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A study of cannabis potency in France over a 25 years period (1992–2016)

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ABSTRACT

Cannabis contains a unique class of compounds known as the cannabinoids. Pharmacologically, the principal psychoactive constituent is Δ^9-tetrahydrocannabinol (THC). The amount of THC in conjunction with selected additional cannabinoid compounds (cannabidiol/CBD, cannabinol/CBN), determines the strength or potency of the cannabis product. Recently, reports have speculated over the change in the quality of cannabis products, from nearly a decade, specifically concerning the increase in cannabinoid content. This article exploits the analytical data of cannabis samples analyzed in the five French forensic police laboratories over 25 years. The increase potency of both herbal and resin cannabis in France is proved through the monitoring of THC content.

For cannabis resin, it has slowly risen from 1992 to 2009, before a considerable increase in the last four years (mean THC content in mid-2016 is 23% compared to 10% in 2009). For herbal cannabis, it has known three main stages of growth (mean THC content is 13% in 2015 and mid-2016 compared to 7% in 2009 and 2% in 1995). The calculation of THC/CBD ratios in both herbal and resin samples confirms the recent change in chemotypes in favor of high potency categories. Finally, the CBN/THC ratios in marijuana samples were measured in order to evaluate the freshness of French seized hemp.

1. Introduction

Cannabis sativa L., commonly known as marijuana, is one of the oldest cultivated plants in the world. Each part of the plant is used. The stalks give the (hemp) fibers used in the industry (fabrics, ropes, papers, etc.). The seeds are often cold-pressed to give hempseed oil, or used directly in animal and bird feed. The flowers and leaves contain the psychoactive substances and are used as drug and medicine [1].

Herbal cannabis is produced in almost every country, while the production of cannabis resin is confined to a few countries in North Africa, the Middle East and South-West Asia. Morocco reported 47,196 ha of cannabis cultivation in 2013, a slight decrease compared with the 52,000 ha reported in 2012, while Mongolia reported 15,000 ha of land covered by cannabis. With 10,000 ha under commercial cannabis plant cultivation in 2012, producing some 1400 t of cannabis resin, one of the largest producers of cannabis resin is Afghanistan, where cannabis cultivation is linked to opium poppy cultivation. Europe is one of the world's largest consumer markets for cannabis resin, yet the market in Western Europe may now be dominated by herbal cannabis [2,3].

In France, cannabis is by far the most seized and consumed illicit drug [4]. However, contrary to many other European countries, it is the resin type, commonly known as hashish, which is the most popular form, even if local cultivation and consumption of herbal cannabis, i.e. marijuana, has been increasing for the last three years [5]. Cannabis resin is often smuggled as light to dark brown compressed bars. The most common form is the 100 g flat bar even if others such as the 200 g flat bar, the 250 g soap bar and the 10 g egg-shaped bar are sometimes found. According to the French national central office for illicit drug traffic control, most of the cannabis resin seized in France comes from Morocco whereas herbal cannabis is mainly from The Netherlands and, at a lower extent, from domestic production [6].

There are more than 500 chemical compounds in herbal cannabis, 100 of which belong to a specific class of terpenophenolic compounds called cannabinoids [7,8]. Content of the major cannabinoids, Δ^9-tetrahydrocannabinol (THC), cannabidiol (CBD), and cannabinol (CBN) in different cannabis plants can be related to their region of origin [9]. They may be also classified by their chemical phenotype or chemotype as drug-type or fibre-type plants, using different ratios such as THC/CBD and the (THC + CBN)/

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CBD [9,10]. However, such cannabinoid ratios proved to be insufficient to fully discriminate samples between the two categories, causing a possible misclassification with judiciary consequences in some countries [11]. This issue might be solved by using a multivariate approach, taking into account a larger number of compounds (terpenes, cannabinoids), which improves the discrimination power of the characterizing method [12].

In France, the largest part of the herbal cannabis samples examined by the forensic laboratories are mature plants (flowers, leaves and mixtures of both). The differentiation between drug-type and fibre-type plants does not rely on the chemical characterization but on context related elements. However, the THC/CBD and the (THC + CBN)/CBD ratios have been calculated on the herbal cannabis data in order to tentatively identify chemotypes.

In parallel, freshness of cannabis samples was evaluated by measuring the relative concentration of CBN to THC [9,13–15].

The aim of this study is to report statistical data over time about cannabis in France and to compare trends with other observed data from worldwide.

2. Methods

2.1. Origin of samples

The five French forensic police laboratories routinely analyze cannabis samples according to the same procedure. In case of cannabis resin, the analyst takes, first, a picture of the logo (if applicable), then he measures the length, width and thickness of the bar, and weigh the sample. Last, he quantifies the three major cannabinoids THC (total content), CBD and CBN. For herbal cannabis, he only weighs the sample and quantifies the three major cannabinoids.

All the determined data are then recorded into the national database, named S.T.U.P.S.© (Système de Traitement Uniformisé des Produits Stupéfiants). This database was created in 1986 to store heroin data, before being extended to other drug categories (cocaine in 1989, cannabis, Amphetamine Type Stimulants and other drugs in 1999). Each year, data are extracted in order to provide an overview of the market of seized drugs in terms of chemical content to health and law enforcement services.

