Title page

Changes in the composition of cannabis from 2000-2017 in Denmark: analysis of confiscated samples of cannabis resin

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Abstract

Globally, recent studies report increases in Δ-9-tetrahydrocannabinol (THC) concentration in seized samples of cannabis for human consumption. This is important, because use of cannabis with a high concentration of THC has been linked to a number of adverse health outcomes. The objective of this study was to assess recent changes in the composition of seized cannabis resin in Denmark by: (a) examining THC concentration in samples from Danish forensic laboratories from 2000 to 2017 (N=430); and (b) examining cannabidiol (CBD) concentration and the THC:CBD concentration ratio in samples from the forensic laboratory in Western Denmark from 2008-2017 (N=147). Cannabis resin samples were analysed using a gas chromatographic analysis with flame ionization detection quantifying the total THC and CBD concentration. Results showed that the THC concentration increased three-fold from 2000 (mean: 8.3%) to 2017 (mean: 25.3%). Significant increases occurred in all areas of Denmark. After 2011, we found a dramatic increase in cannabis resin samples with high THC concentration and the near disappearance of cannabis resin samples with medium- and low THC concentration. Furthermore, the THC:CBD concentration ratio increased significantly from 1.4 in 2008 to 4.4 in 2017. While THC concentration increased, CBD concentration remained stable at ~6%. In Conclusion, the THC concentration of cannabis resin, and THC:CBD concentration ratio, have increased dramatically in Denmark, potentially leading to higher risk of harm to users. Policy makers, treatment professionals, and educators should be aware of this change.

Keywords

Cannabis; THC; CBD; Gas chromatography with flame ionization detector.

Public significance statements

Based on seized cannabis resin samples from 2000-2017, we observe a three-fold increase in THC concentration and a rise in THC:CBD concentration ratio, suggesting that cannabis users may be exposed to higher doses of THC, which may a carry greater risk. Observed trends are strikingly similar to trends reported in France, suggesting that the emergence of new, resin products with higher THC concentration has widely penetrated European markets, including Scandinavia. Policy makers, treatment professionals, and educators should be aware of this change.

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Cannabis contains at least 144 different cannabinoids, of which the main psychoactive component is Δ-9-tetrahydrocannabinol (THC) (Hanus, Meyer, Munoz, Taglialatela-Scafati, & Appendino, 2016). The cannabinoids are produced and stored in glandular trichomes, mainly around the flowering tops of the female cannabis plant (Potter, 2014). Prevention of pollination increases the number of trichomes the plant produces, which results in a product with higher THC concentration (i.e. %THC by weight of sample). Broadly speaking, cannabis products can be divided into four categories: high-THC-concentration/sinsemilla (unpollinated flower), herbal (pollinated flower), hash/resin (compressed cannabis trichomes along with plant matter) and cannabis concentrates (such as hash oil, wax dabs, butane hash oil, shatter etc.) (Potter, Hammond, Tuffnell, Walker, & Di Forti, 2018).

During the past two decades, increases in the THC concentration of cannabis have been reported in the United States (ElSohly et al., 2016; Smart, Caulkins, Kilmer, Davenport, & Midgette, 2017) and Europe (Dujourdy & Besacier, 2017; Freeman et al., 2019; Pijlman, Rigter, Hoek, Goldschmidt, & Niesink, 2005; Potter, Clark, & Brown, 2008; Potter et al., 2018; Zamengo, Frison, Bettin, & Sciarrone, 2014, 2015). A large study of confiscated samples in the United States reported that the THC concentration of illicit cannabis products (overall) increased consistently from about 4% in 1995 to about 12% in 2014, and that over the last four years, the number of high-THC-concentration samples seized has increased while the number of low-THC-concentration samples (herbal) has decreased (ElSohly et al., 2016). In Washington State, a dramatic increase in THC concentration was recently reported within 2 years of legal sales (average 20.6%), where extremely high-THC-concentration extracts (average 68.7% THC) now compromise around 21.2% of purchases (Smart et al., 2017).

