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Development of a Vaping Machine for the Sampling of THC and CBD Aerosols Generated by Two Portable Dry Herb Cannabis Vaporisers

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Cannabis · CBD · THC · Vaping machine · Vaporiser

Abstract
Cannabis sativa is known for its recreational use, but also for its therapeutic potential. There has been wide discussion over the use of cannabis for medical purposes in recent years, especially because a consensus has not been reached regarding its risk/benefit balance. Among the more common modes of administration, vaping with a vaporiser is most frequently used for self-medication. Vaping seems to be a better alternative to preventing adverse health effects due to toxic compounds produced during combustion when cannabis is smoked. However, the delivery kinetics and efficiency of most portable vaporisers are not fully characterised with an appropriate vaping regime. This determination requires a specific vaping machine operating under realistic puffing conditions. In this study, a vaping machine was conceived to fit with the common uses of portable vaporisers that requires conditions different from those used for electronic cigarettes. The experimental setup in this study was optimised to sample aerosolised cannabinoids. The delivery kinetics, efficiency, and decarboxylation yields of two commercially available vaporisers (DaVinci® and Mighty Medic®) were evaluated for delta-9-tetrahydrocannabinol (THC) and cannabidiol (CBD). Among all tested sampling supports, the glass fibre filter is the most efficient medium to collect mixed THC and CBD aerosols. From the delivery kinetics of cannabinoids, a single-parameter model was used to calculate the extraction coefficient of each vaporiser. The results show that the Mighty Medic® vaporiser had a higher extraction coefficient (0.39) and a more immediate release of cannabinoids than the DaVinci® vaporiser (0.16), which had a gradual and slower rate of vaporisation. This parameter could be a quantitative input in pharmacokinetic models of administration of volatile compounds using vaporisers and a useful tool for the comparison of vaporisers.

Introduction

The medical use of cannabis, either prescribed or self-medicated, is becoming ever more popular and the social pressure to legalise its use is increasing [1]. Swiss law considers cannabis a narcotic drug, and the therapeutic administration of its flower tops is not yet allowed. Cur-

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rently, only one product is licensed for sale. As in many other countries, a delta-9-tetrahydrocannabinol (THC) and cannabidiol (CBD) 1:1 from standardised cannabis extracts can be administered as an oromucosal spray (Sativex®) to reduce spasticity symptoms in multiple sclerosis [2]. In Switzerland, the use of cannabis is limited to a few applications, such as the treatment of chronic pain and spastic disorders related to multiple sclerosis or nausea induced by chemotherapy [3].

Cannabis sativa L. (Cannabaceae) is a plant with controversial medicinal benefits resulting from lack of rigorous randomised double-blind, placebo-controlled studies [4, 5]. Nevertheless, according to Zettl et al. [6], the efficacy of the THC-CBD oromucosal spray has been proven in randomised, controlled clinical studies. The dose and frequency of consumption [7], the usual co-use of cannabis and tobacco [8], the age at the beginning of consumption [9, 10], the routes of administration, and the context and the profiles of users significantly influence the effects and reactions of consumers of cannabis extracts and/or raw flower tops [11]. In addition, a small number of users appear to be especially vulnerable to the side effects and addictive properties of cannabis [12]. This vulnerability is very likely under genetic [13] and environmental influence [14]. To be supported by the Swiss public health system, any treatment must be adequate, effective, and economical [15].

Because of its high price, in Switzerland, cannabis medical treatment is not systematically reimbursed through insurance and is instead treated on a case-by-case basis [16]. For these reasons, people commonly purchase cannabis on the legal or black market for self-medication. In contrast to medically accepted dosage forms such as oral pills or sublingual sprays, raw cannabis is generally smoked as joints when self-medicated, either with or without tobacco present. One of the main motivations for this use is to manage insomnia disorders [17]. The inhalation of cannabis joints is certainly the most popular administration method for those who practice self-medication, but also among recreational and compulsive users [7]. The combustion and volatilisation of cannabinoids is improved by mixing cannabis with tobacco [18]. Through this route of administration, the delivery of cannabinoids is rapid and efficient. However, smoking of cannabis, especially when mixed with tobacco, may be harmful for the consumer [7] and for those who passively inhale the side-stream smoke.