The seizures recorded in the database come from everywhere in France, as the forensic police laboratories are located in different cities and regions (Lille, Paris, Lyon, Marseille, and Toulouse). Moreover, the laboratories receive both street level and wholesale seizures. Therefore, the extracted data are representative of the national drug market.

The present paper focuses on the cannabis data extracted from S.T.U.P.S.© for the 1999–2016 period. However, the analytical data stored in the laboratories from 1992 to 1999 in local paper-based databases were also extracted, resulting in a 25 years collection period (1992–mid 2016).

2.2. Statistical analyses

In the database, a record can result from a single specimen or from an average of several similar specimens (close cannabinoid contents and macroscopic parameters), in order to avoid the influence of big seizures containing several similar items compared to small seizures with only one item for instance. The number of records refers to the number of different sample types which have been analyzed.

Dataset of records were obtained in both resin and herbal samples and used to investigate THC/CBD and THC/CBN ratios.

Data were collected and processed using Microsoft Excel 2010 and RStudio Version 0.99.467 with ggplot2 package. RStudio is an integrated development for R version 3.2.2 (2015-08-15) [16–18].

2.3. Analytical measurements

Quantification of THC, CBD and CBN was performed in the five laboratories by using gas chromatography coupled with Flame Ionisation Detector (GC-FID), with CBN as reference calibration material (Lipomed, Arlesheim, Switzerland). Proficiency tests (internal or coming from the European Network of Forensic Science Institutes—ENFSI) were regularly conducted in order to monitor the performance of individual laboratories for these specific measurements.

3. Results & discussion

3.1. Cannabis resin data

Descriptive statistics were calculated for the percentage of THC in cannabis resin obtained from 1992 to mid-2016. In order to summarize the distribution of about 12,484 values, notched box plots were used (Figs. 1 and 2). The box shows the interquartile range (IQR). The notch displays the α confidence interval around the median, which is normally based on the median $\pm 1.57 \times \mathrm{IQR}/\sqrt{n}$ (n being the number of values). If two boxes' notches do not overlap, there is 'strong evidence' (95% confidence) that their medians differ [19].

From 2012 to 2015 (2016 is not complete), notches do not overlap between themselves meaning that the rise in resin content is significant (Fig. 2).

In Fig. 2, extreme values (black dots) are noticeable in the 2010s, reaching a peak of 81% THC content in 2014. They are due to homemade resin samples, seldom seen in France, but which are much more concentrated than the Moroccan hashish.

In Fig. 3, the full distribution of THC concentration from 1992 to 2016 is plotted in three distinct time periods: A (from 1992 to 2000), B (from 2001 to 2010) and C (from 2011 to 2016). It can be observed that distributions A and B are both unimodal. Distribution B is characterized by a higher mean and a larger range than A, meaning a slight increase of the THC content in cannabis resin between the two time periods.

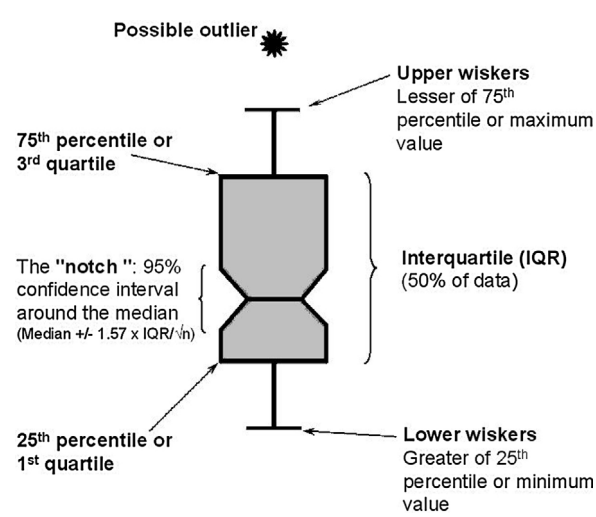

Fig. 1. Graphical representation of a notched box whisker. Picture was inspired by David's Statistics website available on https://sites.google.com/site/davidsstatistics/ (accessed 09.12.2016).