A comprehensive study of confiscated samples from France reported that THC concentrations in cannabis resin increased slowly from 1992 to 2009 followed by a dramatic

increase from 10% in 2009 to 23% mid-2016 (Dujourdy & Besacier, 2017). The authors reported that since 2011, two types of resin samples have become available on the French cannabis market: "classic" medium THC concentration resin (around 13%) and a new high THC product (around 26% THC). In 2016, almost three quarters of resin samples had a THC concentration above 20%. The appearance of this new, high THC form of resin may be attributable to changes in cannabis production in Morocco, from landrace "kif" plants towards higher THC-dominant strains (Chouvy & Afsahi, 2014; Stambouli, El Bouri, & Bouayoun, 2016). A recent analysis of data submitted to the European Monitoring Centre for Drugs and Drug Addiction (EMCDDA) indicated that the THC concentration of resin showed minimal change from 2006 to 2011, before increasing almost two-fold from 2011 to 2016 (Freeman et al., 2019). This suggests that the emergence of new, higher-THC-concentration resin products is not limited to France but instead has penetrated European markets, including central Europe and Scandinavia. Of note, Denmark reported the highest THC concentration of resin among all countries submitting data to the EMCDDA in 2016 (Freeman et al., 2019).

The THC concentration of cannabis is important, as it has been linked to a number of adverse outcomes including increased risk of psychotic disorder (Di Forti et al., 2015; Schoeler et al., 2016), negative impact on cognitive functions (D'Souza et al., 2004; Morgan et al., 2012; Morrison et al., 2009) and poorer addiction outcomes (Curran et al., 2018; Freeman & Winstock, 2015; Meier, 2017). A recent 16-year study found positive time-dependent associations between changes in cannabis concentration and first-time admissions to drug treatment, after adjusting for age, sex and non-cannabis drug treatment admissions (Freeman et al., 2018).

Another main cannabinoid important to monitor is cannabidiol (CBD). Accumulating evidence suggests that CBD displays opposing neural, cognitive and behavioural effects that interact with, and possibly counteract, effects of THC (Englund, Freeman, Murray, & McGuire,

2017; Iseger & Bossong, 2015; Osborne, Solowij, & Weston-Green, 2017; Rømer Thomsen, Callesen, & Ewing, 2017), including effects on psychotic symptoms (Bhattacharyya et al., 2018; Leweke et al., 2012; McGuire et al., 2018; Morgan et al., 2018; Zuardi et al., 2009; Zuardi et al., 2006) and cognitive functions (Das et al., 2013; Englund et al., 2013; Morgan, Schafer, Freeman, & Curran, 2010). Hence, information on CBD concentration, and the THC:CBD concentration ratio in cannabis products provides important information on the potential health risks and benefits in addition to THC concentration alone, although more systematic studies are needed to inform us on "optimal" ratios that carry least risk of harm (Englund et al., 2017).

Although recreational cannabis use is illegal in Denmark, it is widespread; among 16-44-year olds nearly half report that they have tried cannabis resin (Danish Health Authority, 2017). Since 2000, use of cannabis resin has been stable in this age group and decreased among 15-16-year olds (Danish Health Authority, 2017; EMCDDA & ESPAD, 2016; Pedersen, Frederiksen, & Pedersen, 2015). The first published data on the THC concentration of cannabis in Denmark is from 1970, reporting a mean THC concentration of 0.6% (based on 21 samples) (Nielsen, 1970). Since then, a number of reports have been published (see an overview of these findings in Table 1), and since 2014 the National report, *Drugs on Street Level,* published by the Danish forensic laboratories and the Danish Health Authority also includes analyses of THC concentration in the seized cannabis resin samples submitted to forensic analysis (e.g. Lindholst et al., 2017). Importantly, no previous studies have examined changes in THC concentration of cannabis resin seized from 2000-2017 in Denmark, and similarly, we lack examinations of changes in CBD concentration and THC:CBD concentration ratios in cannabis products in Denmark.

Aims of the study

The aim of our study was to examine changes in the composition of cannabis resin confiscated by the Danish police by: (a) examining changes in THC concentration in cannabis resin preparations confiscated from 2000-2017 (based on data from all three forensic laboratories in Denmark); and (b) examining changes in CBD concentration and THC:CBD concentration ratio in cannabis resin preparations confiscated from 2008-2017 (based on data from the forensic laboratory located in Western Denmark).

