the flavour, it was not always necessary, and absinthe could be ordered *sans sucre* ('without sugar'). It is unclear when it became commonplace to add sugar and water to

**Figure 2.**

**Left: *The Drinkers* (1908) by Jean Béraud depicts a man pouring water into his absinthe.** (Public domain - Wikimedia Commons).

**Right: An perforated spoon and sugar cube placed on an absinthe glass.** (Wikimedia Commons - Creative Commons licence).

absinthe, but by the 1850's the absinthe ritual had taken form. Although art depicting the iconic perforated absinthe spoon did not appear until the 1880's, it was nonetheless often depicted with a cordial spoon or swizzle stick used for mixing sugar and water (Nathan-Maister 2009).

Absinthe was the favourite beverage of artists and writers during this period. Painters such as Henri de Toulouse-Lautrec, Edouard Manet, Edgar Degas, and even Pablo Picaso (who was not known for drinking) were inspired by the allure of absinthe (Figure 3; Conrad 1988). Famously, Vincent van Gogh was said to be addicted to absinthe during the last years of his life while suffering from various psychotic breaks, hallucinations, and self-mutilation (Arnold 1992). French writers and poets including Charles Baudelaire, Alfred de Musset, and Paul Marie Verlaine were known for popularising absinthe (Conrad,1988; Baker 2001; Adams 2004). Indeed, Barnaby Conrad wrote about Théodore Pelloquet:

*'Then there was the poet Théodore Pelloquet who never found consistent work as satisfying as the pleasure of conversation and absinthe at a cafe called Dinochau's. His habits took him to the edge of insanity. It is said that as he lay dying in Nice, he struggled to say some word but could only utter the first syllable: 'abs… abs…' Those around him thought he was asking for absolution until he finally wheezed: 'absinthe.'*

Absinthe was also popular among American writers, including Ernest Hemingway and Edgar Allen Poe, as well as the Irish author Oscar Wilde (Conrad 1988; Baker 2001; Adams 2004; Nathan-Maister 2009). These affiliations contributed to the portrayal of absinthe as an emblem of the bohemian lifestyle and perception of an inspirational muse.

The reputation of this emerald, green spirit was further enhanced by rumours of its hallucinogenic effects. However, with industrialisation of commodities came a change in attitude towards intoxicants during the second half of the 1800s in Western Europe and North America. Laudanum was a popular narcotic used recreationally by people throughout much of Europe (Berridge and Edwards 1981; Hodgson 2001). Hashish was promoted by doctors for various medical ailments (Grinspoon and Bakalar 1993; Booth 2004) and opium was both legally and illegally trafficked to the United States from China (Courtwright 2001). Further, pure plant extracts such as cocaine and morphine were rapidly becoming more commonplace (Hodgson 2001; Jay 2010).

Alcoholism was also becoming a pandemic in several Western countries (Levine 1978; Prestwich 1994; Saxton 2015). Absinthe was said to elicit a euphoric reverie and functioned as an aphrodisiac. It was also known for causing overexcitement, frenzied imaginings, and anxious delusions in people who abused absinthe regularly. Claiming to have


**Figure 3.**

A: ***Monsieur Boileau au Café*** **(1864) by Henri de Toulouse-Lautrec.**
B: ***Cafétafel met Absint*** **(1887) by Vincent van Gogh.**
C: ***The Absinthe Drinker*** **(1859) by Édouard Manet.**
D: ***Dans un Café*** **(1875-1876) by Edgar Degas.**
E: ***Femme au Café*** **(1901-1902) by Pablo Picasso.** (Public domain - Wikimedia Commons).

quoted Oscar Wilde, John Fothergill in his memoir *My Three Inns* described the effects of drinking absinthe as *'The first stage is like ordinary drinking, the second when you begin to see monstrous and cruel things, but if you can persevere you will enter in upon the third stage where you will see things that you want to see, wonderful curious things'* (Fothergill 1951; Conrad 1988). With this growing reputation, it did not take long for physicians, journalists, and politicians to take note of the reports of the effects and abuse of absinthe.

## The fall of absinthe

One of the first examples of a psychiatric observation of an absinthe drinker was conducted by Dr. Auguste Alexandre Motet. In 1859, Motet published his thesis titled *Considérations générales sur l'alcoolisme, et plus particulièrement des effets toxiques produits sur l'homme par la liqueur d'absinthe* ('General considerations on alcoholism and more specifically of the toxic effects produced in man by the liquor absinthe'). Here, he hypothesised that absinthe affected drinkers differently than other alcoholic beverages. He describes a man - under observation for his alcoholic behaviour - beset by strange delusions and hyperactive psychosis after ingesting substantial amounts of alcohol, including absinthe. He was treated for nightmares, general confusion, and fever over the first week of his stay, symptoms that reflect those of detoxification for alcoholics today. After two weeks in hospital, the patient was deemed cured of his insanity, and like many alcoholics at the time, was told to abstain from spirits and only drink wine (Motet 1859; Prestwich 1994).

Following this, others began to study the effects of absinthe. Grand wormwood - the principal ingredient - was found to contain a potentially toxic monoterpene termed thujone (thought to be an isomer of camphone at the time). Some physicians blamed the plant for the deleterious effects of absinthe, with Dr. Valentin Magnan publishing several studies demonstrating the poisonous effects of wormwood extracts on animals (Magnan 1864; Magnan 1874). Based on this, Magnan coined the term *absinthism* as a separate condition from alcoholism. Absinthism was attributed to drinking absinthe with symptoms that were vague and broadly described. Some indications of the syndrome were madness, idiocy, seizures, paralysis, hallucinations, numbness, vertigo, stressful delusions, erratic behaviour, and hair loss (Amory 1868; Conrad 1988; Adams 2004; Saxton 2015). The validity of this condition was debated at the time and there were significant criticisms of the conclusions that Magnan and others made about the poisonous nature of absinthe. Despite this, the damage to the reputation of absinthe was considerable and by the early 1900s absinthism was an explanation for the 'degeneration of the French race' (Saxton 2015; Eling and Vein 2018).

By the end of the 1800s, temperance movements calling for the prohibition on alcoholic beverages were appearing in Europe and the United States (Prestwich 1979; Adams 2004; Schrad 2021). Efforts by these groups and media organisations caused absinthe to become sensationalised by its detractors becoming a symbol of debauchery. The upper echelons of society blamed the influx of vagrancy on absinthe, with the middle-class viewing absinthe as a path to homelessness. It was not long before crime and violence were attributed to absinthe, together with the general decline of society (Conrad 1988; Adams 2004). Further demonisation by the wine industry - who were suffering lost sales to the spirit - caused an environment in Europe where conservative groups, temperance movements, and politicians were proposing to ban the beverage.

This came to a head in 1905, when in Switzerland Jean Lanfray consumed two glasses of absinthe before murdering his pregnant wife and two young daughters before botching his own suicide; a mistake that was rectified after being convicted of murder. Despite Lanfray being an alcoholic, and consuming daily at least a litre of wine, as well as brandy, cognac, liqueurs, and other spirits, absinthe alone was linked by the media for the crime (Conrad 1988; Baker 2001; Adams 2004; Saxton 2015). Following this and other incidents, European countries instituted bans on the production of absinthe, beginning with Belgium in 1905 (Figure 4) and Switzerland in 1908 (Conrad 1988; Adams 2004). Citing health concerns, various other European nations followed suit with their own bans of absinthe. In 1912, wormwood was banned from all food substances in the United States with Dr. Harvey Wiley - the first Commissioner of Food and Drugs - saying that absinthe was 'one of the worst enemies of man and if we can keep the people of the US from becoming slaves to this demon, we will do it' (Conrad 1988; High and Coppin 1988). France, the heart of absinthe culture, banned the spirit in 1915 after it was blamed for the unpreparedness of soldiers in World War I (Conrad 1988; Baker 2001; Adams 2004). Although Germany was the last European nation to enforce a ban in 1923 (Conrad 1988; Lachenmeier et al. 2006a), some countries (Spain and the Czech Republic) chose not to prohibit absinthe and, whilst not particularly popular, continued to produce the spirit in the 20th century (Conrad 1988).

This overemphasised moral panic and social scapegoating surrounding absinthe was not unprecedented. Between 1720 and 1760, Great Britain experienced the 'Gin Craze,' where cheap and unregulated gin consumption was blamed for a rise in crime, poverty, and social decay in London (Warner 2002). The engraving *Gin Lane* by William Hogarth reflected the public's fears surrounding gin-induced degeneracy. Similarly, in 1920's America, temperance reformers popularised the phrase 'demon rum' to personify the corrupting influence of alcohol, portraying liquor as a direct threat to morality, family, and nation (Rorabaugh 1981). Absinthe, like gin and rum, became a symbolic target for anxieties about addiction, class struggles, and social order. These anxieties were stoked by sensationalist media, business and religious opportunism, and political manoeuvring. The rhetoric followed a well worn path of demonising specific substances as the catalyst for broader social collapse.

## Modern day

The process of legalisation of absinthe in Europe began with a report (Codex 1979) on food flavouring additives with subsequently the General Requirements for Natural Flavourings (Codex 1985) defining the use of naturally occurring bioactive compounds including thujone in foods. A European Union Council Directive (EEC 1988) then legalised foods with thujone in the EU but with strict limits. These were later amended (EC 2008) with defined thujone levels: 0.5 mg/kg in non-alcoholic beverages produced with *Artemisia* species, 10 mg/kg in alcoholic beverages not produced from *Artemisia* species, and 35 mg/kg in alcoholic beverages from *Artemisia* species. However, the use of thujone from wormwood is entirely forbidden in food preparations. In the US, the presence of thujone in food and beverages has yet to be adopted by the Food and Drug Administration (FDA), but an amendment to the regulations allows 'thujone free' as defined by the Official Methods of Analysis of the Association of Official Analytical Chemists (AOAC


## Figure 4.

**Left: *Alcool! Voilà l'Ennemi* (1910) by Frédéric Christol.** This poster was made in support of temperance movements and claims that absinthe is poisonous, and spirits are more harmful than war and plague. Wine and beer are not mentioned!

**Right: *La Fin de la 'Fée Verte'* (1910) by Albert Gantner.** A poster depicting a caricature of the Blue Cross member holding a bible and standing triumphantly over the corpse of a green woman. (Public domain - Wikimedia Commons).

1980). This method has a limit of detection of 10 mg/L (AOAC 1980; FDA 2004), allowing the production of absinthe containing less than 10 mg/L thujone (FDA 2024).

The global market for absinthe has increased from $34.25 billion in 2022 to $35.12 billion in 2023 (ReportLinker 2023). Such growth is anticipated to continue with a compound annual growth rate of 3.6%, with a global value greater than $47 billion by 2030. Although in popular culture absinthe has a reputation as a hallucinogenic drug albeit without any credible evidence for this. Indeed, the reputation of absinthe has improved, with it considered as an artisanal and luxury product.