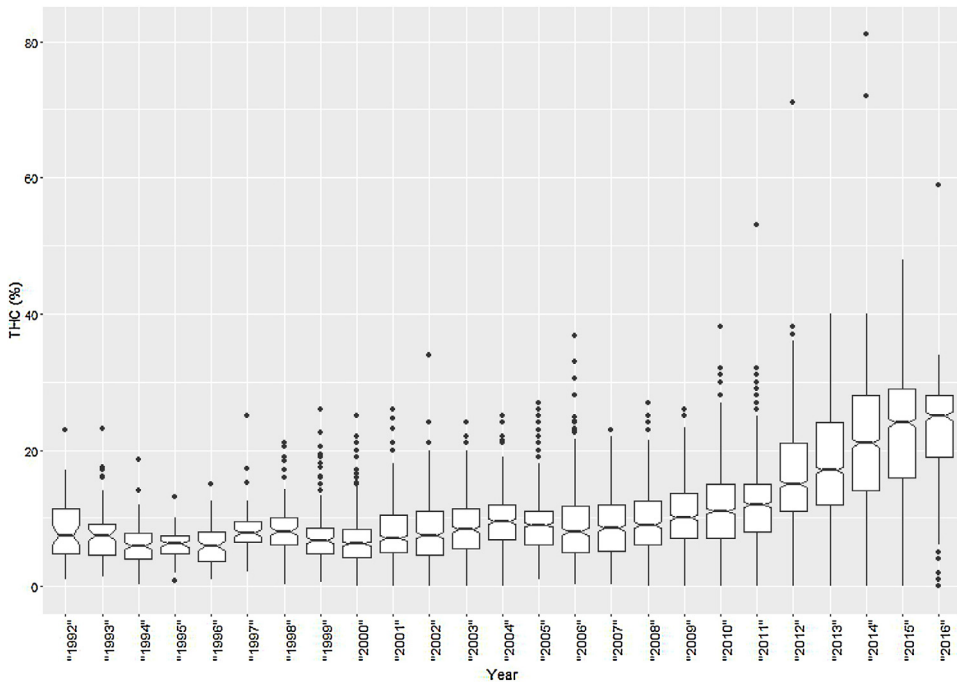

Fig. 2. Distribution (notched box plots) of THC concentration in cannabis resin from 1992 to mid-2016.

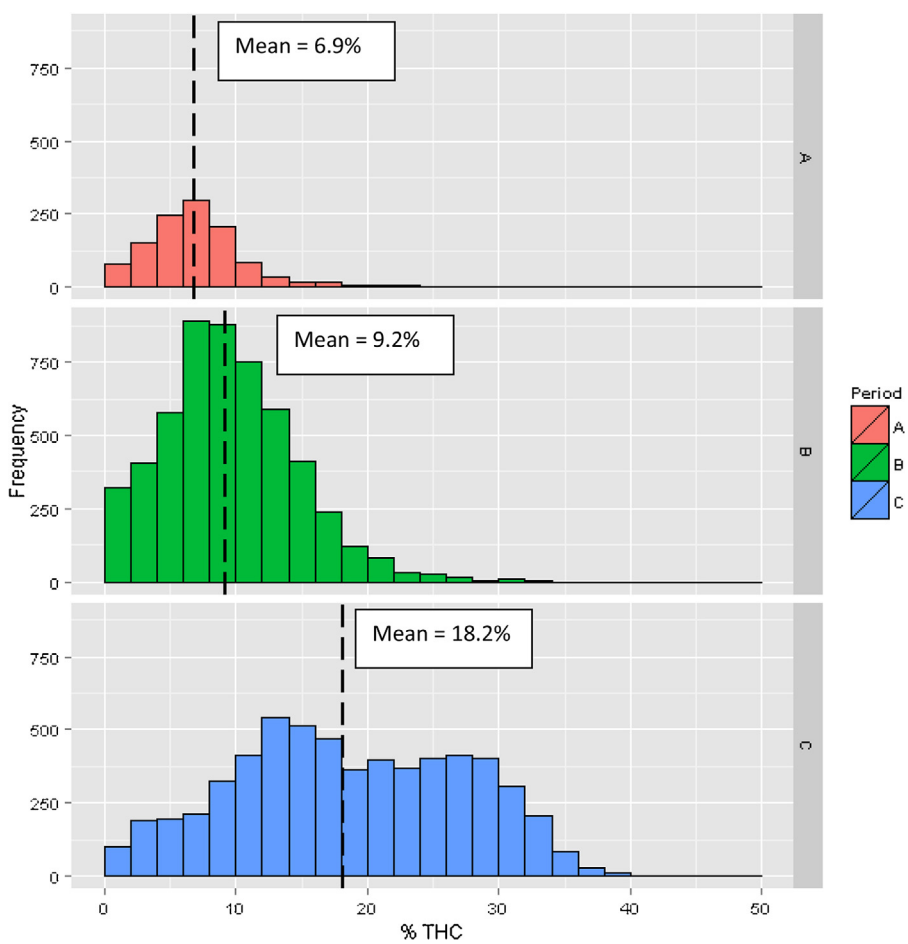

Fig. 3. Distribution (histogram) of THC concentration in cannabis resin for 3 time periods: A (1992–2000), B (2001–2010) and C (2011–mid 2016) (bandwidth of histogram equal to 2%). In dashed black, the overall mean for each period.

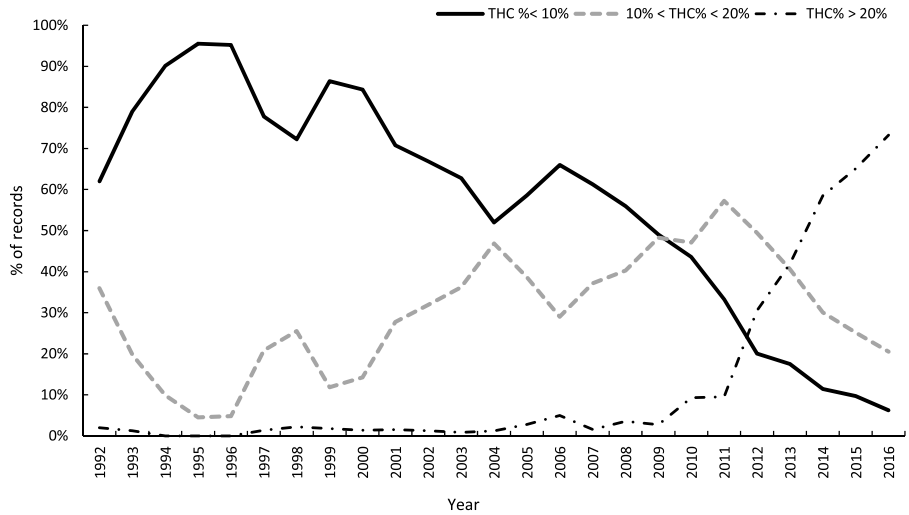

Fig. 4. Distribution frequency of cannabis resin records over 25 years for three THC content categories.