Methods

Origin of sample material

Denmark is divided into 12 police districts serviced by three regional forensic laboratories located in Eastern Denmark (Copenhagen), Southern Denmark (Odense) and Western Denmark (Aarhus). Not all Danish cannabis seizures are subjected to forensic analyses. The decision whether a sample is to be analysed rely on a police professional assessment in each case. Therefore, only a limited number of samples of the national seizures are analysed and available as study material.

The first part of the study (where we examine THC concentration) includes seizures of cannabis resin made by Danish police in the period from 2000-2017 from the three available forensic laboratories. The second part of the study (where we examine THC and CBD concentrations) includes seizures of cannabis resin made by Danish police and subjected to forensic analysis at the regional forensic laboratory in Aarhus in the period from 2008-2017.

Due to a reported increase in the THC concentration in cannabis resin in 2012 and 2013 in internal reports from the forensic laboratories, The Danish Health Authority decided to include cannabis resin in the national monitoring program (*Drugs on Street Level*) from 2014. The period from 2000-2013 therefore includes all cannabis resin samples analysed by the forensic laboratories from all police districts over Denmark, while the period from 2014-2017 includes systematically

collected resin samples from three of the twelve police districts: Copenhagen, Funen (including Odense) and Eastern Jutland (including Aarhus). Also, cannabis resin samples from 2014-2017 are described in more detail in terms of inclusion criteria and are more systematically collected (compared to 2000-2013): The police in Copenhagen, Southern Denmark, and Eastern Jutland select a small seizure of cannabis resin every month and send it for analysis in the associated forensic laboratory, amounting to 12 samples from each of the three areas per year (a few missing). Hence some geographical areas may be over/underrepresented when comparing the sample period, and may vary in the number of annual samples and yearly distribution.

The study did not require approval from the Ethics Committee.

Chemical analyses

The three forensic laboratories analyse the total THC concentration (i.e. %THC by weight of sample) of cannabis resin according to similar analytical procedures. The material is described according to weight, colour, and physical size. Chemical analysis is conducted using a gas chromatographic analysis with flame ionization detection (GC-FID) quantifying the total cannabinoid content (i.e. combined amount of THC and THC acid, THCA). All laboratories are accredited according to the ISO 17025 standard by the Danish Accreditation Fund (DANAK). The analytical methods used for THC quantification were validated and accredited since 2009 (Copenhagen lab) and 2011 (Aarhus lab). The method used in the regional laboratory in Odense was not validated.

The quantification of the total CBD concentration (i.e. %CBD by weight of sample) was conducted using the same GC-FID based analytical method as for the quantification of THC (described above). Consequently, both total THC and total CBD could be quantified in the same analytical procedure.

Statistical analyses

In the first part of the study, linear regression analyses were used to assess the associations between year of seizure and THC concentration of cannabis resin. In the first model, THC concentration was entered as the dependent variable, and year of seizure as the independent. In the second analysis, separate slopes were estimated for each of the three areas (Western, Southern, and Eastern Denmark), using the same model, and the coefficients were compared using F-tests. Bivariate plots with fractional polynomial fitted lines with 99% confidence intervals are used to present the data in terms of time trends. Due to the exploratory nature of this study, α for significant differences was set to 0.01. The Breusch-Pagan test was used to assess for heteroscedacity, and the variance inflation factor to evaluate multicollinearity. After evaluating multicollinearity, the time variable was centered at the mean value, corresponding to the calendar year 2010.

In the second part of the study, linear regression analyses were conducted to assess the associations between CBD concentration, THC concentration, and year of seizure. In the first analysis, year of seizure and THC concentration were both entered as linear predictors. Following a visual inspection of a bivariate scatterplot of CBD concentration as a function of THC concentration, a non-linear association between the two was considered. We tested a quadratic coefficient for THC concentration, but did not consider a cubed coefficient due to the small number of observations. Nested regression was used to assess the additional value of adding the quadratic coefficient, using the F-test and change in R^2 (ΔR^2). For time trends in CBD concentration only, a Pearson correlation was used to assess the bi-variate association between year of seizure and CBD concentration.

Given that the policy with regard to sample analyses changed in 2014, so that twelve samples were analysed for each region in each year, the results might differ before and after this

change in policy. We therefore conducted an additional analysis in which we allowed the slope to change at the beginning of 2014. In the analysis, time was centered up to 2013 and after 2013, and a dummy variable was constructed representing up to versus after 2013. The THC concentration of seizures was then regressed on the dummy code, the centered time value, and the interaction between the two.