For the sake of harm reduction, vaporisation of raw cannabis flower tops at low temperatures is preferred over combustion of mixtures of cannabis and tobacco at high temperature (700–900 °C) [19]. Combustion of these plant materials generates a wide range of toxic pyrolysis substances. Furthermore, the combined inhalation of nicotine and THC induces dual drug dependence and addiction. The vaporisation of raw cannabis below its combustion point (about 230 °C) reduces the formation of toxic by-products and the occurrence of pulmonary symptoms [20]. Since tobacco is not needed, the risks of dependence and addiction caused by nicotine inhalation are reduced. Compared to the oral route that is slow to cause an effect, unpredictable and with interindividual variability in pharmacokinetics [21], vaporisation provides delivery characteristics (yield and kinetic) that are considered very similar to those of smoking. The only requirement is that the temperature of the heating chamber prefilled with grinded cannabis flower tops be high enough (>100 °C) to rapidly convert all the acidic precursors (THC acid A [THCA] and cannabidiolic acid [CBDA]) of the cannabinoids into their corresponding active and neutral forms (THC and CBD) [22, 23] and to subsequently vaporise them.

Depending on the wanted effect the users will select different varieties and chemovars [24]. Cannabis smoked for its euphoric and intoxicating properties is generally very rich in THC and poor in CBD, while a more balanced composition between THC and CBD is preferred for medical cannabis. When combined with THC, high doses of CBD reduce the intoxicating and unwanted side effects of THC [25]. The presence of other substances, such as terpenes (e.g., myrcene and caryophyllene), which influence the aroma and pharmacological properties of cannabis strains through their synergistic ("entourage") effect [26], may also play a role in consumer choice. One of the advantages of vaporisation is an early onset of the effects, which start between 5 and 10 min compared to oral administration that is significantly delayed in its effects (60–180 min) [20].

Many options and at least three main classes of electronic devices exist for the aerosolisation of cannabinoids: desktop stationary vaporisers that are unfit for transport – e.g., Volcano® (Storz & Bickel, Tuttlingen, Germany) [27, 28]; e-liquid portable atomisers from e-cigarettes that are dedicated to the vaporisation of propylene glycol/glycerol cannabinoid mixtures [29–31]; and hand-held portable dry herb vaporisers [32, 33]. When compared to desktop devices, portable vaporisers have the advantage of being small, easily transportable, discreet, easy to use, cordless, and reasonably priced. Nowadays there is a wide variety of equipment that is marketed, easily purchased on the web, and constantly changing and

evolving (e.g., vaporisers described by Red Vape [34]). Some vaporisers are offered for sale for very short periods, while others seem to be more successful and remain available for purchase for a longer time. Commercially available cannabis vaporisers differ in design, construction, handling, and performance. A rapid and easy method to assess the pros and cons and to evaluate the suitability and effectiveness under realistic conditions of these vaporisers is necessary to sort all existing equipment and offer patients the most appropriate portable vaporisers able to alleviate their pathology.

These portable electronic vaporisers must gradually deliver a therapeutic dose of cannabinoids in a reasonable number of puffs. The slow incrementation of doses combined with titration of effects should minimise the risks of unwanted adverse effects [35, 36]. Therapeutic unit doses, vaporised and typical for raw cannabis flower tops, are about 2–5 mg for THC. For medical indications, many patients obtain some benefits with daily oral doses of 5–20 mg of CBD. The effective dose of CBD administered as an aerosol using a vaporiser is not yet known [4, 20]. However, a few recent, randomised, placebo-controlled trials used vaporisation (especially with desktop vaporisers) as a means of cannabinoid administration. CBD was inhaled at doses ranging from 4 to 400 mg in combination with or without THC [25]. Forensic investigations were also carried out, but with varieties rich in THC and low in CBD as preferred by most recreational users [37]. Epidemiological studies reported that about one-third of US patients enrolled in an electronic survey were using vaporisation, while still the majority preferred to smoke conventional joints [38].

In this study, we evaluated two commercially available portable vaporisers for their vaporisation efficiency and delivery performance using a homemade vaping machine. Various configurations of the machine were tested. The inhalation pattern was standardised to assess inhaling rates, volumes, and puff durations as well as interpuff intervals that are as close as possible to real-life conditions. We also put the focus on finding the best cannabinoid aerosol sampling materials. To this aim, we evaluated different types of sampling media. We also discuss the pros and cons of two vaping devices used in this study and make recommendations for adequate use of cannabis vaporisers.