On the opposite, distribution C is bimodal showing a significant and recent change of the hashish market in France. Since 2011, two types of samples have been available: ones with a medium THC content (mean around 13%) corresponding to the "classical" resin and others with a high THC content (mean around 26%) corresponding to "new" hashish products. As both hashish types come from Morocco, it means that the producers have changed their process.

The increase of THC concentration in the Moroccan cannabis resin, from 2008 till now, has been highlighted by Stambouli et al. who published statistics on cannabis in their country [20]. In order to compare our data with Stambouli's results, records of THC content were separated into three categories: (a) THC% < 10%, (b) 10% < THC % < 20% and (c) THC% > 20% (Fig. 4).

Two differences between Stambouli's results and our study have to be mentioned: firstly, Stambouli et al. reported the number of seizures instead of the number of records, and secondly the covered period in Stambouli's study goes from 2005 to 2014.

The number of records from category (a), i.e. low THC content, was predominant during the 1990s. They have decreased from 1996 until 2009 in favor of category (b), i.e. medium THC content. There are some irregularities in the decrease (in 1999 and 2006) but it does not affect the general trend. So, until 2010, our observations are in line with Stambouli's results.

But, after 2010, the records from category (b) started to decrease too. Category (c), i.e. high THC content, then passes over the two other categories. In 2016, almost 3/4 of records correspond to a THC content above 20%. This recent emergence of a high potency category of resin in Morocco was not noticed by Stambouli et al., probably because of the rather low number of studied exhibits (in 2014, 109 samples to be compared to 1111 records in our study).

However, this recent trend was addressed by Chouvy et al. who stated that in the past decade cannabis cultivation underwent radical changes in Morocco [21,22]. They wrote that even if the cannabis cultivation has decreased by 65%, Moroccan hashish is still widely available in Europe and its potency increase was due to

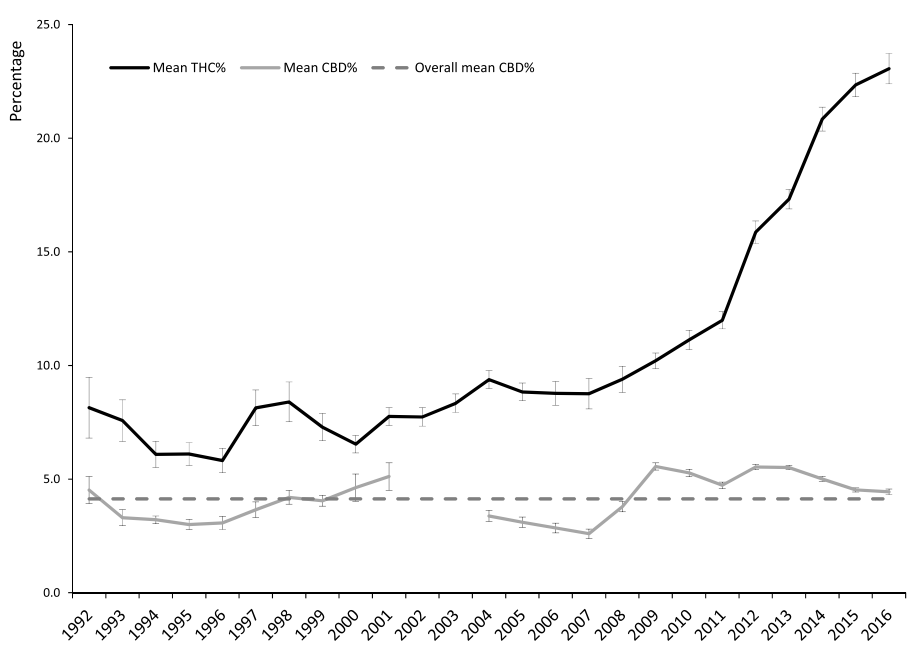

Fig. 5. Distribution frequency of THC and CBD (mean value) in cannabis resin by year, from 1992 to mid-2016. Error bars are based on standard error of the mean (standard deviation divided by the square root of the sample size) with 95% confidence interval—assuming that the means are distributed according to a normal distribution.