## Absinthe production

The production of absinthe has some notable peculiarities that differentiate it from other spirits, including those derived from botanicals (Figure 5). In the first step, dried herbs and botanicals are macerated by immersing them in spirit (65-80% alcohol by volume/ABV). In its early days, absinthe was made from grape spirit, but this declined with the phylloxera outbreak in the 1850s. Today, it is common is to use rectified, neutral spirit made from grains or beets. Immersion lasts from several hours to days, during which essential oils and other flavour compounds are extracted and infused into the

### Figure 5.

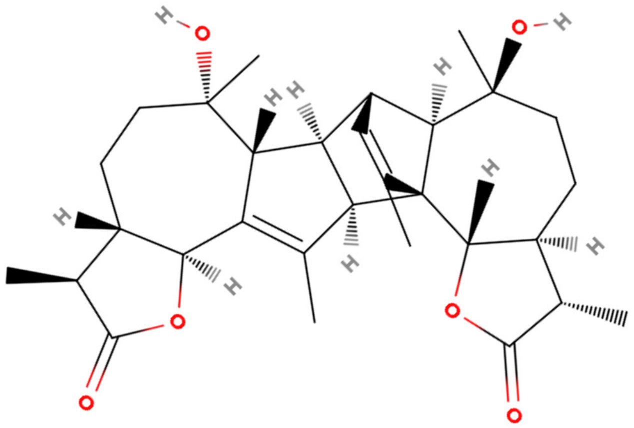
**The production steps of distilled spirits.**


spirit (Duplais 1871; Brévans 1890; Fritsch 1926; Nathan-Maister 2009). Prior to distillation, the spirit becomes a greenish-brown in colour and highly aromatic with an intense bitter taste. The key botanicals include grand wormwood, green anise (*Pimpinella anisum*), and fennel seed (*Foeniculum vulgare*) and the macerate may be filtered before distillation, although many producers choose not to (Duplais 1871; Brévans 1890; Fritsch 1926; Nathan-Maister 2009). The infused macerate is diluted to 30-60% ABV before distillation to facilitate the separation of volatile oils and improve the efficiency of distillation. Only the 'heart' of the distillation is retained while the 'heads' (containing volatile impurities such as low boiling aldehydes and esters) and 'tails' (higher alcohols/fusel oils) are discarded or recycled in subsequent distillations. This approach captures the volatile aromatic compounds in the spirit while leaving behind the heavier, bitter substances. The result is a clear, sweet tasting spirit with pronounced notes of anise and herbal complexity. Distillation was historically performed using copper alembic stills; a practice that continues among traditional producers.

On its own, grand wormwood, has an intensely bitter taste reflecting the dimeric sesquiterpene lactone absinthin (Figure 6) and its derivatives (Beauhaire et al. 1980; Yashiso et al. 2004; Turak et al. 2014). Absinthin is likely the most bitter compound in absinthe and is associated with *A. absinthium* but may be found in other species in the *Artemisia* genus (Lachenmeier 2007; Talmon et al. 2019; Ekiert et al. 2022). However, in distilled absinthe, absinthin is present in trace amounts as it is not volatile enough to carry over during distillation (Lachenmeier 2007). Despite its low concentration, it is highly flavour active with recognition thresholds between $10^{-9}$ and $10^{-6}$ M (Roudnitzky et al. 2015). Other chemical compounds also contribute woody or earthy flavours such as α- and β-thujone, p-cymene, α-pinene, and caryophyllene oxide (Judžentienė 2016). The chemical composition of wormwood exhibits variability depending on processing method, growing conditions, and harvesting period (Nguyen et al. 2018a). For instance, drying even slightly above room temperature may reduce wormwood quality and harvesting before or after flowering alters the content of thujone (Tateo and Riva 1991; Nguyen et al. 2019). Despite this, drying

## Figure 6.

**Structure of the triterpene absinthin.**




and storage does not appear to affect the absinthin content (Schneider and Mielke 1979).

The bitterness of wormwood must be offset by the addition of other botanicals to make a more palatable spirit. These include green anise which has a sweet flavour and a liquorice like quality. This is due to essential oil containing 75-90% (w/w) *trans*-anethole (Shojaii and Abdollahi Ford 2012; Sun et al 2019), which is up to 13 times sweeter than sucrose, with an herbaceous flavour and a spicy, fruit and liquorice aroma (Ashurst 1999; Marinov and Valcheva-Kuzmanova 2015). Fennel seed essential oil also has a relatively high concentration of *trans*-anethole (30-80%, w/w) and estragole (3-10%, w/w) (Diao et al 2014; Alam et al. 2019; Ben Abdesslem et al. 2021). Fennel also contains the monoterpenes fenchone (5-25%, w/w), and limonene (5-10%, w/w). Fenchone has a camphor aroma and bitter, earthy flavour with limonene contributing characteristic citrus aroma and flavour (Diao et al 2014; Alam et al. 2019; Ben Abdesslem et al. 2021). Together, wormwood, green anise, and fennel seed give absinthe a complex, sweet taste with bitter earthy and wood flavours. Other botanicals associated with absinthe include liquorice root, star anise seed, coriander seed, juniper berries, angelica root, veronica, melissa, and mint (Duplais 1871; Brévans 1890; Fritsch 1926; Nathan-Maister 2009).

After distillation, the characteristic green colour of absinthe is achieved through a secondary maceration. This involves infusing the clear distillate with additional botanicals, such as petite wormwood (*Artemisia pontica*, also known as small or Roman wormwood), hyssop (*Hyssopus officinalis*), and lemon balm (*Melissa officinalis*). These botanicals enhance the flavour with subtle bitterness and herbal notes while contributing chlorophyll, giving the spirit its signature colour (Duplais 1871; Brévans 1890; Fritsch 1926; Nathan-Maister 2009). However, chlorophyll is sensitive to environmental factors, including light, heat, and oxygen, which results in its degradation over time (Kephart 1955). When exposed to light, chlorophyll undergoes photodegradation, breaking down into pheophytins and other compounds that cause the green colour to fade into brownish or yellowish tones (Schwartz and Von Elbe 1983; Canjura et al. 1991). This process, accelerated by improper storage conditions, is why absinthe is often stored in opaque bottles or kept in dark environments. The chemical stability of chlorophyll can also be affected by the alcohol content of the spirit as the high ethanol level in absinthe offers some preservative effects, preventing the gradual loss of chlorophyll. In the past, 'alum' (potassium aluminium sulphate) may have been used to preserve the colour of absinthe, but this is attributed to just one source (Duplais 1871).

The secondary maceration/extraction step typically only lasts a few hours, as any longer can cause the spirit to become excessively bitter and unpalatable. After this process, the spirit is diluted to the desired strength, usually within a range of 45-75% ABV, for bottling (Duplais 1871; Brévans 1890; Fritsch 1926; Nathan-Maister 2009). While traditional absinthe is green, some modern producers have experimented with other natural colourings, including hibiscus for red absinthe and butterfly pea flower for blue absinthe. White absinthe or 'Blanche' or 'La Bleue,' skip the colouring step and rely on a broader botanical selection to create complexity in the flavour (Duplais 1871; Brévans 1890; Fritsch 1926; Nathan-Maister 2009). Some traditional absinthe recipes adapted from Duplais and Mckenna (1871) and Fritsch (1926) are outlined in Table 1.

Other absinthes can be flavoured and coloured artificially with plant extracts, artificial flavours, and dyes mixed with alcohol (Duplais 1871; Brévans 1890; Fritsch 1926; Nathan-Maister 2009). These are usually regarded as inferior products compared with artisanal absinthes.

## Table 1.

### Historic absinthe recipes

| Recipe name and yield | Flavouring ingredient | Quantity (kg) | Colouring ingredient | Quantity (kg) | Special instructions |
|---|---|---|---|---|---|
| Absinthe of Pontarlier* | Green anise | 5.00 | Petite wormwood | 1.00 | None |
| | Fennel | 5.00 | Hyssop | 1.00 | |
| 100 L at 74% ABV | Grand wormwood | 2.50 | Lemon balm | 0.50 | |
| Absinthe of Montpellier* | Green anise | 6.00 | Petite wormwood | 1.00 | None |
| | Fennel | 4.00 | Hyssop | 0.75 | |
| | Grand wormwood | 2.50 | Lemon balm | 0.75 | |
| | Coriander | 1.00 | | | |
| 100 L at 74% ABV | Angelica seed | 0.50 | | | |
| Absinthe of Lyons* | Green anise | 8.00 | Petite absinthe | 1.00 | None |
| | Fennel | 4.00 | Lemon balm | 1.00 | |
| | Grand wormwood | 3.00 | Hyssop | 0.50 | |
| 100 L at 74% ABV | Angelica root | 0.50 | Veronica | 0.50 | |
| Absinthe of Fougerolles* | Green anise | 7.50 | Lemon balm | 0.75 | None |
| | Fennel | 4.20 | Petite wormwood | 0.67 | |
| | Grand wormwood | 2.67 | Veronica | 0.70 | |
| 100 L at 74% ABV | | | Hyssop | 0.58 | |
| Absinthe of Besancon* | Fennel | 6.70 | Petite wormwood | 1.00 | None |
| | Green anise | 5.00 | Hyssop | 0.92 | |
| | Grand wormwood | 4.00 | Lemon balm | 0.50 | |
| 100 L at 74% ABV | Coriander | 0.70 | | | |
| Absinthe of Nimes* | Grand wormwood | 3.75 | Petite wormwood | 0.83 | None |
| | Green anise | 3.75 | Hyssop | 0.75 | |
| | Fennel | 2.50 | Veronica | 0.42 | |
| | Coriander | 0.42 | Mint | 0.42 | |
| | Black alder root | 0.25 | Lemon balm | 0.25 | |
| 100 L at 74% ABV | Angelica root | 0.25 | | | |
| White absinthe (Blanche)* | Green anise | 5.25 | | | No colour step |
| | Fennel | 5.25 | | | |
| | Grand wormwood | 2.75 | | | |
| | Petite wormwood | 1.13 | | | |
| | Hyssop | 1.10 | | | |
| | Coriander | 1.00 | | | |
| | Veronica | 0.55 | | | |
| | Genepi | 0.55 | | | |
| | Angelica seed | 0.55 | | | |
| 100 L at 74% ABV | Chamomile | 0.23 | | | |
| Absinthe Ordinaire** | Grand wormwood | 5.00 | Lemon balm | 0.80 | After colouring add: |
| | Fennel | 3.00 | Peppermint | 0.80 | 0.01 kg star anise extract |
| | Green anise | 3.00 | Petite wormwood | 0.60 | |
| | Angelica root | 0.40 | Hyssop | 0.60 | |
| 100 L at 60% ABV | | | Liquorice root | 0.03 | |
| Absinthe Fine** | Grand wormwood | 3.50 | Lemon balm | 0.80 | After colouring add: |
| | Green anise | 3.50 | Hyssop | 0.60 | 0.05 kg star anise extract |
| | Fennel | 3.50 | Petite wormwood | 0.50 | 0.03 kg guaiac oil |
| 100 L at 72% ABV | Star anise | 0.01 | | | 0.02 kg liquorice extract |
| Absinthe Extra-Fine** | Grand wormwood | 3.75 | Petite wormwood | 0.88 | After colouring add: |
| | Green anise | 3.00 | Hyssop | 0.88 | 0.04 kg star anise extract |
| | Fennel | 3.00 | Lemon balm | 0.88 | 0.04 kg green anise extract |
| | Star anise | 0.50 | Mint | 0.10 | |
| | Caraway | 0.13 | | | |
| 100 L at 72% ABV | Angelica root | 0.06 | | | |

*adapted from Duplais (1871), ** adapted from Fritsch (1926)

Additionally, some products are made from the spirit used to macerate botanicals which is filtered but not distilled. These 'Bohemian' recipes have a strong wormwood flavour and may have an unpleasant bitterness (Lachenmeier et al. 2006a).

Absinthe production has historically varied by region, with each area developing its own unique character. French absinthe, known for its refined balance of botanicals, often includes coriander seeds, lending citrus and pepper notes. Swiss absinthe, particularly 'blanche' style from the Val-de-Travers region, is uncoloured with a complex, clean flavour profile. Further, Swiss absinthe is associated with recipes involving angelica root and caraway seed (Lachenmeier et al. 2006a). In contrast, Czech 'absinth' (without the 'e') diverges significantly from traditional methods, often omitting anise and fennel but including peppermint. These products are typically macerated but not distilled and lack the louche effect characteristic of French and Swiss absinthes. Despite this, Czech absinth has maintained a niche following.

While regional variations have played a significant role in shaping the character of absinthe, its artisanal origins have remained key. Traditional production combines historical ingredients with centuries old techniques, while modern innovations have evolved and deviated from original formulas. While many distillers adhere to historical recipes and practices, others use shortcuts, such as pre-made herbal extracts or artificial colours, which may compromise quality. These practices highlight the ongoing tension between maintaining authenticity and meeting the demands of a growing market. Additionally, contemporary producers face challenges related to regulatory compliance, particularly thujone limits, which vary by region. Despite these challenges, the revival of absinthe has spurred innovation, with producers exploring new botanicals and techniques to create unique expressions of the spirit. While these techniques preserve the complex flavours of absinthe, they also trigger discussion regarding the toxicity of wormwood.