Materials and Methods

Chemicals

Pharmaceutical-grade cannabis female flower tops Bedrocan® – rated THC 5.0% (w/w) and CBD 7.5% (w/w) (sum of the acidic and neutral forms) – were obtained from Bedrocan International BV (Veendam, The Netherlands). Cannabinoid standards were purchased from Lipomed AG (Arlesheim, Switzerland): THC (Dronabinol), 1 mg/mL in ethanol; THCA, 1 mg/mL in isopropanol; CBD, 1 mg/mL in methanol (MeOH); CBDA, 1 mg/mL in acetonitrile; and cannabinol (CBN), 1 mg/mL in MeOH. All organic solvents, dichloromethane, MeOH, acetone, and formic acid were of analytical grade (Sigma-Aldrich [Buchs, Switzerland] or Merck). Glass fibre filters (Whatman GFB, i.d. 37 mm) mounted in a styrene holder (SKC Inc., USA) were provided by VWR (Schlieren, Switzerland). Empty cartridges (EZ-Pak, i.d. 21.4 mm, length 80 mm) were provided by BGB Analytik (Böckten, Switzerland) and filled with 15 g of polyaromatic adsorbent resin for hydrophobic compounds (XAD2, Amberlite with a particle size of 250–700 μm) provided by Sigma-Aldrich.

Vaporisers

Two vaporisers with distinct heating modes were tested. The first vaporiser, mainly employed for medical purposes (Mighty Medic® from Storz & Bickel), has a hybrid heating system combining convection (the air is heated and then sucked through the cannabis) and conduction. The second vaporiser (DaVinci® vaporiser from Organicix LLC) works only by conduction, the cannabis being directly in contact with the heating part. The choice of these vaporisers among other available products was based on sales data and grey literature available in Switzerland. These two brands are top sellers and readily available in shops and via the Internet.

Experimental Setup

A vaping machine was made to generate large puffs consistent with the use of vaporisers. Most vaping/smoking machines used to test tobacco cigarettes or e-liquid electronic cigarettes have a limited puff volume, usually between 35 and 100 mL, which complies with common standards [39, 40]. This range of volumes aims to reproduce a puff controlled by the oral cavity volume. However, inhalation through a vaporiser is more usually related to the larger thoracic volume. Due to the lack of experimental data, the volume of air breathed for each 5-s puff corresponds to the low value of the standard volume of air inhaled by a person at rest. The inhalation topography is assumed to be similar to the one described by Wilsey et al. [41]. A volume of approximately 500 mL was also used in experiments aiming to develop a puff topography instrument for high flow rate smoking devices, such as narghile water pipe and chicha [42, 43]. The inhaled puff volume generated by these devices is very likely similar to that of portable vaporisers. A picture and a schematic representation of the machine are shown in Figure 1. A first circuit connects the vaporiser mouthpiece, the front and back sampling medium, and the pump. A second circuit connects a dummy sampling medium to the pump. This double circuit prevents sudden variations in flow when the solenoid valves are switched. The main airflow of a diaphragm pump was adjusted to 6 L/min with a needle valve using a calibrated carbon-piston flowmeter (Dry-Cal DC Lite; Bios, USA). The puffs are triggered by the opening of valve V2 and the simultaneous closing of valve V1. The vaping regime was set to generate a 500-mL puff lasting 5 s with a frequency of 2 puffs/min. Valves and delays were controlled by a microcontroller with a puff counter (Arduino® development board).

Table 1. Summary of experimental conditions

Sampling support	Number of puffs	Vaporiser	Replicates/ experiment
XAD2 cartridge	0–1–2–5–10–20–30	DaVinci®	1
		Mighty Medic®	1
Glass filter	0–5–10–15–20	DaVinci®	1
		Mighty Medic®	1
XAD2 cartridge	10	DaVinci®	10
		Mighty Medic®	7
Glass filter	10	DaVinci®	4
		Mighty Medic®	4
XAD2 cartridge and glass filter	10	DaVinci®	3
		Mighty Medic®	3