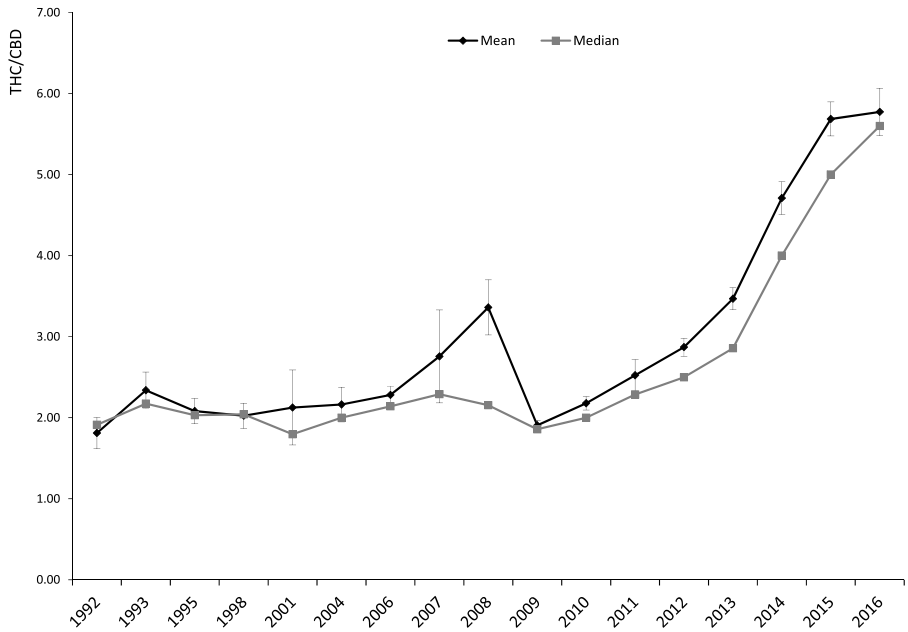

Fig. 6. Evolution of THC/CBD ratio (mean and median) by year, from 1992 to mid-2016.

the switch from "traditional" kif cannabis variety to hybrids (*Cannabis indica* L. and others) with much higher resin yields and THC content [23]. At the same time, a better selection of plants, better sieving and less additives could have led to a better quality of cannabis resin, in line with what is recently seen in France.

3.2. CBD and THC/CBD ratios

Quantitative analysis was carried out for all three major cannabinoids (THC, CBD, CBN) to have a good understanding of the chemical profile of samples, which might affect the overall biological activity of the drug. CBD has a different pharmacology compared to THC and it could be relevant to study its content in cannabis resin. Indeed, Leweke et al. [24] showed that cannabidiol had antipsychotic effects via the inhibition of anandamide deactivation, and Zamengo et al. [25] postulated that variation in proportions of THC and CBD may have implications for the overall psychoactive potential of the material.

Fig. 5 shows the average concentrations of THC and CBD in cannabis resin by year, depicting a constant increase of cannabis potency over time (increase of THC and decrease of CBD), starting from 2000s. From 2011 till now, this trend dramatically grew to reach a peak in 2016.

Unfortunately, CBD data for years 2002 and 2003 could not be included due to a database crash.

The overall mean of CBD in the samples is 4% and 91% of the analyzed samples contain more than 1% of CBD, percentage which is consistent with results from Niesink et al. [15].

Based on the THC/CBD ratio, various chemotypes may be identified [10]. Usually, chemotype I, or drug-type plants have a high THC/CBD ratio, much higher than 1. In French cannabis resin, the median THC/CBD ratio is always above 1. As a matter of fact, it has remained around 2 until 2009 and has then grown up to reach a highest point of 6 in 2016, showing a drastic change in the chemotype (Fig. 6).

Drawing the histogram of THC/CBD ratios for three representative years (2004, 2009, and 2015) shows how the situation has changed (Fig. 7).

In 2004 and 2009, the frequency distribution of THC/CBD is almost the same with most ratios being in the [0.5–5] interval. In 2015, the THC/CBD ratio is spread out over a much larger range of values [0.5–31]. We can notice that there are almost three sample populations, corresponding to three chemotypes. The first one is centered about 3, while the second one is centered about 7.5. The last one, corresponding to very high potency resin samples is a left skewed distribution with a mean value around 10.5. This phenomenon is found in 2016 too.

The two chemotypes with respective mean ratios of 7.5 and 10.5 have appeared quite recently. It confirms the emergence of a high potency cannabis resin on the French drug market.

3.3. Herbal cannabis data

As for cannabis resin, descriptive statistics were calculated for the percentage of THC in herbal cannabis obtained from 1995 to mid-2016. The years 1992, 93 and 94 were not included due to the very small number of values. In order to summarize the distribution of about 3182 values, notched boxplots were used (Fig. 8). The THC content in herbal cannabis is much more variable than in resin. It is due to a large variability in the maturity when plants are seized and to the seized material (stems, leafs, buds). However, we can distinguish three time periods for which notches do not overlap: [1995–2002], [2003–2010], and [2011–2016]. It means that herbal cannabis available on the French market has known three main stages of growth in THC content over 22 years.

Fig. 9 shows a graphic representation of the average THC concentration from 1995 to mid-2016, confirming the constant trend of increased potency of herbal cannabis over time. From 1995 to 2002, values have been below 7.6% (the overall mean). From 2003 to 2009, values have fluctuated about 7.6% and from 2010 to mid-2016, they have grown to reach a peak around 13%.

Zamengo et al. have previously reported a significant increase of THC% in Italian hemp from 6.0% to 9.5% over the 2010–2013 period [25]. In their study, sinsemilla products (buds without seeds) showed the highest median values of THC content (11.1%) compared to buds with seeds (8.64%) and to leaves materials (6.86%). Most of the samples submitted to the French forensic police laboratories fall under the sinsemilla category. It is then logical that the observed THC values in French hemp are consistent with the sinsemilla values published by Zamengo et al.