Results

Time trends: THC concentration

During the years 2000-2017, 430 samples were analysed (from all three regional forensic laboratories). The mean THC concentration was 17.0% (SD 10.8). The number of samples per year varied between five in 2001 and 43 in 2008 (see Table 2). Of all samples, 60% came from Western Denmark, 24% from Eastern Denmark, and 15% from Southern Denmark. A one-way Kruskall-Wallis ANOVA indicated that samples from various areas differed in THC concentration ($\chi^2(2)=63.34$, $p<0.001$). Western Denmark had lower THC concentration (mean: 13.6, SD 9.14), versus 20.4 for Southern Denmark (SD: 8.8), and 23.2 for Eastern Denmark (SD 12.3), (see also Figure 1).

In a univariate regression analysis of the mean THC concentration, year of seizure accounted for 39% of the variance, corresponding to a Pearson correlation of 0.62. When separate slopes were estimated for each region, the model accounted for 44% of the variance. The 5 percent point change in R-squared was significant ($F(2,426)=20.53$, $p<.001$). For all three regions, THC concentration significantly increased with year ($p<0.001$). Table 3 shows the estimated annual increase in THC concentration for each of these three regions. The Breusch-Pagan test did not indicate significant heteroscedacity for the model ($\chi^2(1)=0.03$, $p=0.87$).

Potential influence of policy changes

Due to the changes in policy concerning the analysis of seizures occurring from 2014, we repeated the analyses allowing the slopes to vary up till and after 2013. Up until 2013, the THC concentration increased by 0.74 percent points per year (99% CI: 0.41, 1.08, $t=5.57$, $p<0.001$). On average, THC concentration was 15.12 percent points higher after 2013 (99% CI: 13.00, 17.24, $t=18.45$, $p<0.001$), but then showed a decline of 1.93 percent points per year (99% CI: -3.57, -0.28, $t=-3.03$, $p<0.003$). The model accounted for 46% of the variance ($F(2,427)=180.44$, $p<0.001$). Including the separate intercept and slope resulted in a 1% change in R-squared ($F(2,425)=9.18$, $p<0.003$).

THC concentration categories

Finally, in order to compare our data with the results of Dujourdy & Besacier (2017) from France and Stambouli et al. (2016) and Chouvy & Afsahi (2014) from Morocco, records of THC concentration were separated into three categories: (a) THC < 10%, (b) 20% > THC ≥ 10% and (c) THC% ≥ 20%. The results show a mixture of low- and medium-THC concentration cannabis in the years 2004-2011, followed by a dramatic increase in high-THC concentration cannabis and the near disappearance of medium- and low-THC concentration cannabis after 2011 (see Figure 2).

Time trends: CBD concentration and THC:CBD concentration ratio

During the years 2008-2017, 147 samples were analysed for both THC and CBD concentration at the regional forensic laboratory in Aarhus. The mean THC concentration was 17.2% (SD 6.1), mean CBD concentration was 6.2% (SD: 1.7) and the mean THC:CBD concentration ratio was 2.9 (SD: 1.2). The number of samples per year varied between 8 in 2010 and 31 in 2008 (see Table 4).

Figure 3 shows changes in the concentration of CBD and THC over time. The data show an increase in THC concentration from 2008-2017, whereas CBD concentration remained constant at approximately 6% during this time. Figure 4 shows CBD concentration as a function of THC concentration. There appears to be a curvilinear relationship between THC and CBD concentration. The regression model (see Table 5), indicates that the year of seizure and the linear association between THC concentration and CBD concentration accounts for 14% of the variance, and that the squared association between THC concentration and CBD concentration accounts for a further 44% of the variance. The Breusch-Pagan test for the model with THC squared indicated that there was no significant heteroscedacity in the model ($\chi^2(1)=1.06$, $p=0.30$).

