Estimation of thujone levels in pre-ban absinthe

Dirk W. Lachenmeier

Abstract

Objectives: The media coverage about absinthe, a bitter spirit containing wormwood (*Artemisia absinthium* L.), continues to repeat unsubstantiated myths and legends and the public is systematically misinformed. Especially, the theory about a significant thujone content in absinthe must be put into perspective as there are a number of different wormwood chemotypes with a large variance in thujone content (0-70.6% in essential oil). However, a relatively high thujone amount of 260 mg/l derived from out-of-date calculations is generally presented as "historical content" in addition with reports about unsubstantiated psychoactive or aphrodisiac properties. With the end of absinthe's prohibition and rising public interest in the product, the misinformation in scientific studies was transferred to the popular press. The 260 mg/l is presented as common knowledge, and it is given as fact that the thujone content in the mid-nineteenth century was significantly greater than it is today.

Methods: The thujone concentrations in pre-ban absinthe were calculated using authentic 19th century French recipes under regard of the composition of wormwood oil derived by a literature review.

Results: A typical Absinthe Suisse de Pontarlier was calculated to have contained 23±21 mg/l of thujone. It was, therefore, proven that the previous calculations overestimated the thujone content.

Discussion: The following point about the thujone content of pre-ban absinthe should be stressed: there are no analyses from the 19th century because neither knowledge about thujone nor the required analytical methodologies were in existence. Therefore, so-called "historical thujone contents" are either speculative or derived from calculations using historic recipe books, experimental production of absinthes using such recipes, or analyses of vintage absinthes. The most conclusive evidence is provided by a number of studies about the experimental production of absinthes, and the analyses of vintage absinthes, which consistently showed that they contained only relatively low concentrations of thujone (< 10 mg/l).

1. Introduction

Absinthe – a bitter spirit containing wormwood (*Artemisia absinthium* L.) and other herbs – was one of the most popular alcoholic beverages in late 19th century Europe. Renewed interest in absinthe has been raised by the fact that after a century-long prohibition in many European countries, wormwood was re-legalised as an ingredient of alcoholic beverages in 1988, and currently over 100 types of absinthe are legally available [1,2].

It is remarkable that the media coverage about absinthe continues to repeat unsubstantiated myths and legends, and in the scientific as well as in the lay literature the public is systematically misinformed.

2. Absinthe and thujone

The first and foremost mistake about absinthe is the theory about a significant thujone content in the spirit. One of the most widely cited articles about absinthe is entitled "Absinthe: what's your poison" by Strang et al. [3]. The authors of the article claim that "the thujone content of old absinthe was about 0.26 g/l" and Duplais' French distilling guide [4] is given as reference. This citation is misleading. Duplais' recipes merely give the wormwood content used for absinthe making, and there is no mention of thujone (or any other terpene) in both volumes of Duplais' work. In this context, it must also be pointed out that the exact composition of wormwood oil was unknown in Duplais' time. The composition of wormwood oil was first studied by Leblanc in 1845 [5], and a constituent with the empirical formula $C_{10}H_{16}O$ was identified. The substance was called absinthol by Beilstein and Kupffer in 1873 [6]. It was later proven by Wallach in 1902 [7] that absinthol in wormwood was the same substance as both tanacetone found by Semmler [8] in tansy oil, and a compound in thuja oil that Wallach [9] had named thujone. The correct structure was discovered by Semmler in 1900 [10]. Only at the beginning of the 20th century, therefore, did it become common knowledge that thujone is a constituent of wormwood oil as documented in Gildemeister's and Hoffmann's classic textbook of the volatile oils [11]. Knowledge of the exact composition of wormwood oil has become available only with modern chromatographic methods. The first systematic gas chromatographic (GC) study of wormwood oils was conducted by Chialva et al. [12]. Here, the pre-GC view that thujone is the chief constituent of wormwood [13] was shown to be oversimplified as there are a number of different wormwood chemotypes - a fact that is willingly ignored even in current literature.

3. The Thujone myth - an educated guess?

As there was no mention of 0.26 g/l in Duplais' book it can only be presumed how Strang et al. derived this concentration. Most probably they meant by the 1855 citation, that an educated guess as to the thujone content of absinthe can be made from Duplais' recipe. This becomes clearer by the fact that such a guess was made by Arnold (a co-author of Strang's article) in his book "Vincent van Gogh: chemicals, crises, and creativity" [14]. On the assumption that 100 l of preban absinthe employed 2.5 kg of dried *Artemisia absinthium* L. (1.5% oil, of which 67% is thujone; corresponding to 251 mg/l of thujone in the final product) and 1 kg of dried *Artemisia pontica* L. for coloration (0.34% oil, of which 25% is thujone, corresponding to 9 mg/l of thujone in the final product), the concentration of 260 mg/l may be calculated.