## The birth of absinthism

Absinthe's reputation as a poisonous hallucinogen can be traced to the mid-19th century, during the height of its popularity (Motet 1859; Magnan 1864; Magnan 1874). Despite advancements in scientific understanding, misconceptions of the toxicity of this spirit have persisted in the modern era. As recently as 2022, *Web MD*, a platform for medical advice, had to address and refute myths related to absinthe, emphasising the confusion that has lingered for almost two centuries (Bishop 2022). A pivotal voice in the reputation of absinthe was Dr. Valentin Magnan, a prominent and influential psychiatrist who was among the first to recognise alcoholism as a disease and contributed greatly to the classifications of mental disorders (Luauté 2007; Eling and Vein 2018). Magnan was convinced that absinthe, particularly wormwood, had an effect beyond alcohol and was a cause of epileptic seizures (Eadie 2009). In attempting to prove this, he conducted experiments on animals - including

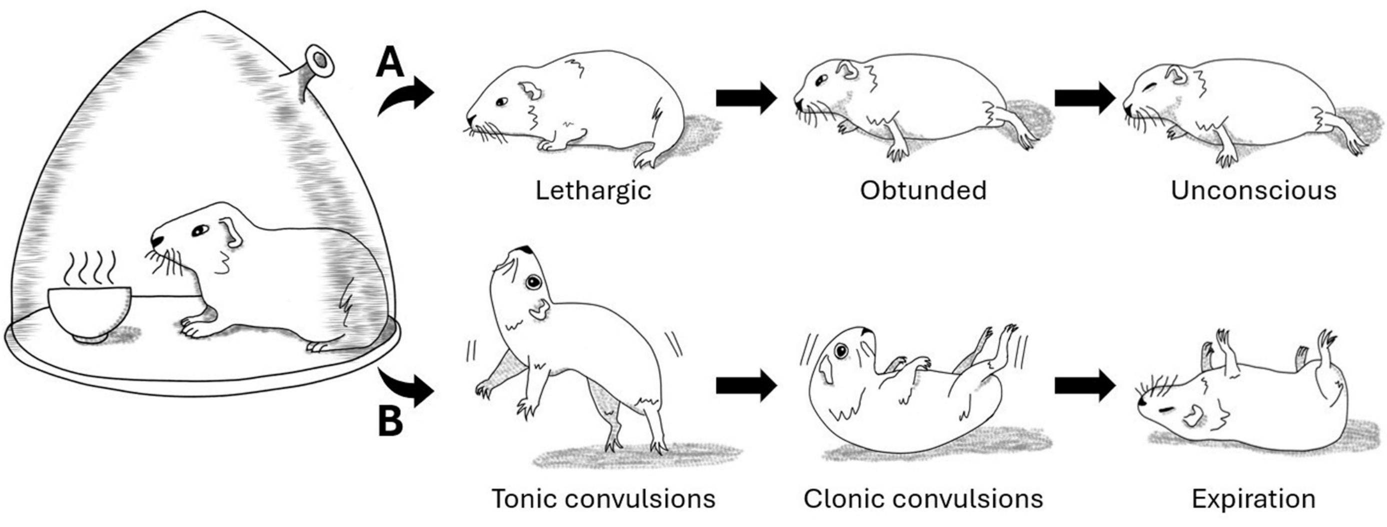
### Figure 7.

**Experimental approach used by Dr. Magnan and others in the late 19th century where animals were sealed in a glass jar with a dish of alcohol or wormwood oil.**

A: Guinea pigs exposed to alcohol vapours exhibited progressive intoxication, becoming lethargic, obtunded (dull pain), and then unconscious.

B: Guinea pigs exposed to wormwood essential oil vapours experienced tonic and clonic convulsions leading to death.

*Subsequent research questioned the validity of these experiments due to flawed methodology.*



guinea pigs, rabbits, birds, frogs, cats and dogs - to differentiate the effects of alcohol and wormwood oil (Figure 7). He described the effect of injections of wormwood oil as being like epileptic seizures where the animals would experience tonic seizures (sudden stiffness of muscles) that could evolve to clonic convulsions (repeated, rhythmic jerking or shaking movements) with increasing doses (Magnan 1874; Amory 1868; Huisman et al. 2007). Based on this, he concluded that absinthe was responsible for the growing population of alcoholics in France (Prestwich 1994; Padosch et al. 2006). While these experiments influenced the public perception of absinthe, they faced scrutiny for methodological flaws and for misinterpretation.

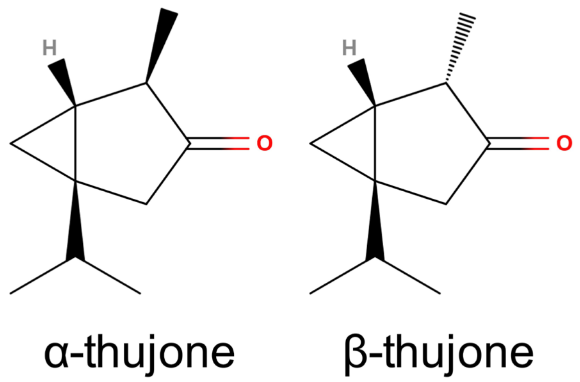
The primary criticism was the use of doses of wormwood oil that were markedly greater than an individual would ingest in drinking absinthe (Lancet 1869; Luauté 2007; Eadie 2009; Eling and Vein 2018). The medical journal *The Lancet* also noted the flawed comparison between the wormwood essence in absinthe and the purified oils used in experiments where guinea pigs were exposed to concentrated vapours under a glass cloche, leading to seizures and death (Figure 7; Lancet 1869; Padosch et al. 2006). Furthermore, many of the symptoms attributed to absinthe, such as sleepiness, hallucinations, paralysis, and tremors, were typical of alcoholism and alcohol withdrawal rather than wormwood itself (Lancet 1869). Attempts by other physicians to replicate Magnan's findings were unsuccessful. Further, semantic errors in translation may have contributed to the confusion (Ossipow 1914), as in French, 'absinthe' can refer to the plant, its essential oils, or the spirit, whereas other languages distinguish between the plant and spirit separately as 'wormwood' and 'absinthe' (Padosch et al. 2006; Lachenmeier et al. 2010). Although Magnan's conclusions were flawed, his work was an important step in our modern understanding of alcohol abuse and the toxicity of wormwood (Dowbiggin 1996). Central to the understanding of absinthe was the identification of thujone, a monoterpenoid compound in wormwood and a known convulsant (Semmler 1900; Lesieur 1906; Ossipow 1914; Chialva et al. 1983). Despite its presence in absinthe, contemporary research has debunked 'absinthism,' and the spirit has not been proven to be harmful other than from the effects of alcohol consumption.

## Wormwood and thujone

Thujone is a naturally occurring bicyclic monoterpene ketone found in plants within the *Asteraceae* family, of the Artemisia genus (Pelkonen et al. 2013). It has two stereoisomers, α-thujone and β-thujone, with four enantiomeric forms: (+)- or (-)-α-thujone and (+)- or (-)-β-thujone (Figure 8). The ratio of thujone isomers is variable between plant species and can even vary intraspecifically in samples grown in different regions, conditions, or climates (Gholami et al. 2005; Rezaeinodehi and Khangholi 2008; Judžentienė and Budiene 2010; Bailen et al. 2013; Nguyen and Németh 2016; Németh and Nguyen 2020). We have postulated in unpublished work that carbon-13 NMR may provide an opportunity to detect differences in vibrational circular dichroism (VCD) spectra, which could help to identify absolute structures of α- and β-thujone enantiomers in wormwood.

### Figure 8.

**Structures of the thujone isomers.**




In this review, unless otherwise specified, 'thujone' refers to the sum of all isomers. In both absinthe wormwood species (*Artemisia absinthium* and *Artemisia pontica*), thujone content fluctuates greatly. β-thujone is usually the dominant isomer representing around 80% of the volatile material with α-thujone accounting for up to 60% (Gholami et al. 2005; Nguyen et al. 2018a). However, wormwood has also been found with trace levels of the thujone isomers, and in some cases wormwood has been described as thujone free (Judžentienė and Budiene 2010, Nguyen et al. 2018a; Németh and Nguyen 2020). It has been suggested that harvesting wormwood at different phenological periods results in varying levels of thujone, specifically, decreasing

## Table 2a.

### Essential oil content, sample origin and α- and β-thujone content of *Artemisia absinthium*

| Sample | Plant part* | Essential oil (%, w/w) | | | α-thujone (% of oil) | | | β-thujone (% of oil) | | | Total thujone (% of oil) | | | N | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | min | max | mean | min | max | mean | min | max | mean | min | max | mean | | |
| **Africa** | | | | | | | | | | | | | | | |
| Algeria | AP dried and fresh | 0.29 | 0.43 | 0.36 | 0.00 | 0.13 | 0.07 | 0.00 | 18.23 | 9.11 | 0.00 | 18.36 | 9.18 | 2 | Benkhaled et al (2020); Benchohra et al (2023) |
| Egypt | AP fresh | 0.78 | 0.78 | 0.78 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1 | Aboutabl et al (1998) |
| Ethiopia | AP dried | n.d. | n.d. | n.d. | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1 | Nibret and Wink (2010) |
| Morocco | WP and AP dried | 0.57 | 2.00 | 1.29 | 39.69 | | | 7.25 | | | 32.20 | 46.94 | 39.57 | 2 | Derwich et al (2009); Alami et al (2024) |
| Tunisia | AP dried | 1.00 | 2.22 | 1.49 | 0.00 | 15.08 | 1.97 | 0.00 | 22.09 | 8.43 | 0.00 | 22.37 | 10.40 | 8 | Msaada et al (2015); Riahi et al (2015) |
| **Asia** | | | | | | | | | | | | | | | |
| Armenia | AP dried | 0.10 | 0.10 | 0.10 | 6.10 | 7.10 | 8.10 | 3.10 | 4.10 | 5.10 | 9.20 | 9.20 | 9.20 | 1 | Orval et al (2006) |
| Azerbaijan | AP dried and fresh | 0.56 | 0.70 | 0.62 | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | 6.45 | 7.98 | 7.35 | 6 | Suleymanova et al (2024) |
| India | WP and AP fresh | 0.16 | 0.30 | 0.23 | 0.00 | 1.00 | 2.00 | 0.00 | 1.00 | 2.00 | 0.00 | 0.00 | 0.00 | 2 | Joshi (2013); Wani et al (2014) |
| Iran | AP dried | 0.24 | 1.30 | 0.76 | 0.00 | 60.00 | 15.43 | 0.00 | 35.10 | 7.92 | 0.00 | 65.50 | 23.34 | 9 | Sefidkin et al (2003); Gholami et al (2005); Morteza-Semnani and Akbarzadeh (2005); Rezaeinodehi and Khangholi Houshmand et al (2024) |
| Saudi Arabia | AP fresh and dried | 0.83 | 0.93 | 0.88 | 0.00 | 0.00 | 0.00 | 0.00 | 1.41 | 0.47 | 0.00 | 1.41 | 0.47 | 3 | Aati et al (2020); Al-Ghamdi (2020); Mohammed (2022) |
| Tajikistan | AP dried | 0.50 | 0.80 | 0.65 | 0.50 | 2.90 | 1.43 | 0.40 | 7.30 | 3.30 | 0.90 | 10.20 | 4.73 | 3 | Sharopov et al (2011) |
| Türkiye | AP dried | 0.67 | 0.67 | 0.67 | 0.20 | 0.20 | 0.20 | 0.50 | 0.50 | 0.50 | 0.70 | 0.70 | 0.70 | 1 | Kordali et al (2005) |
| **Europe** | | | | | | | | | | | | | | | |
| Austria | AP dried | 0.11 | 0.67 | 0.28 | 0.00 | 0.94 | 0.16 | 0.00 | 34.92 | 3.78 | 0.00 | 35.86 | 3.94 | 10 | Nin et al (1995) |
| Belgium | AP dried | 0.61 | 1.86 | 1.25 | 1.20 | 26.45 | 20.29 | 3.50 | 66.80 | 50.44 | 7.30 | 92.20 | 68.89 | 9 | Orav et al (2006); Nguyen et al (2018)a, Nguyen et al (2019) |
| Croatia | AP dried | 0.39 | 1.45 | 0.95 | 0.00 | 2.50 | 0.87 | 14.00 | 48.60 | 28.72 | 14.00 | 51.10 | 29.59 | 10 | Juteau et al (2003) |
| England | AP dried | n.d. | n.d. | n.d. | 1.10 | 1.10 | 1.10 | 2.10 | 2.10 | 2.10 | 3.20 | 3.20 | 3.20 | 2 | Nguyen et al (2018)a |
| Estonia | AP dried | 0.40 | 1.10 | 0.72 | 1.10 | 3.40 | 2.22 | 0.10 | 64.60 | 14.48 | 2.40 | 67.00 | 16.70 | 5 | Orav et al (2006) |
| France | WP fresh; AP dried | 0.11 | 1.60 | 0.65 | 0.00 | 21.60 | 3.91 | 0.00 | 30.09 | 8.84 | 0.00 | 49.87 | 12.75 | 23 | Chialva et al (1983); Carnat et al (1992); Nin et al (1995); Juteau et al (2003); Orav et al (2006) |
| Germany | AP dried | 0.11 | 0.50 | 0.29 | 0.00 | 1.57 | 0.55 | 0.00 | 49.80 | 12.90 | 0.00 | 51.37 | 12.58 | 13 | Tegtmeier and Harnischfeger (1994); Nin et al (1995); Orav et al (2006); Nguyen et al (2018)a |