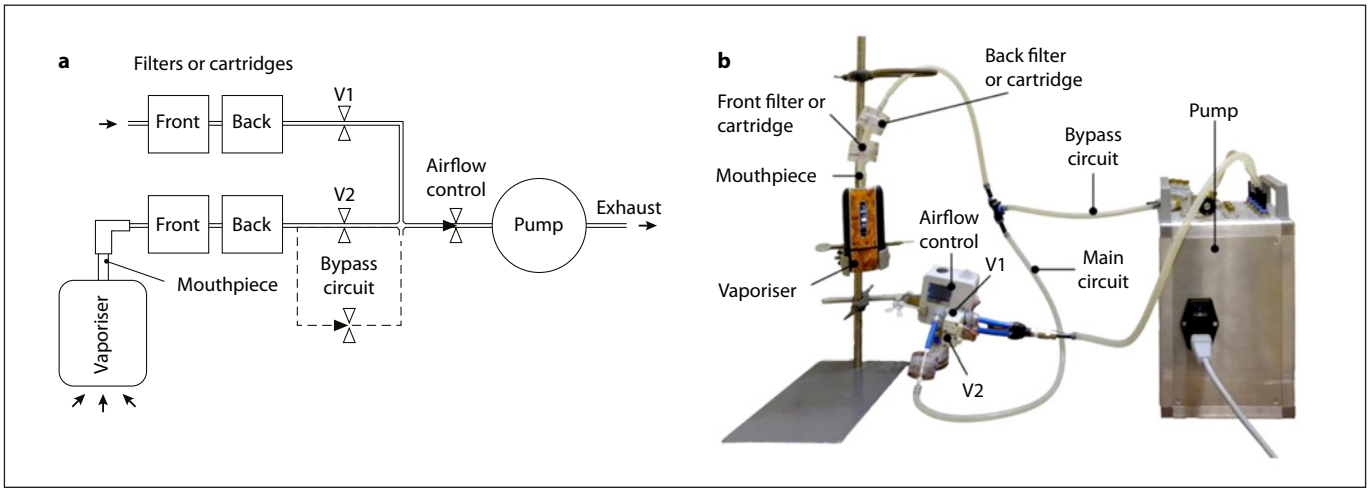

Fig. 1. Diagram (**a**) and image (**b**) of the vaping machine and the experimental setup.

Vapour Generation and Sampling

For each test, 150 mg of finely ground cannabis flower tops were introduced into the vaporiser heating chamber. The vaporiser was then turned on and the temperature set to 210 °C, the maximum temperature shared by both devices. Once the set temperature was reached, the first 5-s puff was triggered after 25 s. Depending on the experiment this 30-s pattern was repeated between 1 and 30 times (Table 1).

XAD2 cartridges were desorbed four times with 10-mL portions of MeOH. Glass filters were immersed in three successive volumes of 10 mL of MeOH, vortexed, and left stand for a minimum of 30 min. For each sampling support, all the portions were pulled together before analysis. After each assay, the mouthpieces and the inner parts of the vaporisers were washed in 30 mL of MeOH to recover the condensed fraction.

In order to evaluate the loss of volatile compounds by leakage or diffusion through the body of the vaporiser, preliminary experiments were carried out with and without a bypass circuit (Fig. 1). The bypass circuit is a small residual air flow (0.06 mL/min) used to maintain a small negative pressure in the vaporiser body between puffs, which keeps vaporised compounds in the system. Subsequently, all experiments were carried out with the open derivation circuit in order to be able to calculate the global mass balance.

Finally, after the vapour generation, the remaining plant heated residues were extracted with 8 mL of MeOH/dichloromethane (9:1 v/v), sonicated for 10 min, agitated for 20 min on a reciprocal horizontal shaker, and then centrifuged for 20 min at 3,400 rpm. The supernatant was transferred to a graduated flask and adjusted to 10 mL with MeOH.

Table 1 summarises all the experiments carried out during the study and indicates the tested experimental conditions. Thirty-five experiments were performed in total and the data issued from each puffing session were analysed and used to determine a kinetic puffing profile and to calculate the vaporisation yield for each vaporiser. The results also allowed us to calculate the recovery efficiency for both sampling media, i.e., XAD2 and glass fibre filters.