However, Arnold failed to mention the wide variations in the oil content of wormwood and the even wider variations of the thujone content in the oil determined in Chialva's and other GC studies. We thoroughly reviewed the literature on the composition of wormwood oil and found 29 references [12,15-42],

which are summarised in Table 1 for *A. absinthium* and Table 2 for *A. pontica*. A wide variation in the oil content of wormwood and even wider variations of the thujone content in the oil is notable. A number of different chemotypes was found in the

Tab. 1: Essential oil and thujone content of *Artemisia pontica* L. (nd: not detected, SD: standard deviation)

Origin of plant	N	Total essential oil [%]	Total thujone [%]	Reference
Italy	5	(no data)	10-25 (mean: 20)	[15]
Italy	1	0.34	25.1	[16]
Bulgaria	1	0.40	Nd	[17]
Kazakhstan	1	0.20	25.9	[18]
(no data)	1	0.25	30.0	[19]
Siberia	14	0.20-0.85 (mean: 0.44)	nd - 22.1 (mean: 3.1)	[20]
Overall	Min	0.2	nd	
	Max	0.9	30	
	Mean	0.3	16.8	
	SD	0.1	12.7	

Tab. 2: Essential oil and thujone content of *Artemisia absinthium* L. (nd: not detected, SD: stan dard deviation)

Origin of plant	N	Total essential oil [%]	Total thujone [%]	Reference
Turkey	1	0.67	0.7	[21]
Iran	2	0.63-0.81 (mean: 0.72)	44-65.5 (mean: 55.3)	[22]
Lithuania	10	(no data)	<0.05-36.6 (mean: 21.1)	[23]
Iran	1	0.65	38.4	[24]
Canada	1	(no data)	35.0	[25]
Iran	1	0.60	6.93	[26]
	1	0.50	4.8	[27]
Egypt	1	0.78	nd	[28]
Iran	1	0.92	5.12	[29]
France	6	(no data)	6.30-49.87 (mean: 28.7)	[30]
Spain	14	0.28-0.42 (mean: 0.35)	nd	[31,32]
Italy	49	0.11-0.82 (mean: 0.28)	nd-70.63 (mean: 10.5)	[33]
Cuba	1	1.25	0.29	[34]
Italy	1	(no data)	1.3	[35]
Argentina	1	(no data)	62.24	[36]
USA	2	(no data)	nd-36.53 (mean: 18.3)	[37]
Several localities	19	0.25-1.60 (mean: 0.78)	nd-42.28 (mean: 9.6)	[12]
India	1	0.27	9.22	[38]
Serbia	1	0.29	20.7	[39]
Russia	1	(no data)	34.5	[40]
France	8	0.38-0.89 (mean: 0.59)	Nd	[41]
Croatia	10	0.39-1.45 (mean: 0.95)	14.0-51.1 (mean: 29,6)	[41]
Several localities	19	0.1-1.1 (mean: 0.5)	1.5-67 (mean 12.89)	[42]
Overall	Min	0.3	nd	
	Max	1.6	70.6	
	Mean	0.6	17.6	
	SD	0.3	18.0	

studies with β-thujone, cis-chrysanthenyl acetat, cis-chrysanthenol, cis-epoxyocimene, sabinyl acetate or bornyl acetate as principal component. Some chemotypes did not contain thujone at all, for example chemotypes from France [41], Italy [12,33], Spain [31], Lithuania [23], and Egypt [28]. It is therefore possible to produce absinthe without any thujone.

The mean essential oil content of *A. absinthium* and *A. pontica* is 0.6±0.3% and 0.3±0.1% and the mean total thujone content in the essential oil is 17.6±18.0% and 16.8±12.7%, respectively. Therefore, it can be concluded that the calculation of 260 mg/l was done with exceptionally high values for both parameters and was an overestimation. If the values from our literature review are used for calculation and considering the distillation behaviour (max. yield 80% according to Ref. [43]) as well as losses in the maceration and colouration steps (a yield of thujone of approx. 90% was determined by Gimpel et al. [44]), the thujone concentrations of distilled absinthe would be as detailed in Table 3. The distribution of the thujone concentrations is shown in Figure 1. Dependent on the recipe, the mean thujone content of absinthe may have been ranged around 17-23 mg/l with large standard deviations of 16-21 mg/l, the median content may haven been around 10-14 mg/l.