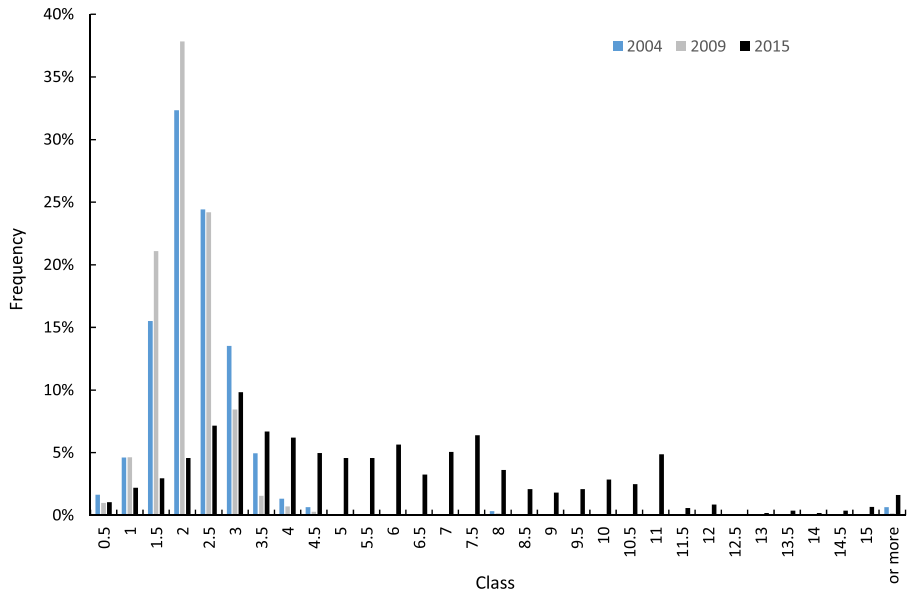

Fig. 7. Distribution of THC/CBD ratios for years 2004, 2009 and 2015.

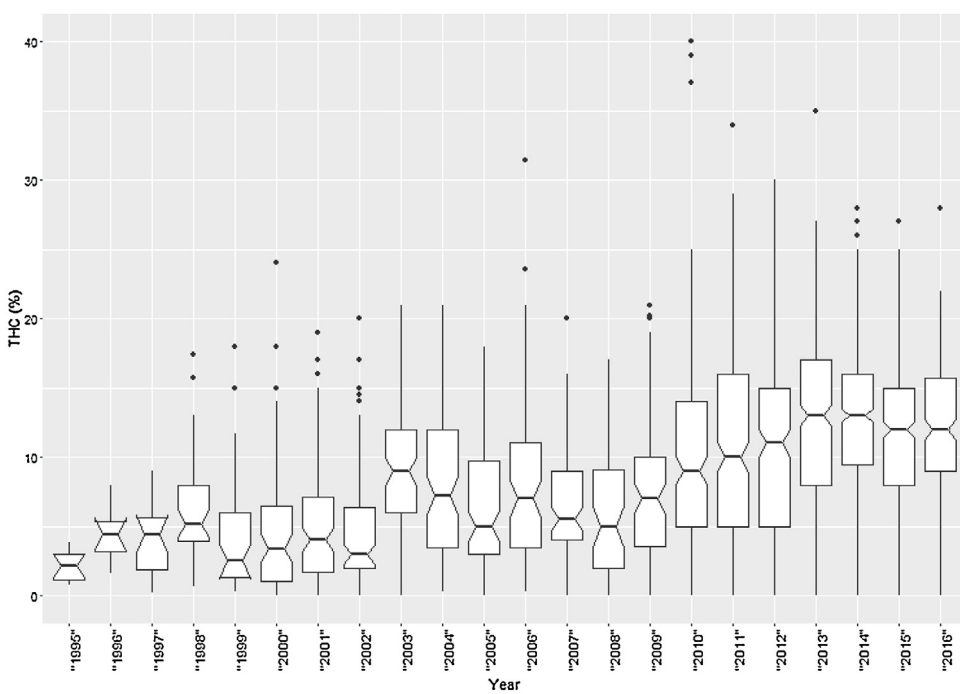

Fig. 8. Distribution (notched boxplots) of THC concentration in herbal cannabis from 1995 to mid-2016.

Another study on cannabis potency over the last two decades in the United States [26] also reported that the increase in the proportionate number of sinsemilla samples versus marijuana is the cause of the overall increase in the confiscated samples potency. Tsumura et al. also mentioned that the majority of marijuana seizures in Japan was seedless buds [27]. Although the origin of seized marijuana was not clearly established, their statistics for 2010 indicated that illicit cannabis was mainly domestically grown now.

In France, it is not possible to determine the origin of seized marijuana either. But, the increase in potency of herbal cannabis may be correlated to the recent spread of domestic cultivation.

3.4. CBN/THC and THC/CBD ratios

Cannabinol (CBN) may be an indicator of the freshness of herbal material. It is not present in fresh marijuana and is regarded as a primary degradation product of THC. Storage conditions, such as humidity and temperature, play an active role in the degradation process. However, in previous studies, the CBN/THC ratio has been used to evaluate the age of marijuana samples [28]. It can be considered that a “fresh”, i.e. less than 6 months, herbal cannabis sample has a CBN/THC ratio below 0.013. From age 1 year up to 2 years, CBN/THC is between 0.04 and 0.08. The higher the ratio is measured, the older the marijuana should be. In Fig. 10, it can be observed that CBN/THC in French marijuana samples is very variable with an overall mean equal to 0.06 which means that the