Discussion

THC concentration of seized cannabis increased from 2000-2017

First, we examined changes in THC concentration of cannabis resin preparations confiscated by the police in Denmark from 2000 to 2017. Overall, our findings show that the THC concentration of seized cannabis resin samples increased substantially (three-fold) between year 2000 and 2017. THC concentration increased at a roughly similar rate across Denmark, although the increase was largest in the Eastern part of Denmark, containing the capital area. These findings add to previous evidence for increases in THC concentration in cannabis in Europe (Dujourdy & Besacier, 2017; Freeman et al., 2019; Pijlman et al., 2005; Potter et al., 2008; Potter et al., 2018; Zamengo et al., 2014, 2015), and in the United States (ElSohly et al., 2016; Smart et al., 2017). In line with a recent study in France (Dujourdy & Besacier, 2017) and trends reported across Europe (Freeman et al., 2019), our data suggest that the THC concentration of cannabis resin increased dramatically since 2011, which may be attributable to a new higher THC concentration type of resin being produced in Morocco (Chouvy & Afsahi, 2014; Stambouli et al., 2016). Another possible contributor to these

trends might be the emergence of resin produced from high-THC-concentration plants in Europe (EMCDDA & Europol, 2016). When considering the THC concentration of cannabis resin seizures from Europe, the trends described in this study (dramatic increase in high-THC-concentration cannabis and near disappearance of medium- and low-THC-concentration cannabis after 2011) are strikingly similar to those recently reported in France (Dujourdy & Besacier, 2017). In comparison to findings from Morocco, a compelling difference is that in both France and Denmark, nearly all of the cannabis resin analysed has a high THC concentration (>20% THC concentration). From 2012-2014, approximately 10% of resin samples in Morocco contained >20% THC (Stambouli et al., 2016). Our findings suggest that the emergence of high THC concentration cannabis resin is not only limited to France (Dujourdy & Besacier, 2017), but also occurs in Scandinavia, supporting other evidence that it has widely penetrated European drug markets (Freeman et al., 2019). Furthermore, our data suggest that the THC concentration of resin in Denmark may have been higher than those in Morocco during the same time period. These novel findings may indicate that resin found in Denmark (and perhaps elsewhere in Europe) could originate from domestic production within Europe rather than Morocco alone.

The increases in THC concentration of cannabis have been reported across Europe and the United States, despite regional differences in cannabis legislation. In Washington State, a dramatic increase was recently reported following legal sales (Smart et al., 2017), whereas in Denmark, the increase has occurred during a period of zero-tolerance against possession of cannabis and against driving a motor vehicle with blood testing positive for cannabinoids. The crackdown has been particularly hard in Eastern Denmark (Moeller, 2009), where we found the largest increase in THC concentration.

The reported increase in THC concentration in cannabis resin from 2000 to 2017, and the dramatic increase in high-THC-concentration cannabis resin products after 2011 is concerning,

considering the established positive association between high levels of THC and adverse health outcomes. Laboratory studies indicate that THC can induce psychotic-like symptoms in a subset of healthy volunteers (D'Souza et al., 2004; Morrison et al., 2009). These effects are dose-dependent, which implies that products with higher THC concentration may carry a greater risk of harm. In support of this, findings from naturalistic studies suggest that cannabis users do not fully adapt their smoking behaviour to differences in THC concentration (Freeman et al., 2014; van der Pol et al., 2014). This implies that products with higher THC concentration will deliver larger doses of THC to users. A case-control study of first-episode psychosis reported that daily use of cannabis with high THC concentration is associated with a 5-fold greater risk of psychotic disorder, compared to no use (Di Forti et al., 2015). By contrast, use of cannabis with low THC concentration was not associated with an increased risk of psychosis in that study, even if used daily. Frequent use of cannabis with high THC concentration was also found to be associated with a greater risk and frequency of relapse in people with first-episode psychosis (Schoeler et al., 2016). THC has demonstrated impairments to cognitive functions such as memory and learning in healthy controls and cannabis users (D'Souza et al., 2004; Morgan et al., 2012; Morrison et al., 2009). Use of cannabis with high THC concentration has also been linked to poorer addiction outcomes. Cross-sectional surveys show a stronger association between dependence and use of cannabis products with high THC concentration compared to products with lower THC concentration, particularly among young users (Curran et al., 2018; Freeman & Winstock, 2015), and a robust association between cannabis with very high THC concentration (butane hash oil) and dependence after accounting for possible confounds using both covariate adjustment and propensity score matching (Meier, 2017). In the Netherlands, changes in THC concentration of cannabis over a 16-year period were positively associated with the number of people entering drug treatment for cannabis

problems, after adjusting for age, sex, and non-cannabis drug treatment admissions (Freeman et al., 2018).