Tab. 3: Wormwood content in historic distilled absinthe recipes and possible resulting thujone concentration in absinthe. (SD: standard deviation)

Recipe after Duplais	*A. pontica*	*A. absinthium*	Thujone concentration [mg/l]*				
(1855)[4]	(kg/hl)	(kg/hl)	Min.	Max.	Mean	SD	Median
Absinthe ordinaire	-	2.5	0	68	19	21	10
Absinthe demi-fine	1.0	2.0	0	62	19	17	13
Absinthe fine	0.5	2.0	0	58	17	16	10
Absinthe Suisse de Pontarlier	1.0	2.5	0	76	23	21	14

4. Error propagation the absinthe way

In the years following the publication of Strang et al. [3], the imprecise citation of 260 mg/l led to further propagation of an inaccurate assumption. The estimated thujone content is now presented as a known fact, e.g. “Absinthe contains a number of terpenes and terpene derivatives, including thujone (ca. 2.4 mM)” [45]. The working group of Casida at Berkeley [46-48] derived that thujone is best known as the active ingredient and toxic principle of absinthe, which is a presumption unsupported by literature data. In the next step, the “guessed” thujone

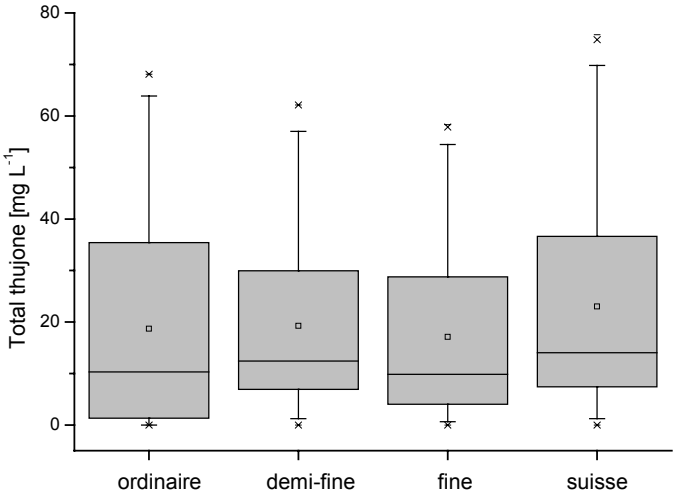

Fig. 1: Box chart of possible thujone concentration in different recipes for pre-ban absinthe

content was given as "historical" content [49]. The author has to admit that in an own study, this wrong information was repeated, and it was impreciselyindicated that thujone concentrations as high as 260 mg/l were reported in the 19th century [50]. Hutton [51], also falling for this mistake, pointed out that analytical techniques in the 19th century were not capable of separating thujone from many of the related compounds and it was therefore likely that concentrations were grossly overestimated. It is now clear, that there are in fact no analyses from the 19th century. If there is an overestimation, it took place in the 1990's during Arnold's calculation.

Experimental evidence pointing to this overestimation was provided by a number of studies. Absinthes produced according to historic recipes only contained relatively low concentrations of thujone (mean: 1.3 ± 1.6 mg/l, range: 0 - 4.3 mg/l) [50]. Concentrations below 10 mg/l were also found in a number of tests of vintage absinthes [50-53]. In contrast, experimental evidence is still lacking to confirm Arnold's calculation of a high thujone content.

5. The final misinformation of the consumer

With the end of absinthe's prohibition and rising public interest in the product, the misinformation in scientific studies was transferred to the popular press. The 260 mg/l is presented as common knowledge, and it is given as fact that the thujone content in the mid-nineteenth century was significantly greater than it is today [54-58]. In the worst cases, totally unsubstantiated recommendations are given to consumers, e.g. that "it is only true absinthe if it contains the wormwood with thujone (the psychoactive ingredient of wormwood)" [59].

Nowadays, this is so widely accepted that most absinthe manufacturers advertise the thujone content and supposed psychoactive or aphrodisiac properties

of their products on their websites or even on the bottle labels [2]. Most modern absinthe has been created from a mixture of aroma and colouring with no reference to the original product and is marketed on the basis of the thujone hype. Furthermore, those who search for the mythical thujone are offered so-called absinthe essences (with high thujone contents of 750 mg/l) to „enhance“ their normal absinthes above the European Union’s maximum limits.