Table 2. Results of the experiments carried out to measure the recovery efficiency of two supports: percentage of THC and CBD recovered on XAD2 and glass fibre filters using the Mighty Medic® vaporiser

Percent of the loaded amount (150 mg of Bediol® flower tops) THC: 7.5 mg = 100% CBD: 11.2 mg = 100%	Type of sampling support			
	front: glass fibre filter back: glass fibre filter		front: XAD2 cartridge back: glass fibre filter	
	THC	CBD	THC	CBD
(1) Front support	84%	76%	51%	52%
(2) Back support	0%	0%	19%	17%
Recovery efficiency (1) / [(1) + (2)]	100%	100%	73%	75%

Sampling Support Recovery Efficiency

The recovery efficiency was calculated from the amount found in the front and back supports (Table 2). Six experiments were carried out with two sampling supports connected in series: XAD2 cartridge or glass fibre filters in front position, and glass fibre filters in back position.

Optimal Desorption Volume

The minimum volume required to desorb the cannabinoids from the sampling supports was determined by using successive unit volumes of MeOH to wash a sampling support after a 10-puff session. Each unit volume of 10 mL was separately collected and analysed by high-performance liquid chromatography coupled to diode array detection (HPLC-DAD, Agilent 1100).

Cannabinoid Identification and Quantification

Unequivocal identification of the main neutral cannabinoids was performed by gas chromatography-mass spectrometry (GC-MS) [44]. Native acid precursors (THCA and CBDA) of neutral cannabinoids were identified after silylation with N-methyl-N-(trimethylsilyl)trifluoroacetamide. Terpenes were tentatively identified using the NIST 2017 mass spectra database. Quantification of cannabinoids of plant material extracts, wall condensates, unheated and heated cannabis flower top residues, and aerosols collected in various sampling media were performed by HPLC-DAD (Agilent 1100) for all main five cannabinoids (THC, THCA, CBD, CBDA, and CBN) [44]. The injection volume was 10 µL. Cannabinoids were separated on a Macherey-Nagel 250/3 Nucleodur 100-5 C8ec reversed-phase column (5 µm particle size). Two eluents were used: A = MeOH-deionised water (1:1 v/v) with 25 mM formic acid, and B = MeOH with 25 mM formic acid. Linear gradient elution was obtained by mixing increasing amounts of eluent B (from 40 to 100% in 25 min). The column oven was set at 45 °C. Absorption signals of cannabinoids were monitored at 210, 222, and 275 nm (bandwidth = 5 nm). The reference wavelength was fixed at 450 nm (bandwidth = 50 nm). Calibration curves were prepared with increasing concentrations of cannabinoids for each standard (0, 1, 2, 5, 10, 25, 50, 75, and 100 µg/mL) [45]. Validation was obtained by seven repetitive analyses of six quality controls from 10 to 100 µg/mL for three successive days. Interday and intermediate precisions for THC and CBD were <5% except for the lowest quality control level (10 µg/mL) for which it was <15%. The limit of quantification was 5 µg/mL and the limit of detection was 1 µg/mL. The coefficient of correlation was >0.99 for all cannabinoids [45].

Results and Discussion

Identification and Quantitation of Cannabinoids in Bediol® Flower Tops

In Bediol® tops extract, neutral and acidic forms of THC, CBD and also traces of cannabigerol, cannabichromene, and CBN were identified by GC-MS. Quantification by HPLC-DAD of THC/THCA and CBD/CBDA was 5.0% (w/w) and 7.5% (w/w), respectively.

Decarboxylation Yield

For both vaporisers neither the acidic precursors THCA nor CBDA were detected in the cannabis residue or the vapour after four puffs. The decarboxylation is therefore considered complete already after 2 min.

Optimal Desorption Volume

After two successive washes of the glass fibre filter, the third 10-mL portion contained a quantity of cannabinoids below the limit of quantification. Therefore, the optimal desorption volume for the glass fibre filter was set to three portions of 10 mL. Using the same approach, the optimal volume of XAD2 cartridge desorption was set to four portions of 10 mL.