THC:CBD concentration ratio in seized cannabis resin increased from 2008-2017

Next, we examined changes in the THC:CBD concentration ratio in cannabis resin preparations confiscated by the Danish police from 2008 to 2017 in the Western part of Denmark. Overall, our findings show that the ratio of THC:CBD concentration increased substantially from 2008 to 2017. Our findings are consistent with data from France, in which the THC:CBD concentration ratio of cannabis resin rose substantially from around 2 in 2009 to 6 in 2016 (Dujourdy & Besacier, 2017). As in that study, we also found that THC concentrations rose whereas CBD concentrations remained stable during our study period, at ~6%. This is concerning, considering emerging evidence suggesting that CBD may counteract some of the harmful effects of THC. For example, CBD has been shown to enhance learning and memory, and inhibit THC-elicited impairments (Das et al., 2013; Englund et al., 2013; Morgan, Schafer, et al., 2010), and accumulating evidence suggests that CBD has antipsychotic and anxiolytic effects (Bergamaschi et al., 2011; Leweke et al., 2012; McGuire et al., 2018; Morgan et al., 2018; Schubart et al., 2011; Zuardi et al., 2009; Zuardi et al., 2006). For example, UK's low-THC-concentration cannabis resin, which has a 1:1 ratio of THC:CBD, was found not to increase psychosis risk (Di Forti et al., 2015), and cannabis users in the Netherlands who use cannabis with higher CBD concentration were significantly less likely to experience sub-clinical psychotic like effects (Schubart et al., 2011). Furthermore, a lower THC:CBD ratio was found to reverse the attentional bias towards cannabis cues compared to a higher THC:CBD ratio – suggesting a greater abuse potential in products with high levels of THC and low levels of CBD (Morgan, Freeman, Schafer, & Curran, 2010). These effects are mirrored in emerging functional imaging studies, which have revealed opposing acute effects of THC and CBD

in areas pivotal to key cognitive processes involved in the effects of cannabis, including amygdala (processing of emotional information); striatum, hippocampus and prefrontal cortex (processing of salience); and auditory- and visual cortex (processing of auditory and visual information) (Bhattacharyya et al., 2010; Borgwardt et al., 2008; Fusar-Poli et al., 2009; Winton-Brown et al., 2011). Taken together, the increase in THC concentration and THC:CBD concentration ratio reported here and by Dujourdy and Besacier (2017), suggest that cannabis users may be exposed to higher doses of THC and/or lower doses of CBD. This may mean that they experience stronger effects, and in the long term, may experience greater harms.

Interestingly, we observed a curvilinear relationship between THC and CBD concentration: in cannabis resin samples <20% THC, CBD concentration increased at a comparable level. However, in cannabis resin samples >20% THC, mean level of CBD concentration decreased. Because THC and CBD are produced from a single precursor (cannabigerol, CBG), a plant that produces more THC will typically produce less CBD as a result (and vice versa). This is genetically determined with plants being either THC dominant, CBD dominant, or mixed THC/CBD (de Meijer et al., 2003). When measuring cannabinoids within a single plant, it might be expected that as THC increases, CBD would decrease due to the common precursor. However, as resin contains material from many different plants, there may be other reasons for changes in THC and CBD. Importantly, these include the mixture of different types of plants used (e.g. THC dominant, CBD dominant, or mixed THC/CBD), the efficiency of extraction, and other cannabinoid biosynthesis pathways (e.g. Cannabichromene (CBC) is also synthesised from CBG). Landrace crops such as those in Morocco have typically contained a mixture of all three chemotypes. Depending on how efficient the extraction technique is, there may be more or less cannabinoids, but the ratio of THC to CBD can be expected to remain constant as long as the same mixture of plant chemotypes are used to make the resin. This may explain the first part of Figure 4 where THC concentrations were low to