* AP = aerial parts, WP = whole plant, ** n.d. = no data provided

## Table 2b.

### Essential oil content, sample origin and α- and β-thujone content of *Artemisia absinthium*

| Sample | Plant part* | Essential oil (%, w/w) | | | α-thujone (% of oil) | | | β-thujone (% of oil) | | | Total thujone (% of oil) | | | N | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | min | max | mean | min | max | mean | min | max | mean | min | max | mean | | |
| Greece | AP dried | 0.30 | 0.30 | 0.30 | 4.50 | 4.50 | 4.50 | 38.70 | 38.70 | 38.70 | 43.20 | 43.20 | 43.20 | 1 | Orav et al (2006) |
| Hungary | AP dried | 0.30 | 0.30 | 0.30 | 0.00 | 4.20 | 1.00 | 0.00 | 77.00 | 13.98 | 0.00 | 78.80 | 14.98 | 11 | Orav et al (2006); Nguyen et al (2018a) |
| Italy | WP fresh; AP dried | 0.11 | 1.24 | 0.44 | 0.00 | 2.70 | 0.51 | 0.00 | 49.21 | 9.94 | 0.00 | 50.51 | 10.44 | 35 | Chialva et al (1983); Mucciarelli et al (1995); Nin et al (1995); Orav et al (2006) |
| Latvia | AP dried | 0.40 | 0.40 | 0.40 | 5.80 | 5.80 | 5.80 | 6.20 | 6.20 | 6.20 | 12.00 | 12.00 | 12.00 | 1 | Orval et al (2006) |
| Lithuania | WP and AP dried | 0.20 | 3.60 | 1.70 | 0.00 | 36.80 | 6.04 | 0.00 | 48.90 | 11.10 | 0.00 | 71.70 | 17.14 | 62 | Judžentienė and Mockutë (2004); Orav et al (2006); Judžentienė et al (2009); Judžentienė and Budiene (2010) |
| Moldova | AP dried | 0.20 | 1.20 | 2.20 | 3.00 | 3.00 | 3.00 | 0.40 | 0.40 | 0.40 | 3.40 | 3.40 | 3.40 | 1 | Orval et al (2006) |
| Norway | AP dried | n.d. | n.d. | n.d. | 19.65 | 19.65 | 19.65 | 13.15 | 13.15 | 13.15 | 33.15 | 33.15 | 33.15 | 2 | Nguyen et al (2018)a |
| Romania | WP dried | 0.25 | 0.25 | 0.25 | 0.63 | 0.63 | 0.63 | 14.76 | 14.76 | 14.76 | 15.39 | 15.39 | 15.39 | 1 | Chialva et al (1983) |
| Russia | AP dried | 0.30 | 0.30 | 0.30 | 1.90 | 20.80 | 11.35 | 1.70 | 13.70 | 7.70 | 3.60 | 34.50 | 19.00 | 2 | Khalilov et al (2001); Orav et al (2006) |
| Scotland | AP dried | 0.80 | 0.80 | 0.80 | 5.00 | 5.00 | 5.00 | 3.50 | 3.50 | 3.50 | 8.50 | 8.50 | 8.50 | 1 | Orval et al (2006) |
| Serbia | AP dried | 0.08 | 1.88 | 0.44 | 0.00 | 12.83 | 2.74 | 0.00 | 63.40 | 17.88 | 0.00 | 65.20 | 20.62 | 6 | Blagojevic et al (2006); Mihajilov-Krstev et al (2014); Janaćković et al (2019) |
| Siberia | AP dried | 0.30 | 1.20 | 0.75 | 0.12 | 9.37 | 4.75 | 0.58 | 7.57 | 4.01 | 0.70 | 16.94 | 8.82 | 2 | Chialva et al (1983) |
| Spain | AP fresh, dried, frozen | 0.10 | 0.60 | 0.36 | 0.00 | 10.90 | 0.82 | 0.00 | 40.20 | 1.82 | 0.00 | 50.60 | 2.75 | 37 | Ariño et al (1999a), Ariño et al (1999b), Orav et al (2006); Bailen et al (2013); Llorens-Molina and Vacas (2015); Nguyen et al (2018a) |
| Ukraine | AP dried | 0.40 | 0.40 | 0.40 | 5.40 | 5.40 | 5.40 | 6.30 | 6.30 | 6.30 | 11.70 | 11.70 | 11.70 | 1 | Orav et al (2006) |
| **North America** | | | | | | | | | | | | | | | |
| Canada | WP fresh; AP dried | 0.50 | 0.50 | 0.50 | 0.00 | 2.90 | 1.20 | 10.10 | 32.10 | 16.50 | 10.60 | 35.00 | 17.70 | 4 | Chiasson et al (2001); Lopes-Lutz et al (2008 |
| Cuba | AP dried | 1.25 | 1.25 | 1.25 | 0.00 | 0.00 | 0.00 | 0.29 | 0.29 | 0.29 | 0.29 | 0.29 | 0.29 | 1 | Pino et al (1997) |
| USA | AP dried | 0.12 | 0.55 | 0.23 | 0.00 | 3.42 | 0.62 | 0.00 | 69.68 | 10.48 | 0.00 | 70.63 | 11.09 | 11 | Tucker et al (1993); Nin et a (1995) |
| **South America** | | | | | | | | | | | | | | | |
| Argentina | n.d.** | n.d. | n.d. | n.d. | 2.34 | 2.34 | 2.34 | 59.90 | 59.90 | 59.90 | 62.24 | 62.24 | 62.24 | 1 | Sacco and Chialva (1988) |

* AP = aerial parts, WP = whole plant, ** n.d. = no data provided

## Table 3.

### Essential oil content, sample origin and α- and β-thujone content of Artemisia pontica

| Sample | Plant part* | Essential oil (%, w/w) | | | α-thujone (% of oil) | | | β-thujone (% of oil) | | | Total thujone (% of oil) | | | N | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | min | max | mean | min | max | mean | min | max | mean | min | max | mean | | |
| **Africa** | | | | | | | | | | | | | | | |
| Kenya | AP fresh | 2.00 | 2.00 | 2.00 | 33.18 | 33.18 | 33.18 | 9.74 | 9.74 | 9.74 | 42.92 | 42.92 | 42.92 | 1 | Kiplimo et al (2016) |
| Morocco | WP, AP dried | 0.31 | 2.00 | 1.16 | 22.13 | 22.13 | 22.13 | 2.56 | 2.56 | 2.56 | 24.69 | 29.30 | 26.99 | 2 | Derwich et al (2009); Alami et al (2024) |
| **Asia** | | | | | | | | | | | | | | | |
| Kazakhstan | AP dried | 0.20 | 1.20 | 2.20 | 23.20 | 23.20 | 23.20 | 2.70 | 2.70 | 2.70 | 25.90 | 25.90 | 25.90 | 1 | Talzhanov et al (2005) |
| Türkiye | AP dried | n.d.** | n.d.** | n.d.** | 22.30 | 22.30 | 22.30 | 7.30 | 7.30 | 7.30 | 29.60 | 29.60 | 29.60 | 1 | Tabanca et al (2011) |
| **Europe** | | | | | | | | | | | | | | | |
| Bulgaria | AP dried | 0.40 | 0.40 | 0.40 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1 | Bos et al (2005) |
| Italy | AP dried | 0.34 | 0.34 | 0.34 | 10.00 | 25.00 | 20.45 | 0.00 | 4.20 | 2.10 | 10.00 | 25.10 | 20.03 | 6 | Chialva and Liddle (1981); Nano et al (1966) |
| Lithuania | AP dried | 0.30 | 0.80 | 0.55 | 0.00 | 0.12 | 0.06 | 0.00 | | | 0.00 | 0.12 | 0.06 | 2 | Saunoriūtė et al (2020) |
| Serbia | AP dried | 0.20 | 0.85 | 0.35 | 0.00 | 20.10 | 1.70 | 0.00 | 6.80 | 3.60 | 0.00 | 22.10 | 5.30 | 15 | Radulović et al (2021); Khanina et al (2000) |
| Ukraine | n.d. | n.d. | n.d. | n.d. | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 | 2.00 | 0.00 | 0.00 | 0.00 | 1 | Panasenko et al (2021) |
| **Unspecified** | | | | | | | | | | | | | | | |
| n.d. | AP dried | 0.25 | 1.25 | 2.25 | 30.00 | 30.00 | 30.00 | n.d. | n.d. | n.d. | 30.00 | 30.00 | 30.00 | 1 | Hurabielle et al. (1977) |

* AP = aerial parts, WP = whole plant, ** n.d. = no data provided

## Table 4.

### Essential oil and thujone content of *Artemisia absinthium* and *Artemisia pontica*

***Artemisia absinthium*** (N=291)

| | % Essential oil (w/w) | α-thujone (% oil) | β-thujone (% oil) | Total thujone (% oil) |
|---|---|---|---|---|
| Min | 0.08 | 0.00 | 0.00 | 0.00 |
| Max | 3.60 | 60.00 | 77.00 | 92.20 |
| Mean | 0.76 | 3.90 | 11.25 | 14.75 |
| SD | 0.51 | 7.72 | 16.03 | 18.64 |
| Median | 0.50 | 0.60 | 3.87 | 7.97 |

***Artemisia pontica*** (N=31)

| | Essential oil % (w/w) | α-thujone (% of oil) | β-thujone (% of oil) | Total thujone (% of oil) |
|---|---|---|---|---|
| Min | 0.20 | 0.00 | 0.00 | 0.00 |
| Max | 2.00 | 33.18 | 9.74 | 42.92 |
| Mean | 0.66 | 13.84 | 2.52 | 17.01 |
| SD | 0.63 | 12.16 | 3.17 | 13.75 |
| Median | 0.33 | 20.10 | 1.00 | 23.40 |

after the flowering stage (Carnat et al. 1992; Nguyen et al. 2018b).

Building on the literature review of Lachenmeier and Nathan-Maister (2007), the composition of essential oils in *A. absinthium* (Table 2) and *A. pontica* (Table 3) are reported using data from 58 publications. The key statistics for both species are reported in Table 4, with the average essential oil content of *A. absinthium* at 0.76 ± 0.51% (w/w) of plant material, with thujone representing 14.8 ± 18.6% of the total essential oil. For *A. pontica*, the essential oil content is 0.66 ± 0.63% (w/w) of plant material, with thujone comprising 17.0 ± 13.8% of its essential oil.