Sampling Media Recovery Efficiency

The recovery efficiency of the glass fibre filters was >99% for both THC and CBD. For the XAD2 cartridge, the recovery efficiency was significantly lower, with values of 73 and 75% for THC and CBD, respectively. The low recovery efficiency could be due to several factors: (1) the high air flow through the support that leads to a reduced total capacity of the media, (2) the large particle size of the medium that reduces the air/resin interaction, (3) a non-optimised compaction of the filling medium that promotes the formation of wide air passages, (4) the low affinity of the phase with the cannabinoids, and

Table 3. Percentage of the total amount of THC or CBD loaded in the vaporisers, calculated for the sampling support, residue, and mouthpiece after ten puffs (total time for ten puffs with intervals: 5 min)

	DaVinci® vaporiser				Mighty Medic® vaporiser			
	glass fibre filter		XAD2		glass fibre filter		XAD2	
	THC	CBD	THC	CBD	THC	CBD	THC	CBD
Sampling support, %	42±6	43±5	19±14	26±13	84±4	76±4	57±11	60±14
Residue, %	34±8	28±6	50±12	41±8	0±0	2±0.4	0±0	2±0.5
Mouthpiece, %	12±2	13±2	9±1	11±1	24±1	21±0.5	24±1	21±1
Total, %	88±7	84±5	78±8	78±8	108±4	99±4	81±12	83±15

(5) the saturation of the medium surface by other compounds. Among these factors, it is likely that it is the strong airflow and the coarse particle size of the medium that decrease the recovery efficiency of cartridges for cannabinoid aerosols. Unlike the XAD2 resin, glass fibre filters captured all the cannabinoids, probably due to the low porosity and highly specific surface of the filters, which favour aerosol impaction.

However, at present there is poor knowledge regarding the physicochemical properties of vaporiser aerosols [46], and further elucidation of these characteristics is needed for a better understanding of their interaction with different sampling supports.

Global Vaporisation Efficiency

During the preliminary experiments, tests were performed with and without the bypass circuit (Fig. 1). The comparison of the two configurations allowed us to estimate leakage losses of about 20% for the DaVinci® vaporiser and 24% for the Mighty Medic® vaporiser after ten puffs. These losses could be due to the internal geometry of the devices and the tightness of the closing seals.

Table 3 shows the percentage of the total amount of THC or CBD loaded in the vaporisers found in the sampling support, the residual plant material, and the mouthpiece after ten puffs.

Using results from the glass fibre filters, for the Mighty Medic® vaporiser, the amount of vaporised THC and CBD was 84 and 76%, respectively. In the residue, these percentages were <1% and 2% for THC and CBD, respectively. About 24% of THC and 21% of CBD were found in the mouthpiece of the vaporiser. The total amount found in the vapour phase, in the residue, and in the mouthpiece was about 100%. For this device, the vaporisation of cannabinoids is considered complete after ten puffs.

For the DaVinci® vaporiser, the amount of vaporised THC and CBD was 42 and 43%, respectively. In the residual plant material, these percentages were 35 and 28% for THC and CBD, respectively. About 12% of THC and 13% of CBD were found in the mouthpiece of the vaporiser. The total amount found in the vapour phase, in the residue, and in the mouthpiece was <88%. For this device, the vaporisation of cannabinoids is not complete after ten puffs, and the mass balance shows a loss of about 12 and 16% for THC and CBD, respectively. We suggest that these losses can be explained by the hollow cavity under the heating chamber of this device, which could lead to the loss of a few fragments of cannabis material, and also by the fact that one of the moving parts of the retractable mouthpiece was not desorbed.

Kinetics of Cannabinoid Delivery

A kinetic profile of cannabinoid delivery (from 0 to 20 puffs) was performed for each vaporiser using either XAD2 cartridges or glass fibre filters. Figure 2 shows the amounts of THC and CBD found in the residue, the mouthpiece, and the trapping support versus the number of puffs. After five puffs, >90% of the cannabinoids were vaporised by the Mighty Medic® vaporiser, while only half of the cannabinoids were vaporised with the DaVinci® device. For the Mighty Medic®, the vaporiser rate was higher compared to the DaVinci®, and the cannabinoids reached a non-detectable amount between 10 and 15 puffs in the residue.

The THC and CBD content in the plant residue of the DaVinci® vaporiser presented a more gradual decrease. Twenty puffs were not enough to vaporise the total cannabinoids loaded in the heating chamber. For both vaporisers, small amounts of cannabinoids condensed in the mouthpiece, and these quantities marginally increased over time with the number of puffs.