medium (i.e. the resin samples showed the same THC:CBD concentration ratio, but with differences in concentrations of both cannabinoids due to the efficiency of extraction). The second part of Figure 4 where THC concentrations were medium to high is likely to be explained by changes in the type of plants used (i.e. more THC-dominant plants) which would increase THC concentration and concomitantly reduce CBD concentration. Although these interpretations are somewhat speculative, our finding that CBD concentrations remained relatively stable over time at ~6%, is in line with findings in France (Dujourdy & Besacier, 2017) and clearly shows that CBD-producing cannabis plants are still used in new resin production methods. These may be combined with plants producing higher THC concentrations and/or more efficient extraction methods, resulting in a higher THC and THC:CBD concentration ratio despite a stable concentration of CBD. These findings show that European cannabis resin differ significantly from other cannabis resin markets. For example, the most recent data from the United States (Chandra et al., 2019) shows that THC concentrations in resin have risen in the last decade (rising to 46% THC in 2017) whereas CBD levels have remained consistently low (0.4% in 2017).

Importance of monitoring cannabis products

Taken together, these data underscore the urgent need to monitor and measure the THC concentration and THC:CBD concentration ratio in cannabis products nationally and in studies of cannabis and its impact on health related issues, in order to strengthen cross-national comparisons and monitoring of regional and international trends (Englund et al., 2017; Freeman & Swift, 2016; Rømer Thomsen et al., 2017).

In order to improve the validity and reliability of cannabis monitoring, randomized sampling at the retail level is the optimum methodological approach, as adopted in the Netherlands (Niesink, Rigter, Koeter, & Brunt, 2015; Pijlman et al., 2005), although this is not possible in illicit cannabis

markets. However, increasing the sample size each year and using consistent sampling methods across successive years could have improved the reliability of our estimates, and we highly recommend Danish authorities to improve this in future forensic surveillance.

Furthermore, we strongly recommend Danish surveillance programs to measure different types of cannabis products. Currently, national surveillance programs of cannabis use and admissions to treatment for drug use disorders only measure cannabis resin or cannabis as a whole. At a minimum, national surveillance programs should survey the four broad categories: high-THC-concentration/sinsemilla (unpollinated flower), herbal (pollinated flower), hash/resin (compressed cannabis trichomes along with plant matter) and cannabis concentrates (such as hash oil, wax dabs, butane hash oil, shatter etc.) (Potter et al., 2018).

Limitations

Some limitations in this study must be acknowledged. Only confiscated drugs could be included, and the number of samples analysed compromise a small percentage of the total amount of samples confiscated by Danish police; further, the likelihood of a seizure being analysed vary depending on the circumstances surrounding the seizure, between areas, and over time. Furthermore, we were only able to obtain information on CBD concentration from the forensic laboratory in Aarhus. These data should therefore be interpreted as providing an estimate of cannabis resin composition rather than a precise indication. The changes in methodological procedures (i.e. the more systematic sampling from 2014 and onwards) should be considered when interpreting trends in the data over time. However, the increase in THC concentration was apparent and robust until 2013, and while a decrease in THC concentration was observed after 2013, levels remained much higher, mirroring the situation in France in terms of timing and effects.

Conclusion

The THC concentration of seized cannabis resin increased three-fold in Denmark between 2000 and 2017. The trends reported here (dramatic increase in cannabis resin with high THC concentration and near disappearance of cannabis resin with medium- and low THC concentration after 2011) are strikingly similar to trends reported in France. The ratio of THC:CBD concentration in seized cannabis resin rose substantially from 2008 to 2017, with CBD concentrations remaining stable at ~6%. These data, and those reported by Dujourdy and Besacier (2017), suggest that cannabis users in Europe may be exposed to higher doses of THC and/or lower doses of CBD. This may mean that they experience stronger effects, and in the long term, may experience greater harms. Policy makers, treatment professionals, and educators should be aware of this potential risk. These findings provide important new insights into changes in international drug markets, at a time of rapid policy change surrounding cannabis.

Figure titles and notes

Figure 1. THC concentration of cannabis resin samples as a linear-quadratic function of year of seizure, 2000-2017, in three regions of Denmark

Notes: The values show the median, inter-quartile range, and outliers for THC concentration. Whiskers show the adjacent values (the most extreme values within 1.5 times the inter-quartile range of the nearer quartile).

Figure 2. Distribution frequency of cannabis resin records for three THC concentration categories, 2000-2017

Figure 3. Changes in the concentration of THC and CBD in Western Denmark, 2008-2017

Figure 4. Bivariate scatterplot of THC and CBD concentration with linear-quadratic fit (99% confidence interval)

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