6. Solution to the thujone mystery?

So much attention is focused on absinthe’s myths and supposed effects that almost everyone has forgotten that it was once a gourmet product with all the finesse of the best high-quality spirits. The figure of 260 mg/l of thujone that was repeated over and over might have kept producers at the beginning of the absinthe renaissance in the 1990s from using historical recipes such as those of Duplais. Only in recent years, have a number of authentic distilled absinthes become available on the market. Our analyses showed that such products easily do comply with the thujone maximum limits and this fact may also prove the prior overestimation of the thujone contents [60]. Now, only the consumer has yet to learn that absinthe should be enjoyed purely for its taste like any other spirit.

7. Literatur

[1] Lachenmeier D W, Walch S G, Padosch S A, Kröner L U (2006) Absinthe - A review. Crit. Rev. Food Sci. Nutr. 46: 365-377

[2] Padosch S A, Lachenmeier D W, Kröner L U (2006) Absinthism: a fictitious 19th century syndrome with present impact. Subst. Abuse Treat. Prev. Policy. 1: 14

[3] Strang J, Arnold W N, Peters T (1999) Absinthe: what's your poison? Br. Med. J. 319: 1590-1592

[4] P. Duplais (1855) Traité des liqueurs et de la distillation des alcools ou le liquoriste & le distillateur modernes. Lacroix-Comon, Paris, France

[5] Leblanc F (1845) Composition de l'essence d'absinthe. Journal de Pharmacie et de Chimie. VII: 379

[6] Beilstein F K, Kupffer C (1873) Ueber Wermuthöl. Justus Liebig's Annalen der Chemie und Pharmacie. 170: 290-297

[7] Wallach O (1902) Zur Kenntnis der Terpene und der ätherischen Öle (Fünfundfünfzigste Abhandlung). Justus Liebig's Annalen der Chemie. 323: 333-373

[8] Semmler F W (1892) Ueber Campherarten, welche die Ketongruppe $CO.CH_3$ enthalten. Berichte der deutschen chemischen Gesellschaft. 25: 3343-3352

[9] Wallach O (1893) Zur Kenntniss der Terpene und der ätherischen Öle; zweiundzwanzigste Abhandlung. I. Über die Bestandtheile des Thujaöls. Justus Liebig's Annalen der Chemie. 272: 99-122

[10] Semmler F W (1900) Ueber Tanaceton und seine Derivate. Berichte der deutschen chemischen Gesellschaft. 33: 275-277

[11] E. Gildemeister, F. Hoffmann (1913) The volatile oils. John Wiley & Sons, New York

[12] Chialva F, Liddle P A P, Doglia G (1983) Chemotaxonomy of wormwood (*Artemisia absinthium* L.) I. Composition of the essential oil of several chemotypes. Z. Lebensm. Unters. Forsch. 176: 363-366

[13] E. Guenther (1952) The essential oils. Vol. V. Van Nostrand, New York

[14] W.N. Arnold (1992) Vincent van Gogh: chemicals, crises, and creativity. Birkhäuser, Boston, MA, USA

[15] Nano G M, Martelli A, Sancin P (1966) Indagini chimiche sulle Artemisie coltivate in Piemonte. Riv. Ital. Ess. Prof. Piante Off. Arom. Sap. Cosm. Aerosol. 98: 409-412

[16] Chialva F, Liddle P A P (1981) Sur la composition de l'huile essentielle de artemisia pontica linnaeus cultivée en piémont. Riv. Ital. EPPOS. 63: 350-352

[17] Bos R, Stojanova A, Woerdenbag H J, Koulman A, Quax W J (2005) Volatile components of the aerial parts of Artemisia pontica L. grown in Bulgaria. Flavour Fragr. J. 20: 145-148

[18] Talzhanov N A, Sadyrbekov D T, Smagulova F M, Mukanov R M, Raldugin V A, Shakirov M M, Tkachev A V, Atazhanova G A, Tuleuov B I, Adekenov S M (2005) Components of Artemisia pontica. Chem. Nat. Comp. 41: 178-181

[19] Hurabielle M, Tillequin F, Paris M (1977) Chemical study of Artemisia pontica essential oil. Planta Med. 31: 97-102