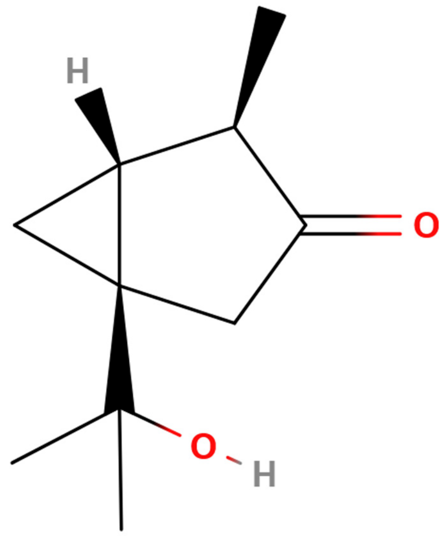
Given the comparatively high standard deviations compared to the mean, it is useful to consider the median thujone content in the essential oil, which is 8.0% for *A. absinthium* and 23.4% for *A. pontica*. Additionally, the thujone content of wormwood is variable with many chemotypes containing only trace amounts or none. Indeed, around 60% of the studies had samples in which thujones were present in trace amounts or could not be detected. The dominant chemotype of each region was also determined (data not shown). The dominant chemotype is the component or components that make up a major portion (around 30%) of the essential oil composition. Our findings indicate that only around half the samples, either α-thujone, β-thujone, or combined thujones were part of the dominant chemotype.

## The health effects of wormwood

The convulsant effect of thujone is due to it acting as a modulator for the γ-aminobutyric acid (GABA) receptors in the brain. Specifically, GABA-gated chloride channels ($GABA_A$) regulate inhibitory signals in the brain by allowing chloride ions to decrease the likelihood of neurons firing by hyperpolarisation. By disrupting this system, chloride ions are unable to reach neurons, which may become overexcited, causing uncontrolled neuronal activity such as seizures (Höld et al. 2000; Höld et al. 2001; Szczot et al. 2012; Czyzewska and Mozrzymas 2013). Although both isomers of thujone show neurotoxic effects, α-thujone is around two to three-fold more potent than β-thujone (Rice and Wilson 1976; Höld et al. 2000). Additionally, the primary detoxification metabolite of α-thujone, 7-hydroxy-α-thujone, has been observed at almost three times the concentration of α-thujone in mice at the peak of symptoms of poisoning, suggesting a role in the neurotoxic effects (Figure 9; Höld et al. 2000). Although α-thujone was demonstrated to be 56 times more likely to bind to GABAA proteins than 7-hydroxy-α-thujone, the neuronal effect of thujone toxicity appears to be reversible (Höld et al. 2001).

### Figure 9.

**Structure of 7-hydroxy-α-thujone,** a metabolite produced during the breakdown of α-thujone.




The serotonin 5-$HT_3$ receptor has also been evaluated as a potential target for α-thujone (Deiml et al. 2004). It was shown that α-thujone inhibits serotonin signalling through 5-$HT_3$ receptors by enhancing the blocking activity of the natural ligand, possibly contributing to its psychotropic effect. Dettling et al. (2004) demonstrated that individuals who consumed alcohol with high concentrations of thujone (100 mg/L) exhibit a negative impact on reaction times, attention performance, and 'present anxiety'. Control subjects who received only alcohol or alcohol with a low concentration of thujone (10 mg/L) did not experience these effects. Whilst interesting, the limitations of the study (including a lack of placebo control and blinding) undermine definitive conclusions (Dettling et al. 2004).

More recently (Sultan et al. 2017), α-thujone has been shown to function as a non-competitive inhibitor of the α-7-nicotinic acetylcholine (α7-nACh) receptor, a widely distributed chemoreceptor in the nervous system that is implicated in memory and long-term learning. Sultan et al. (2017) suggested that thujone may function as an allosteric modulator for various receptors and ion channels accounting for its array of pharmacological effects.

Interestingly, the GABAA, 5-$HT_3$, and α7-nACh are all a part of the Cys-loop family of neurotransmitters (Thompson et al. 2010). This family also includes glycine receptors which are homologous in structure to GABA receptors and are linked to motor coordination, pain perception, and respiratory rhythms (Lynch 2009; Zeilhofer et al. 2012). This may explain why Rice and Wilson (1976) witnessed the antinociceptive (reduction/blocking of pain) properties of thujone during their animal tests. We are unaware if this receptor system been explored in relation to the effects of thujone as with the rest of the Cys-loop family.

Del Castillo et al (1975) proposed that thujone and $\Delta^9$-tetrahydrocannabinol may affect the same chemoreceptors in the central nervous system due to their similar structures and functional groups (Figure 10). However, after the cannabinoid receptor system was elucidated (Howlett 1995), thujone was shown not to bind or activate receptors at physiologically relevant concentrations, discounting the hypothesis despite their structural similarities (Meschler and Howlett 1999). However, the combined effects of cannabis and thujone have gone unexplored.

While there have been reports detailing thujone toxicity (Weisbord et al. 1997; Benezet-Mazuecos and de la Fuente 2006; Stafstrom 2007), other research has shown a wide variety of health effects. For example, thujone has been implicated in reduced liver and kidney function in mice (Siveen and Kuttan 2011a) and may contribute to hepatic porphyria (Bonkovsky et al. 1992). According to the National Toxicology Program (NTP 2011), chronic exposure to thujone results in genotoxic and carcinogenic effects.

Conversely, thujone has demonstrated anticancer effects in animal studies where it increased the immune response to solid tumours and helped to inhibit melanoma metastasis (Siveen and Kuttan 2011a; Siveen and Kuttan 2011b). Other studies on the cytotoxicity of thujone have provided a route for the development of new cancer drugs (Biswas et al. 2011; Torres et al. 2016; Mughees et al. 2019; Pal et al. 2022). Further, Akkol et al. (2015) reported that thujone may be helpful in the treatment of polycystic ovary syndrome, reducing cholesterol and triglycerides in diabetic rats and may treat diabetic neuropathy (Al-Haj Baddar et al. 2011; Bhargava et al. 2022). In addition, like many other plant-derived monoterpenes, thujone has significant antibacterial and antifungal activity (Jaafar et al. 2018; Teker et al. 2021; Janz et al. 2022).

## Toxicity of Thujone

For regulatory purposes it is important to understand the limits of safe exposure to naturally occurring bioactive toxins. The majority of risk studies on thujone toxicity have been conducted using animals and extrapolated to provide dose effect. Acute thujone toxicity is associated with tonic-clonic (jerking) and epileptiform (epilepsy like) seizures caused by a sudden burst of electrical activity in the brain (Keith 1931; Wenzel and Ross 1957;

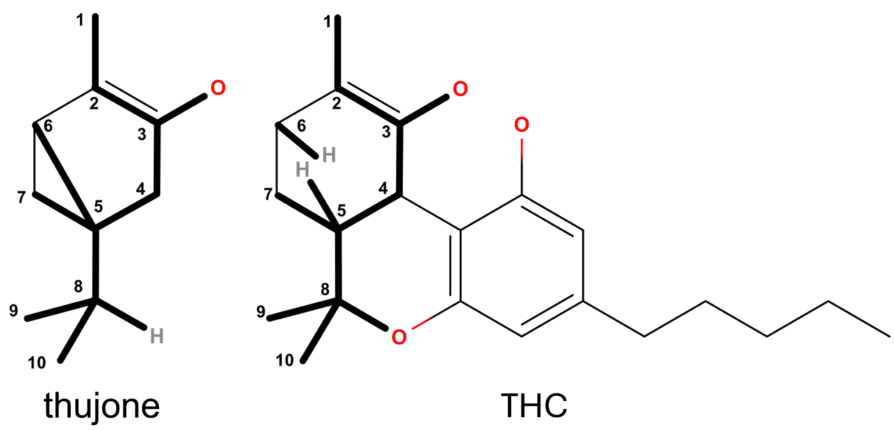



**Figure 10.**

**Structural similarities between tetrahydrocannabinol (THC) and α-thujone.**

As suggested by Del Castillo et al (1975), this does not indicate similar functions in the cannabinoid receptor system

Le Bourhis and Soenen 1973; Rice and Wilson 1976; Lachenmeier and Uebelacker 2010; Pelkonen et al. 2013). A report by the World Health Organization (WHO 1981) includes evaluations of thujone toxicity and provides dose-effect data. Single dose toxicity is expressed as 'lethal dose' (LD), with LD50 the dose that is lethal to 50% of a test population. Short term studies determined the oral LD50 of thujone to be 230-250 mg/kg of body weight in mice, 192 mg/kg in rats, 396 mg/kg in guinea pigs, and 250 mg/kg (α-thujone) in dogs (Margaria 1963; Le Bourhis and Soenen 1973; Joint FAO/WHO Expert Committee on Food Additives [JECFA] 1981). Subcutaneous injections of β-thujone in mice had an LD50 of 442 mg/kg while α-thujone was 134 mg/kg of body weight (Rice and Wilson 1976; JECFA 1981). Intraperitoneal (abdominal cavity) injections had an LD50 of 140 mg/kg in rats and 45 mg/kg in mice (JECFA 1981; Höld et al. 2000). Intravenous injection - the most lethal - had an LD50 of 0.031 mg/kg of body weight in rats (Pelkonen et al. 2013).

More long term animal exposure to thujone has also been explored. Unpublished studies from the 1960's are summarised by the European Commission Science Committee on Food (Scientific Committee on Food [SCF] 2003) and the European Medicines Agency's Committee on Herbal Medicinal Products (HMPC 2011). In 1962, Surber dosed groups of 20 rats, both male and female, with α- and β-thujone by force feeding with 0, 12.5, 25, and 50 mg/kg of body weight, five days a week for 13 weeks. The highest dose rate had a 60% mortality rate among females and 37% in males, with a no-observed-adverse-effect-level (NOAEL) of 12.5 mg/kg per day being determined for males. Conclusions could not be made for female rats due to the lowest dosage group displaying periodic symptoms (SCF 2003; Lachenmeier and Uebelacker 2010). Margaria (1963) conducted a similar study with groups of 20 rats, both male and female, which were dosed with α- and β-thujone by force feeding at 0, 5, 10, or 20 mg/kg of body weight, 6 days a week for 14 weeks. This study determined a NOAEL of 5 mg/kg per day for females and 10 mg/kg for males (SCF 2003; Lachenmeier and Uebelacker 2010; HMPC 2011). In both studies there were no significant haematological or histopathologic effects observed between treatment groups.

The National Toxicity Programme (NTP 2011) conducted a series of animal studies on thujone toxicity (Table 5) with two short term experiments, each lasting around two weeks, in which α-thujone or isomeric thujone were administered. Additionally, a three month and a two year experiments were conducted using isomeric thujone. The experiments were performed with rats and mice with the treatment being force fed with a solution of 0.5% (v/w) methylcellulose. The top dosage groups had increased incidents of seizures and higher mortality rates with both mice and rats. The day on which the first seizures were recorded during the long-term experiment also revealed female rats to be more sensitive than males. This may be an expression of higher absolute bioavailability in female rats, with 96.2% of α- and 56.5% isomeric thujone, compared to males, with 23.8% α- and 22.6% isomeric thujone (Waidyanatha et al. 2013). Female rats also had greater ratio of thujone in their brains than plasma following administration than males, indicating a greater effect despite no differences in toxicokinetics between sexes (Waidyanatha et al. 2013). The difference between the sexes was not seen in mice, though this may reflect insufficient testing at early time points.

Lachenmeier and Uebelacker (2010) used the data from the National Toxicity Programme (NTP 2011) long term study to calculate a benchmark dose (BMD). Toxicological effects can be determined using BMD modelling using a dose-response relationship curve (EFSA Scientific Committee 2017). Here, a benchmark response of 10% was selected, for a dose level of thujone at which there is a 10% increase in the risk of an adverse effect on test animals compared to a control group. The benchmark dose lower confidence limit (BMDL10) is the statistical lower limit of the BMD interval at a confidence level of 95%. The BMDL10 based on the two year study, was 11 mg/kg of body weight a day. Applying an uncertainty factor of 100 (assumes humans are 10 times more sensitive than test animals and have a 10-fold range of sensitivities), gives a daily thujone intake of 0.11 mg/kg of body weight per day without adverse effects (Lachenmeier and Uebelacker 2010).