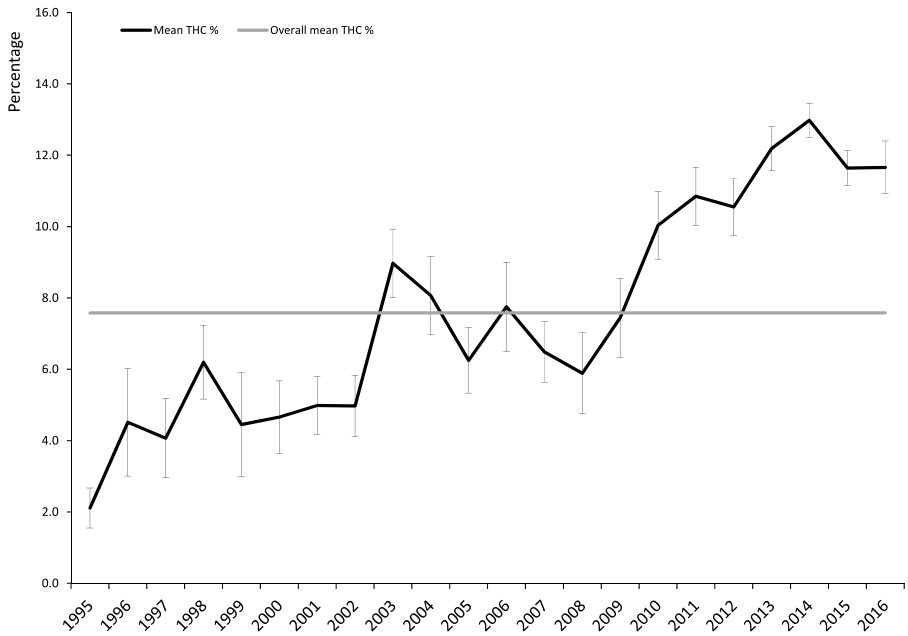

Fig. 9. Average THC concentration of samples by year, from 1995 to mid-2016. Overall mean = 7.6%.

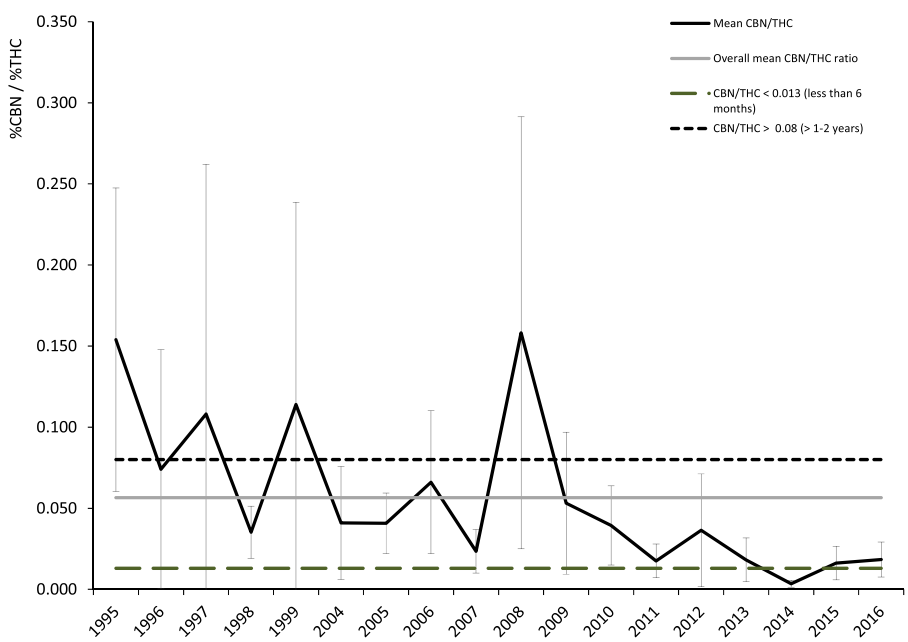

Fig. 10. Evolution of CBN/THC ratio mean by year, from 1995 to mid-2016. Overall mean = 0.06.

average age of samples would be between 1 and 2 years. However, a decrease was initiated in 2009 and from 2012 till now, seized materials have been fresher than before (less than one year). This new situation is in line with published results from Italy [13,25] and The Netherlands [15].

One explanation could be that more and more French consumers grow their own cannabis, either in small apartments or in large indoor cannabis farms. Samples are then seized closer to their growing place, giving access to fresher materials.

According to the system of classification of Hillig and Mahlberg [10], two chemotypes of cannabis plants can be determined from the log ratio of THC and CBD (Fig. 11). Samples in which CBD was not detected were excluded from that study. Chemotype I, or drug-type plants have high log (THC/CBD) ratios, greater than 1 (corresponding to THC/CBD = 10), chemotype II, or intermediate-type plants, have intermediate log (THC/CBD) ratios between −0.6 (THC/CBD = 0.25) and 1.

Chemotype III, or fiber-type plants, with ratios lesser than −0.7 (THC/CBD = 0.2) were not observed in our study.

Evolution of chemotypes over time has been studied (Fig. 12). There are some variations but a trend can be drawn: chemotype II was predominant until 2009 but from 2010 till now chemotype I has taken the lead even if a confirmation is required in 2016. This change in chemotypes is in line with the increase in potency of herbal cannabis in France over years.