[20] Khanina M A, Serykh E A, Korolyuk A Y, Bel'chenko L A, Pokrovsky L M, Tkachev A V (2000) Composition of essential oil of Siberian populations of Artemisia pontica L. - as a promising medical plant. Khim. Rast. Syr'ya. 2000: 85-94

[21] Kordali S, Cakir A, Mavi A, Kilic H, Yildirim A (2005) Screening of chemical composition and antifungal and antioxidant activities of the essential oils from three Turkish Artemisia species. J. Agric. Food Chem. 53: 1408-1416

[22] Gholami M, Azizi A, Salehi P (2005) Variations in essential oil components in cultivated and regenrated Artemisia absinthium L. Asian J. Chem. 17: 2229-2232

[23] Judzentiene A, Mockute D (2004) Chemical composition of essential oils of *Artemisia absinthium* L. (wormwood) growing wild in Vilnius. Chemija. 15: 64-68

[24] Morteza-Semnani K, Akbarzadeh M (2005) Essential oils composition of iranian artemisia absinthium L. and artemisia scoparia Waldst. et Kit. J. Essent. Oil Res. 17: 321-322

[25] Chiasson H, Belanger A, Bostanian N, Vincent C, Poliquin A (2001) Acaricidal properties of Artemisia absinthium and Tanacetum vulgare (Asteraceae) essential oils obtained by three methods of extraction. J Econ. Entomol. 94: 167-171

[26] Rahimizadeh M, Hassanzadeh M K, Danesh N M (2001) Analysis of Iranian Artemisia absinthium L. essential oil. ACGC Chem. Commun. 13: 33-36

[27] Tegtmeier M, Harnischfeger G (1994) Methods for the reduction of thujone content in pharmaceutical preparations of *Artemisia*, *Salvia* and *Thuja*. Eur. J. Pharm. Biopharm. 40: 337-340

[28] Aboutabl E A, El Azzouny A M, El Dahmy S I (1998) Constituents of the essential oil of *Artemisia absinthium* grown in Egypt. J. Essent. Oil Bear. Plants. 1: 82-86

[29] Sefidkon F, Jalili A, Rabie M, Hamzehee B, Asri Y (2003) Chemical composition of the essential oil of five *Artemisia* species from Iran. J. Essent. Oil Bear. Plants. 6: 41-45

[30] Carnat A-P, Madesclaire M, Chavignon O, Lamaison J-L (1992) cis-Chrysanthenol, a main component in essential oil of *Artemisia absinthium* L. growing in Auvergne (Massif Central), France. J. Essent. Oil Res. 4: 487-490

[31] Ariño A, Arberas I, Renobales G, Arriaga S, Dominguez J B (1999) Essential oil of *Artemisia absinthium* L. from the Spanish Pyrenees. J. Essent. Oil Res. 11: 182-184

[32] Ariño A, Arberas I, Renobales G, Dominguez J B (1999) Influence of extraction method and storage conditions on the volatile oil of wormwood (*Artemisia absinthium* L.). Eur. Food Res. Technol. 209: 126-129

[33] Nin S, Arfaioli P, Bosetto M (1995) Quantitative determination of some essential oil components of selected *Artemisia absinthium* plants. J. Essent. Oil Res. 7: 271-277

[34] Pino J A, Rosado A, Fuentes V (1997) Chemical composition of the essential oil of *Artemisia absinthium* L. from Cuba. J. Essent. Oil Res. 9: 87-89

[35] Mucciarelli M, Caramiello R, Maffei M (1995) Essential Oils from some *Artemisia* species growing spontaneously in North-West Italy. Flavour Fragr. J. 10: 25-32

[36] Sacco T, Chialva F (1988) Chemical characteristics of the oil from *Artemisia absinthium* collected in Patagony (Argentina). Planta Med. 54: 93

[37] Tucker A O, Maciarello M J, Sturtz G (1993) Essential oils of Artemisia `Powis Castle' and its putative parents, A. absinthium and A. arborescens. J. Essent. Oil Res. 5: 239-242

[38] Kaul V K, Nigam S S, Banerjee A K (1979) Thin layer and gas chromatographic studies of the essential oil of *Artemisia absinthium* Linn. Indian Perfumer. 23: 1-7

[39] Blagojevic P, Radulovic N, Palic R, Stojanovic G (2006) Chemical Composition of the Essential Oils of Serbian Wild-Growing Artemisia absinthium and Artemisia vulgaris. J. Agric. Food Chem. 54: 4780-4789