## Table 5.

**Thujone toxicity - National Toxicology Program**

**Animal: F344/N rats**

| Substance and study length | Schedule | Dosage groups (mg/kg of BW) | Group | Convulsions observed [dosage] | Mortality [dosage] |
|---|---|---|---|---|---|
| α-thujone for 16 days | 5 days/ week | 0, 1, 3, 10, 30, 100 | 5 males | None | None |
| | | | 5 females | 3 [100] | 3 [100] |
| α/β-thujone* for 16 days | 5 days/ week | 0, 1, 3, 10, 30, 100 | 5 males | None | 1 [100] |
| | | | 5 females | None | None |
| α/β-thujone* for 14 weeks | 5 days/ week | 0, 12.5, 25, 50, 75, 100 | 10 males | 3 [50]; 10 [75]; 10 [100] | 2 [75]; 8 [100] |
| | | | 10 females | 1 [25]; 6 [50]; 10 [75]; 9 [100] | 8 [75]; 9 [100] |
| α/β-thujone* for 2 years | 5 days/ week | 0, 12.5, 25, 50 | 50 males | 1 [0]**; 5 [12.5]; 43 [25]; 50 [50] | 21 [0]; 25 [12.5]; 32 [25]; 50 [50] |
| | | | 50 females | 1 [0]**; 3 [12.5]; 47 [25]; 50 [50] | 15 [0]; 17 [12.5]; 31 [25]; 50 [50] |

NOAEL (no-observed-adverse-effect-level) - 12.5 mg/kg of BW

**Animal: B6C3F1 mice**

| Substance and study length | Schedule | Dosage groups (mg/kg of BW) | Group | Convulsions observed [dosage] | Mortality [dosage] |
|---|---|---|---|---|---|
| α-thujone for 16 days | 5 days/ week | 0, 1, 3, 10, 30, 100 | 5 males | 3 [100] | 4 [100] |
| | | | 5 females | None | 5 [100] |
| α/β-thujone* for 16 days | 5 days/ week | 0, 1, 3, 10, 30, 100 | 5 males | None | 5 [100] |
| | | | 5 females | None | 2 [100] |
| α/β-thujone* for 14 weeks | 5 days/ week | 0, 6.25, 12.5, 25, 50, 75 | 10 males | 10 [50]; 10 [75] | 9 [50]; 10 [75] |
| | | | 10 females | 6 [25]; 10 [50]; 10 [75] | 7 [50]; 10 [75] |
| α/β-thujone* for 2 years | 5 days/ week | 0, 3, 6, 12, 25 | 50 males | 45 [25] | 10 [0]; 7 [3]; 9 [6]; 14 [12]; 36 [25] |
| | | | 50 females | 1 [0]**; 1 [3]; 50 [25] | 11 [0]; 10 [3]; 10 [6]; 9 [12]; 45 [25] |

NOAEL (no-observed-adverse-effect-level) - 12.5 mg/kg of BW
* α/β-Thujone was determined to be a mixture of approximately 70-71% α-thujone, 11-12% β-thujone, and 17-19% various other monoterpenes and water
** The study authors consider seizures in the control group to be incident

# Does thujone make absinthe toxic

Arnold (1992) made the first contemporary calculation of the content of thujone in pre-ban absinthe with about 260 mg/L of alcohol. This was based on recipes of Duplais (1855; 1871) with 2.5 kg of grand wormwood and 1 kg of petite wormwood per 100 L of alcohol (Table 1 - 'Absinthe of Pontarlier' and 'Absinthe of Montpellier'). The calculations assumed that grand wormwood contained 1.5% (w/w) essential oil of which 67% was thujone, while petite wormwood contained 0.34% (w/w) essential oil with 25% as thujone. Accordingly, the total thujone concentration was 0.260 g/L of alcohol. This figure has been cited many times during the renaissance of absinthe (Bonkovsky et al. 1992; Strang et al. 1999; Patočka and Plucar 2003; Lachenmeier et al. 2006b), but subsequent studies suggest this to be an overestimate.

The content of essential oil reported by Arnold (1992) in his book were about twice the average oil content, and three times the median value for grand wormwood. However, the average oil content for petite wormwood is in better agreement being slightly higher than that used by Arnold. Additionally, the thujone content of 67% in the essential oil of grand wormwood is extreme, close to the highest value detected and about five times greater than the average in the literature. In contrast, the 25% thujone content assumed for petite wormwood aligns more closely with values in the literature, which show an average 17.0 ± 13.8% (Table 4). However, petite wormwood is under described, with 13 studies/31 samples, compared to grand wormwood with 45 studies/291 samples.

The calculations of Arnold (1992) assume the complete extraction of thujone from the wormwood during the maceration and colouring stages without distillation. Lachenmeier and Kuballa (2007) found that only about half of the thujone present in the raw materials carries across during distillation, with thujone collecting in the late distillation fractions where more water is present. They estimated a maximum distillation yield of about 80% of the total thujone concentration if the heads and tails were not separated from the distillate (Lachenmeier and Kuballa 2007). Further, approximately 85-90% of the total thujone content was extracted from wormwood during the maceration and colouration steps (Gimpel et al. 2006). However, in this study, grand wormwood was used for both steps, despite petite wormwood being more appropriate for colouration.

Using Arnold's formula together with the literature data, and additional assumptions about thujone lost during maceration, distillation, and colouration, the thujone content of absinthe from historic recipes was estimated by Lachenmeier and Nathan-Maister (2007). Our thujone estimations in absinthe (Table 6) align with Lachenmeier and Nathan-Maister (Lachenmeier et al. 2006b; Lachenmeier and Kuballa 2007; Lachenmeier et al. 2008; Lachenmeier et al. 2009). The average total thujone content ranged from 24.3 to 36.4 mg/L, althoug with large standard deviations. In all but one recipe, the average thujone level was below the current European regulation of 35 mg/L. Given the large ranges compared with the means, it is appropriate to also consider the median values for thujone, which range from 15.6 - 23.4 mg/L and are markedly below the level of 260 mg/L reported by Arnold (1992).

Using the allowable daily intake (ADI) of 0.11 mg/kg body weight per day (Lachenmeier and Uebelacker 2010), a person weighing 80 kg could safely consume 8.8 mg of thujone from absinthe a day. Using the highest value of total thujone, 36.4 mg/L, this would require the consumption of 244 mL of absinthe to reach that limit. With a serving of 30 mL or so, eight servings of absinthe would need to be consumed daily before any risk of long term toxicity to thujone. Arguably, the alcohol content of absinthe would pose a much greater risk to health than thujone!

## Louche and ouzo effect

Alcoholic beverages made from the essential oils of plants - absinthe, ouzo, pastis, and limoncello – when diluted with water exhibit a physical phenomenon termed 'louching', becoming opalescent, with a cloudy-white colour. This phenomenon, also known as the 'ouzo effect' (Vitale and Katz 2003), describes the formation of a microemulsion in a liquid ternary system where the continuous phase is a mixture of water and alcohol, with the dispersed phase consists of oil microdroplets suspended in the solution. More broadly, adding a third component to a stable binary solution can cause a solute to precipitate out of solution, representing a phase separation through homogeneous nucleation (Vitale and Katz 2003).

In the case of botanical spirits, the plant oils are

### Table 6.

**The estimated content of thujone in historic absinthe recipes.** Based on the literature on wormwood (N=264).

| Recipe | *A. absinthium* (kg/hL alcohol) | *A. pontica* (kg/hL alcohol) | Estimated thujone content (mg/L) | | | |
|---|---|---|---|---|---|---|
| | | | Range | Mean | SD | Median |
| Absinthe of Pontarlier | 2.5 | 1.0 | 0 - 109.2 | 28.3 | 28.4 | 15.7 |
| Absinthe of Montpellier | 2.5 | 1.0 | 0 - 109.2 | 28.3 | 28.4 | 15.7 |
| Absinthe of Lyons | 3.0 | 1.0 | 0 - 117.0 | 31.0 | 30.5 | 18.2 |
| Absinthe of Fougerolles | 2.7 | 0.7 | 0 - 102.5 | 24.3 | 23.3 | 15.6 |
| Absinthe of Besancon | 4.0 | 1.0 | 0 - 153.8 | 36.4 | 35.2 | 23.4 |
| Absinthe of Nimes | 3.8 | 0.8 | 0 - 140.3 | 31.7 | 30.1 | 20.8 |
| White absinthe (Blanche) | 2.8 | 1.1 | 0 - 100.7 | 25.9 | 25.3 | 15.6 |
| Absinthe Ordinaire | 5.0 | 0.6 | 0 – 152.0 | 33.2 | 30.4 | 21.1 |
| Absinthe Fine | 3.5 | 0.5 | 0 - 112.1 | 24.5 | 22.3 | 16.5 |
| Absinthe Extra-Fine | 3.8 | 0.9 | 0 - 143.2 | 32.8 | 31.4 | 21.3 |

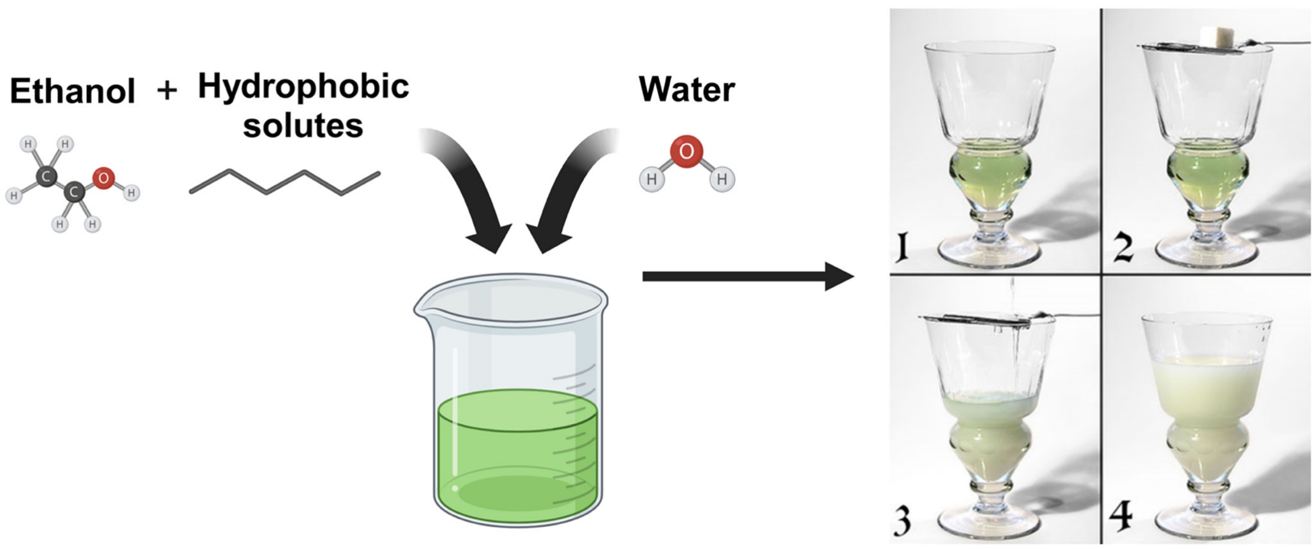
soluble in alcohol but insoluble in water, while alcohol and water are miscible in all proportions. On dilution of the spirit with water, the reduced concentration of alcohol lowers the solubility of the oils, causing them to become supersaturated and form homogeneous microdroplets. This gives the beverage a cloudy appearance as the oil droplets cause light to scatter in all directions (Figure 11).