The ratio between THC and CBD also plays an important role as it can reflect the risk of psychotic effects. Indeed, the higher the

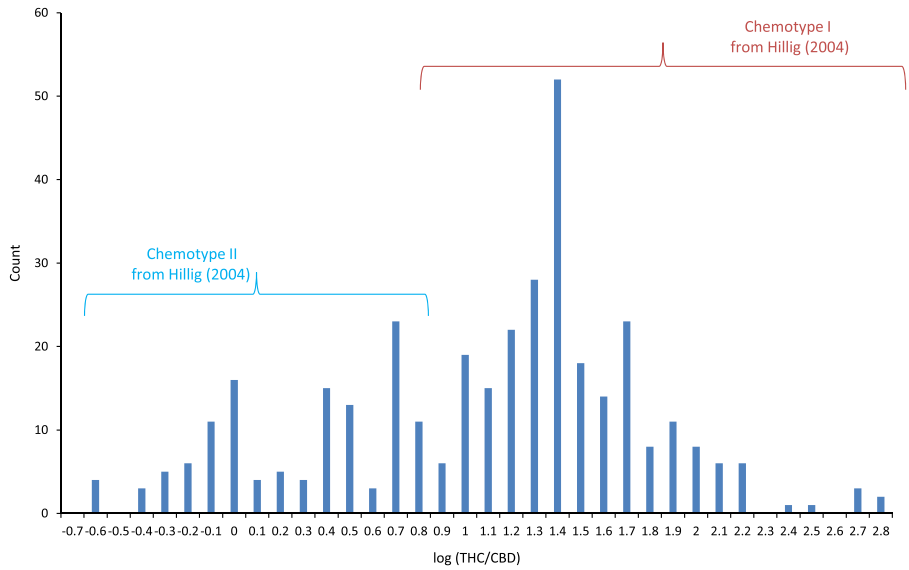

Fig. 11. Distribution of THC/CBD (log values) for 384 records of herbal cannabis from 1995 to mid-2016. Mean = 1, range −0.7 to 2.8, SD = 0.7.

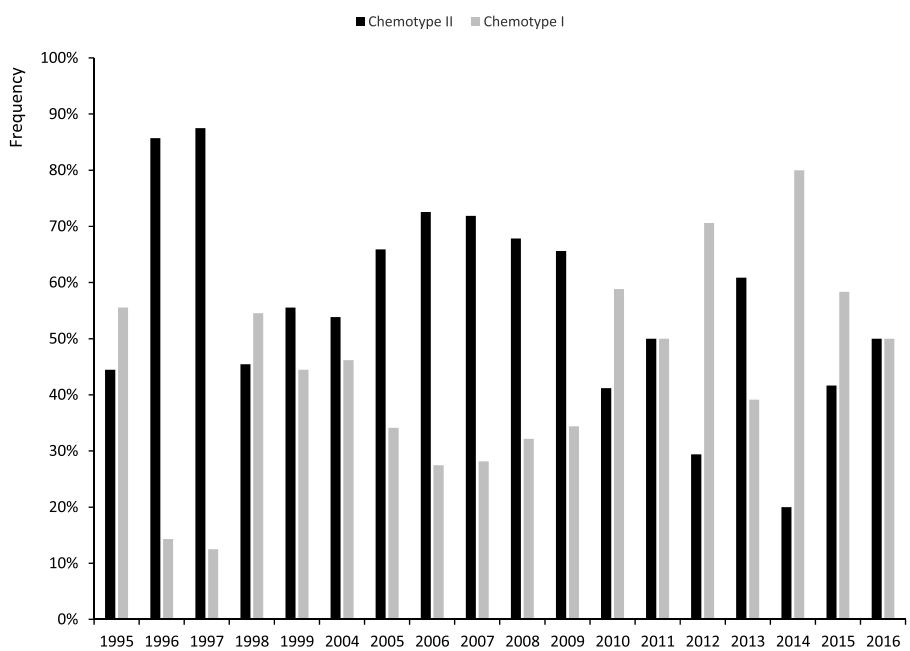

Fig. 12. Evolution of chemotypes by year, from 1995 to mid-2016. In black, chemotype II and in grey chemotype I.

amount of THC and the lower the CBD content, the higher is this risk [15,24].

4. Conclusion

This study shows that the potency of both resin and herbal cannabis seized in France has increased for the last 25 years.

For cannabis resin, the THC content has slowly risen from 1992 to 2011, which is in line with other studies in Europe [13,15,25] and Morocco [20]. Then, it has dramatically increased for the last four years to reach a peak in 2016 (a 92% growth in mean THC content from 2011 to mid-2016). This unexpected and considerable growth is due to the emergence of a new hashish product on the French market.

The calculation of THC/CBD ratios in resin samples confirms this recent change in chemotypes, which has probably two explanations: the switch from "kif" to hybrids plants in Morocco, and the optimisation of the production process [21–23].

For marijuana, the major cannabinoids contents are more variable than in resin but trends were noticed though. The mean THC concentration has reached a peak around 12% for the last three years. It was around 7% over the period 2003–2010 and around 5% between 1995 and 2002. An increase in the proportion of sinsemilla samples is probably the cause of the overall increase from year 2009. The in-house cultivation of marijuana in France has grown recently leading to the availability of good quality and fresh samples, as noticed with THC/CBD and CBN/THC ratios.

The increase in potency of herbal and resin cannabis in France in terms of health impact still needs to be evaluated.

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