[40] Khalilov L M, Paramonov E A, Khalilova A Z, Odinokov V N, Muldashev A A, Baltaev U A, Dzhemilev U M (2001) Identification and biological activity of volatile organic compounds emitted by plants and insects. IV. Composition of vapor isolated from certain species of *Artemisia* plants. Chem. Nat. Comp. 37: 339-342

[41] Juteau F, Jerkovic I, Masotti V, Milos M, Mastelic J, re J M, Viano J (2003) Composition and antimicrobial activity of the essential oil of Artemisia absinthium from Croatia and France. Planta Med. 69: 158-161

[42] Orav A, Raal A, Arak E, Müürisepp M, Kailas T (2006) Composition of the essential oil of *Artemisia absinthium* L. of different geographical origin. Proc. Estonian Acad. Sci. Chem. 55: 155-165

[43] Lachenmeier D W, Kuballa T (2007) Behaviour of thujone during distillation and possible concentration ranges in pre-ban absinthe. J. Sci. Food Agric. in press

[44] Gimpel M, Hönersch Y, Altmann H J, Wittkowski R, Fauhl-Hassek C (2006) Absinthe: Thujone content of absinthe spirits using historical recipes. Deut. Lebensm. -Rundsch. 102: 457-463

[45] Bonkovsky H L, Cable E E, Cable J W, Donohue S E, White E C, Greene Y J, Lambrecht R W, Srivastava K K, Arnold W N (1992) Porphyrogenic properties of the terpenes camphor, pinene, and thujone (with a note on historic implications for absinthe and the illness of Vincent van Gogh). Biochem. Pharmacol. 43: 2359-2368

[46] Höld K M, Sirisoma N S, Ikeda T, Narahashi T, Casida J E (2000) α–Thujone (the active component of absinthe): γ-aminobutyric acid type A receptor modulation and metabolic detoxification. Proc. Natl. Acad. Sci. U. S. A. 97: 3826-3831

[47] Höld K M, Sirisoma N S, Casida J E (2001) Detoxification of α- and β-Thujones (the active ingredients of absinthe): site specificity and species differences in cytochrome P450 oxidation in vitro and in vivo. Chem. Res. Toxicol. 14: 589-595

[48] Sirisoma N S, Höld K M, Casida J E (2001) α- and β-Thujones (herbal medicines and food additives): synthesis and analysis of hydroxy and dehydro metabolites. J. Agric. Food Chem. 49: 1915-1921

[49] Hein J, Juckel G, Kienast T, Heinz A (2005) "Die grüne Fee" Absinth - historische und biochemische Fakten. Sucht. 51: 19-25

[50] Lachenmeier D W, Emmert J, Kuballa T, Sartor G (2006) Thujone-Cause of absinthism? Forensic Sci. Int. 158: 1-8

[51] Hutton I (2002) Myth, reality and absinthe. Curr. Drug Discov. 9: 62-64

[52] Schaefer I, Bindler F, Lugnier A (1994) Toxicological rehabilitation of absinthium liqueur. Toxicol. Lett. 74 Suppl. 1: 75

[53] Ashcraft B (2005) The mystery of the green menace. Wired Magazine. 13.11

[54] Milton X M (2001) Absinthe minded. Baudelaire and van Gogh drank it, will you? The McGill Tribune. 1/9/01

[55] Hall C T (2000) Absinthe was a toxic cocktail for the likes of Picasso and van Gogh. San Francisco Chronicle. March 25, 2000: A3

[56] Food & Dink Europe (2003) Germans warn of absinth risk. Food & Dink Europe. 04/07/2003

[57] Wu C (2000) Toxin in absinthe makes neurons run wild. Science News. 157: 214-

[58] Rekand T (2006) Absinthe, the nervous system and painting. Int Rev. Neurobiol. 74: 271-278

[59] Parvaz D (2001) Absinthe: This highly intoxicating liquor comes with a bad-boy image. Seattle Post-Intelligencer. July 24

[60] Lachenmeier D W, Emmert J, Sartor G (2005) Authentification of absinthe - the bitter truth over a myth. Deut. Lebensm-Rundsch. 101: 100-104

Dr. Dirk W. Lachenmeier
Chemisches und Veterinäruntersuchungsamt Karlsruhe
Weißenburger Str. 3
D-76187 Karlsruhe
Deutschland
E-Mail: Lachenmeier@web.de