One of the earliest reports of spontaneous emulsification, underlying louche and the ouzo effect, was using toluene-water mixtures with solutes such as ethanol, propanol, and propionic acid (Ruschak and Miller 1972). This work suggested that these emulsions result from regions of local supersaturation near their interface leading to the phase transformation through nucleation. McCracken and Datyner (1974) later demonstrated polymerising latex by adding water to a solution of styrene and methanol. This resulted in uniform and spherical polystyrene beads without the use of surfactants that had a higher stability than produced by conventional methods (McCracken and Datyner 1974). Following this, spontaneous emulsification has been explored as an efficient, low energy, and surfactant free method of shear less emulsification for multiple industrial processes (Ganachaud and Katz 2005). Of note, is applying the louche/ouzo effect in the creation of nano capsules for drug delivery systems (Botet 2012; Lepeltier et al. 2014; Martínez Rivas et al. 2017; Goubault et al. 2020) and material fabrications (Aschenbrenner et al. 2013; Lamb et al. 2021; Kempe and Kempe 2022; Rosenfeld et al. 2024).

Multiple techniques have been used to investigate the effect. Vitale and Katz (2003) used particle size analysis, which pumped the emulsion through a small orifice while measuring the change in electrical resistance across the opening. The volume of the droplets could be estimated by the changes in resistance. Other particle size analyses has been conducted using dynamic light scattering (DLS) (Sitnikova et al. 2005; Marcus et al. 2015; Goubault et al. 2021; Kempe and Kempe 2022; Iglicki et al. 2023). DLS is a widely used technology that determines the size of Brownian particles by measuring the light they scatter when a beam is shone through the sample. This technique has limitations and is not usable with turbid samples due to photons experiencing multiple scattering events. However, Sitnikova et al (2005) suggested that multiple scattering was negligible, as their ouzo samples were not sufficiently cloudy. Less common techniques include small angle x-ray scattering (SAXS) and small angle neutron scattering (SANS) which have been used to explore the size of droplets in the dispersed phase (Grillo 2003; Marcus et al. 2015; Chiappisi and Grillo 2018; Prévost et al. 2021). Nuclear magnetic resonance (NMR) has also been used to characterise the aggregation of ouzo droplets during the formation of the microemulsion (Carteau et al. 2007a; Carteau et al. 2007b; Carteau et al. 2008; Chiappisi and Grillo 2018).

## Figure 11.

**The principle behind louching in absinthe.** (Wikimedia Commons - Creative Commons license).



Collectively, these techniques reveal the formation of oil droplets with diameters of 200 - 400 nm, with their volume increasing over time. After a few hours this stops with droplet diameters of 1 to 10 µm (Grillo 2003; Prévost et al. 2021; Chiappisi and Grillo 2018). The initial formation of droplets can be attributed to aggregate coalescence with subsequent growth due to 'Ostwald ripening' (Vitale and Katz 2003; Sitnikova et al. 2005; Carteau et al. 2007b). Coalescence describes the process by which two or more small droplets come into contact and consolidate into larger ones, leading to an exponential increase in size over time. Ostwald ripening occurs when smaller droplets redissolve into the continuous phase and are redeposited in the larger droplets, which grow linearly over time (Figure 12; Taylor 1998). However, Vratsanos et al (2023), challenged this using liquid phase transmission electron microscopy (LPTEM), arguing that droplet growth did not follow the linear pattern characteristic of Ostwald ripening. Instead, they proposed a more rapid, diffusion-driven process that led to accelerated droplet growth (Vratsanos et al. 2023).

With absinthe, spontaneous emulsification plays a central role in the louching phenomenon. The interplay between solubility, phase separation, and particle dynamics plays an integral role in this process. Despite the historical and cultural significance of absinthe, research on the physical chemistry of louching is limited. While the ouzo effect has been subject to extensive research in ouzo and pastis (Scholten et al. 2008; Grillo 2003), polymer systems (Kempe and Kempe 2022) and model solutions (Carteau et al. 2007b), only one study has measured parameters of the louching/ouzo effect in absinthe. Bickel et al (2021) examined the temperature dependence of louche formation in absinthe using UV-vis spectroscopy and laser light transmission, suggesting that warmer temperatures inhibit louche formation, and that turbidity increases due to an increase in the number of droplets present in the microemulsion.

Future investigations into the ouzo effect in absinthe could provide insight into improved production techniques and storage conditions while enhancing the consumer experience. Additionally, a detailed exploration of spontaneous emulsification in absinthe may contribute to a broader understanding of the dynamics of emulsion with potential applications in food science and pharmaceuticals.

## Authenticity and analysis

The authenticity of absinthe, while legally undefined, is a cornerstone of its modern revival, as consumers seek products that reflect traditional methods and quality. The history of prohibition and misinformation has underscored the importance of maintaining standards that honour heritage while ensuring safety. For absinthe, this is an important topic, as it has a history of adulteration and unsafe manufacturing practices (Duplais 1871; Lachenmeier et al. 2006a; Padosch et al. 2006). Indeed, during the 19th century, producers - attempting to cut costs or enhance visual appeal - would resort to harmful practices and ingredients. For instance, copper sulphate was added to intensify the green colour of absinthe, giving the illusion of a high quality product (Vogt and Montagne 1982;

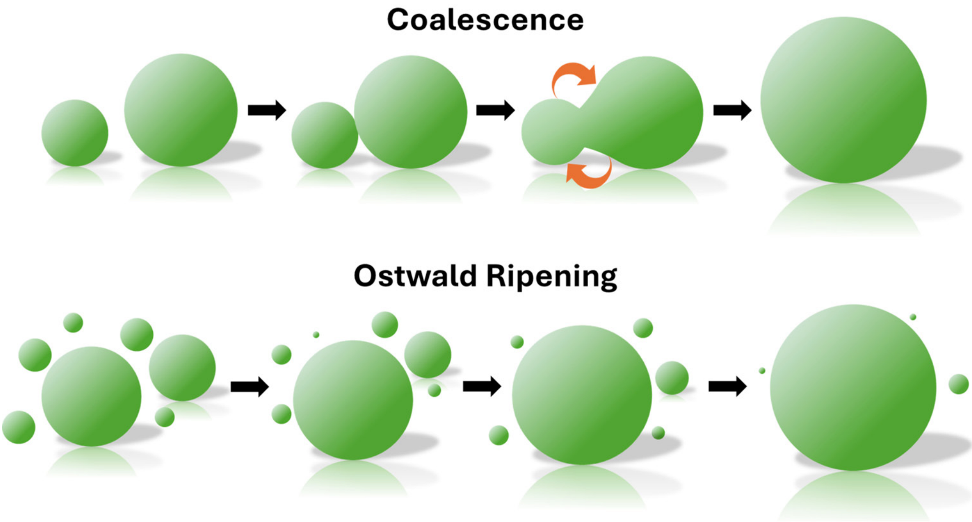



**Figure 12.**

**Coalescence and Ostwald ripening.**

Coalescence describes smaller droplets fusing to form larger droplets. Ostwald ripening describes large droplets becoming larger from the loss of smaller droplets.

Arnold 1989; Lachenmeier et al. 2006a). Further, the addition of toxic antimony salts, such as trichloride or tartrate, exaggerated the louche effect during dilution (Lancet 1873; Vogt 1981; Arnold 1989; Padosch et al. 2006; Lachenmeier et al. 2008). In other cases, illicit producers would incorporate the heads and tails of distillation - fractions rich in toxic compounds and fusel alcohols - resulting in potentially a poisonous spirit (Walker 1906; Arnold 1989; Lachenmeier et al. 2008). Although these adulterants have not been detected in the analyses of vintage bottles of absinthe, Lachenmeier et al. (2008) suggested that this is due to the cheaper, lower quality and possibly adulterated brands being sold in casks. In contrast, higher quality products were bottled in glass and could be stored for decades (Lachenmeier et al. 2008).

In addition to chemical adulterants, the authenticity of absinthe was challenged by inferior imitations with products being made using herbal essences rather than by distillation (Duplais and McKenna 1871; Brévans 1890; Tibbles 1908; Fritsch 1926). Concentrated herbal extracts were added to alcohol creating an approximation of absinthe with toxic plants (sweet calamus or tansy), to mimic the flavour of absinthe and thujone content (Duplais 1871; Lachenmeier et al. 2006a; Padosch et al. 2006). These essences were often used in absinthe made from unrectified (lower ABV) alcohol mixed with flavouring extracts and coloured with food dye or copper salts (Tibbles 1908; Vogt and Montagne 1982; Padosch et al. 2006). These low quality products were sold by dubious vendors, often in low socioeconomic areas of Paris, which further damaged the reputation of absinthe. Adulteration may also explain the cases of absinthism, particularly with symptoms such as blurred vision, which is associated with methanol poisoning (Lachenmeier et al. 2006a; Lachenmeier et al. 2008). Methanol can be a concern in absinthe if the 'heads' are not removed from grape spirit. However, most modern commercial absinthes are made from highly rectified (repeatedly distilled) neutral spirit.

Ensuring the authenticity of absinthe requires analytical techniques that can verify composition and detect adulteration. As absinthe continues to grow in the global market, these methods are crucial for maintaining regulatory compliance and protecting customers. Modern methods aid the detection of hallmark compounds in absinthe to prove authenticity, and identification of artificial colourants, flavours, or adulterants to preserve integrity. Previously, Lachenmeier (2007) demonstrated the effectiveness of high performance thin layer chromatography paired with sensory evaluation in identifying the presence of absinthin. This dimeric sesquiterpene lactone (Figure 6) is characteristic of wormwood and predominantly responsible for the bitter flavour of absinthe (Lachenmeier 2007). This method enables the identification of high quality, botanical based absinthe from inferior or counterfeit products that do not contain wormwood. However, this approach is not appropriate for high quality white, or 'blanche' absinthes that are not coloured with wormwood (Lachenmeier 2007).

The verification of colour is an important aspect of assuring the authenticity of absinthe. Multivariate Curve Resolution (MCR) is a chemometric technique for detecting artificial colourants in absinthe by analysing spectrophotometric data (Lachenmeier and Kessler 2008). This method allows for the separation and quantification of individual colourants in complex mixtures, providing a profile of colouration of the spirit through statistical modelling. MCR has been shown to detect and differentiate synthetic dyes (Lachenmeier and Kessler 2008; Ahmandi et al. 2015), although the use of a dyes does not disqualify absinthe if it adheres to local regulatory requirements and labelling practices. While natural chlorophyll colouring is associated with traditional and high quality absinthe, the inclusion of food colouring may reflect modern manufacturing preferences for product homogeneity rather than adulteration. MCR is better served as a tool for quality control and labelling verification than as a determinant of authenticity. Indeed in 2006, 41% of tested absinthes had mislabelled dye information (Lachenmeier et al. 2006a). Whether this remains the case is unclear, but highlights the importance of correct labelling for product integrity.

Detecting and quantifying thujone in absinthe is important in ensuring product safety and regulatory compliance. As previously discussed, the content of thujone in absinthe in the US is regulated (maximum

10 mg/L) and EU (35 mg/L). Mérat and co-workers (1976) first used flame ionisation detection (FID) in to quantify thujone with mass spectrometry (MS) first used by Galli et al (1984). Subsequent advances in analytical techniques have improved the precision and efficiency of thujone determination, allowing producers and regulators to verify compliance accurately and rapidly. Solid phase extraction (SPE) was found to only recover 40 to 70% of thujone from a sample, and the limit of detection (LOD) was around 0.1 mg/L for α-thujone using GC-FID and GC-MS (Emmert et al. 2004). SPE combined with liquid chromatography (LC) and fluorescence detection achieved a similar recovery of about 60-70% of thujone and an LOD of 0.23 mg/L (Scott et al. 2004). Mindful of the limitations of SPE, head space solid phase microextraction (HS-SPME) has enhanced thujone detection with a reported LOD of 0.71 ug/L (Kröner et al. 2003; Kröner et al. 2005; Schäfer and Lachenmeier 2005). More recently, Dawidowicz and Dybowski (2015) achieved a LOD using SPE and GC-MS to around 0.03 mg/L with a mean recovery of 99.8%. They also determined a limit of quantification (LOQ) of about 0.1 mg/L using GC-FID (Dawidowicz and Dybowski 2015). Bach et al (2016) developed a combined SPME and GC-MS method to analyse the composition of fresh wormwood, focusing on both thujone isomers, absinthin, and other flavonoids. Their goal was to provide producers with a tool for monitoring key metabolite levels before harvest, enabling more precise timing for optimal quality.

Proton nuclear magnetic resonance spectroscopy ($^1$H NMR) is a powerful tool that has been used for analysis of thujone (Monakhova et al. 2011). It has the advantage of being non-destructive and can rapidly analyse multiple samples. However, it is not as sensitive as the GC methods, with a LOD of 0.3 mg/L and LOQ of 0.9 mg/L and is unable to differentiate between the α and β isomers. As the detection limit is more sensitive than required for regulatory purposes, this technique is more useful for high throughput analysis (Monakhova et al. 2011). Together, these techniques provide a range of options for detecting and quantifying total thujone, ensuring regulatory compliance and safety for consumers.

## Absinthe in the modern world

Geographical indications (GIs) play an important role in preserving the authenticity and heritage of artisanal products associated with geographic regions, particularly in the food, wine, and spirits industries (European Commission 2025). For absinthe, such designations would help maintain quality standards and protect traditional production techniques. While there has been some success in securing GIs for absinthe, the process has not been without challenges. In 2006, absinthe producers in the Val-de-Travers region of Switzerland - the purported birthplace of absinthe - filed an application to register the names 'Absinthe', 'Fée Verte', and 'La Bleue' as protected designations. The GIs were awarded in 2010, declaring that only products made in the Val-de-Travers region could use these terms. Unsurprisingly, this ruling was met by criticism from absinthe producers throughout Europe and the decision was challenged and reversed in 2012. This was upheld by the Swiss Federal Administrative Court in 2014, stating that 'Absinthe', 'Fée Verte', and 'La Bleue' were generic and not specific to the Val-de-Travers region (Federal 2014).

In contrast, 'Absinthe de Pontarlier' became a recognised geographical indication in France in 2019. This designation ensures that only absinthe distilled in Pontarlier, a region with a history of absinthe production, can carry the name (European Union 2018; 2019). Other criteria for GIs include the use of traditional methods of distillation and use of wormwood grown in the region. The success of 'Absinthe de Pontarlier' is due to a clearly defined, regional specific qualification and title rather than an all encompassing generic term. This approach may serve as a model for other regions seeking to protect their absinthe heritage, for example 'Absinthe du Val-de-Travers' may be an appropriate GI. As geographic indications open the discussion for defining authenticity, broader standards for absinthe identity will be important to guide production.

Lachenmeier (2007) proposed minimum standards for authentic absinthe and premium grade products. Table 7 presents an expansion of this to reflect modern production. Although this proposal aligns with Lachenmeier (2007), there are some

## Table 7.

**Proposed minimum requirements for the identity of absinthe.**

| Proposed standards, adapted from Lachenmeier (2007) | Updated standards |
|---|---|
| **Minimum requirements** | **Minimum requirements** |
| Characteristic aromatic flavour and bitter taste caused by natural extracts or distillates of wormwood (*Artemisia absinthium*) | Characteristic aromatic flavour and bitter taste caused by natural extracts or distillates of wormwood (*Artemisia absinthium*) |
| Characteristic clouding if diluted with water ('louche effect') | Characteristic clouding if diluted with water ('louche effect') |
| Detectable concentration of absinthin | Detectible concentration of absinthin |
| Standard chemotypes: β-thujone > α-thujone | Standard chemotypes: β-thujone > α-thujone, if thujone is present |
| | Wormwood chemotypes that contain low concentrations of thujone should be used if available |
| Colour: uncoloured or greenish | Uncoloured or coloured naturally or using semi-synthetic dyes only (e.g., copper-chlorophyllin, E141) |
| | Non-green absinthe colour should be derived from botanical sources or semi-synthetic dyes only (e.g., carmine, E120) |
| | Compliance with local thujone limits and other regulatory requirements |
| **Further requirements for premium grade products** | **Further requirements for premium grade products** |
| No artificial dye (colouring achieved only with wormwood and other herbs) | No artificial dye (colouring achieved only with wormwood and other herbs) |
| | Uncoloured or must be greenish |
| Distillation-based manufacturing | Distillation-based manufacturing - herbs must be macerated and distilled |
| | Two species of wormwood should be used, *A. absinthium* and *A. pontica*, for flavouring and colouring respectively |
| Minimum alcoholic strength 45% ABV | Minimum alcoholic strength 45% ABV |
| | Minimal sugar added at bottling |

## Figure 13.

**Poster for Rosinette Absinthe Rosé by Oxygénée** (artist unknown) published by Imprimerie Camis, Paris, France (1900). Evidence that rouge absinthe has some historical precedent. (Public domain - Wikimedia Commons).


differences regarding thujone and colour. Firstly, as previous studies have demonstrated, wormwood can be cultivated with little-to-no thujone and the necessity for chemotypes containing thujone then becomes questionable. Although legal limits ensure absinthe containing thujone safe is to consume, it would be better to opt for alternate wormwood chemotypes when feasible to minimise potential risks. Additionally, since the bitter flavour of wormwood arises from sesquiterpene lactones - rather than monoterpenes like thujone - thujone is not essential for the authentic absinthe flavour (Lachenmeier 2007). In terms of colour, high quality and authentic absinthe must either be colour free or green using traditional, historic methods and ingredients. However, so as not to stifle a growing market, products coloured red or blue with botanical materials or naturally derived dyes may still be considered as absinthe. These products still honour the legacy of absinthe as, while no historical texts describe Absinthe Rosé, a lithograph in 1900 suggests a precedent for its existence (Figure 13).

# Future research

As noted, compared to other popular spirit drinks, absinthe has received limited attention in scientific literature. This presents opportunities for studies of the chemical composition, production methods, and potential health considerations. This review has identified several promising avenues for future research that could enhance our understanding of absinthe. Five platforms for further study are outlined below.

**1. Biological effects of thujone**

An important research area is the potential interaction between thujone and glycine receptors. While the rest of the Cys-loop family of neurotransmitters have been studied in relation to thujone, the glycine receptors have not (Höld et al. 2000; Deiml et al. 2004; Sultan et al. 2017). Given the structural similarities between GABA and glycine receptors, this may be of interest for physiological impacts that may contribute to a more nuanced toxicological profile of thujone (Zeilhofer et al. 2012). Beyond this, further research on thujone could investigate its absorption, distribution, metabolism, and excretion (ADME) in humans. Ethical concerns around administering known toxins pose challenges for human studies, but alternative *in vitro* systems or animal tissue models could help clarify any acute and chronic effects of thujone. Such research could help inform or validate guidelines for production and consumption. Additionally, VCD spectroscopy could be used to differentiate the thujone enantiomers (Felippe et al. 2012). As stereoisomers often exhibit distinct biological activities, this method could determine whether the enantiomers exhibit differences in toxicity or sensory perception.

**2. Biosynthesis of thujone**

Another direction for research is an investigation into thujone production in wormwood. The biosynthesis of terpenoids is regulated by complex genetic and epigenetic mechanisms in other *Artemisia* species, which would suggest similar processes for wormwood (Yi et al. 2022). Investigating the epigenetic modifications that influence thujone production could involve genome-wide methylation studies and transcriptome analyses under varying environmental conditions. This approach may identify regulatory genes and epigenetic markers that modulate secondary metabolite production, offering insight into cultivation practices and genetic variance. Beyond this, comprehensive metabolomic and genomic analyses of different wormwood species may uncover novel biomarkers for quality control and authentication, as well as highlight the environmental factors affecting thujone and other compounds. Further, such work could identify a subspecies of wormwood or cultivation conditions that minimise the synthesis of thujone, leading to a formulation of absinthe with lower risk.

**3. Production and ingredients**

The production methods for absinthe have not been explored in the scientific literature. Investigations into the impact of distillation techniques, botanical extraction methods, and processing conditions on the chemical profile of absinthe would provide insight into flavour optimisation and quality control. Similarly, the volatile components of absinthe have yet to be fully characterised. Analytical techniques, such as GC-MS coupled with sensory evaluation could be used to characterise compounds present in absinthe and their contribution to the flavour and aroma of the spirit. This would improve flavour profiling of absinthe but also standardise production practices. Some outstanding questions could also be answered about traditional recipes. For example, the traditional practice of using different wormwood species for flavour and colour suggests a rationale that has been left unexplained (Duplais 1871). Comparative phytochemical studies could reveal specific compounds that contribute to differences in organoleptic qualities that would guide modern production techniques.

**4. Colour stability**

The stability of the colour of absinthe remains a challenge due to the degradation of chlorophyll over time. To improve the quality of absinthe, projects on the long term stability and aging would assess optimal storage conditions for preserving colour. Alternatively, methods for improving colour retention through natural additives, antioxidants, or process modifications could provide strategies for producers to enhance chlorophyll protection and extend shelf life without compromising on traditional production methods.

**5. Louche effect**

The colloidal and emulsification processes underlying the louche effect remain underexplored, particularly studies on the mechanisms by which this effect takes place. The role of different essential oils in absinthe, or the effect of different additions, like sugar, on the louche effect would be useful for improving production consistency. Emerging technology, like microfluidics, combined with analytical techniques such as DLS or electron microscopy could provide insight into droplet formation and phase separation. Further characterising the louche/ouzo effect in absinthe could help with broader applications for similar emulsions in other industries.

These research directions highlight the need for interdisciplinary approaches to study absinthe, integrating botany, molecular biology, analytical chemistry, sensory science, and rheology. Advancing our understanding in these areas promises to refine absinthe production methods, ensuring both safety and the preservation of a unique history. Additionally, a deeper understanding of these topics may have broader implications for other areas including food science, natural product chemistry, and emulsion technologies.

## Conclusions

Absinthe has a complex history, with production methods and scientific intrigue making it a unique subject for study. This review has examined the historical significance of absinthe, including its medicinal origins, widespread consumption in the 1800s leading to its prohibition, and subsequent revival in recent decades. Once prohibited due to concerns regarding alleged hallucinogenic properties and societal impact, absinthe has undergone a reassessment driven by advancements in analytical chemistry, food science, and regulatory frameworks. Studies have demonstrated that absinthe does not contribute a poisonous or toxic risk beyond that associated with the consumption of alcohol. The early 20th century bans on absinthe were influenced were influenced by moral and political pressures, as well as flawed scientific study and biased media. Research has established that pre-ban absinthes were likely to contain lower levels of thujone than previously believed, and contemporary regulations ensure that commercially available absinthe complies with safety standards. As a result, the historic notion of 'absinthism' as a distinct syndrome has been discredited. Despite this, the chemical composition of absinthe, particularly the variability of thujone in wormwood, remains an area of interest. Analysis of the historical and modern scientific literature suggests variation in the concentration of thujone in wormwood based on geographic location, cultivation conditions, and harvesting techniques. However, further research is required to fully understand how these conditions affect its synthesis. Additionally, the louche effect, a defining characteristic of absinthe, is a useful model for spontaneous emulsification, with applications beyond the food and beverage industry into pharmaceuticals and material sciences.

Ensuring the authenticity and quality of absinthe remains a significant challenge. Historical adulteration, including the use of toxic additives, highlight the need for effective quality control. Modern analytical methods such as HPLC, NMR, and spectroscopic approaches are effective in verifying the authenticity of absinthe. Further refinement of these methods will prevent fraudulent production, maintain consumer confidence and the delivery of a high quality product. Research should prioritise refining identification methods for wormwood chemotypes, enhanced understanding of absinthe aging, the louche effect and the impact of botanical components on health. The legal status of absinthe has evolved from relegalisation to disputes over geographical indications, reflecting the interplay between regulatory policies and cultural perceptions. The resurgence of absinthe as an artisanal product aligns with a broader consumer interest in historic and traditionally crafted spirits. This study is a prescient example of how scientific research can contribute to long standing myths and misconceptions but eventually rectify those misunderstandings and contribute to a more informed perspective. By addressing historical inaccuracies through scientific analysis, absinthe can be better understood and appreciated as both a beverage and as a subject of academic inquiry.

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## Author contributions

**Keenan Schaan:** conceptualisation, investigation, data curation, writing (original draft).
**Paul Hughes:** funding acquisition, supervision, writing (review and editing).

## Conflict of interest

The authors declare there are no conflicts of interest.

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