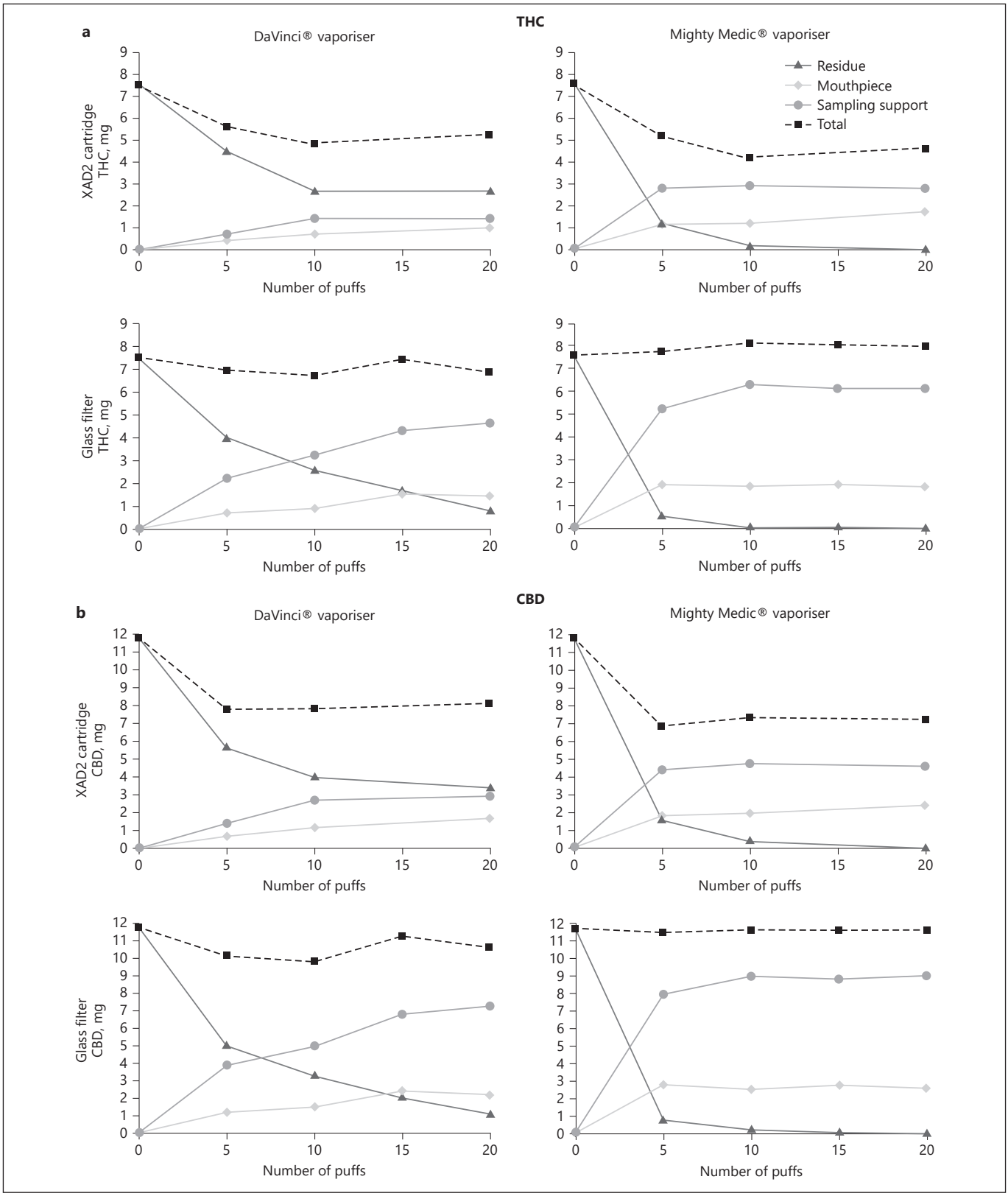

Fig. 2. Kinetic profiles of THC (**a**) and CBD (**b**) amounts found in different parts of the vaping machine connected to the DaVinci® or Mighty Medic® vaporisers and using either XAD2 cartridges or glass fibre filters as sampling support (total time for 20 puffs and interpuffs: 10 min).

Differences in delivery kinetics could be explained by the mode of heat transfer, resistance the device creates during each puff, the geometry of the filling chamber, the path of the airflow, and other factors. Both convection and conduction occur in the Mighty Medic® vaporiser, while only conduction is used in the DaVinci® device. The DaVinci® vaporiser is usually employed for recreational purposes, and a more gradual cannabinoid delivery rate could be preferred by the users. This pattern of delivery could also be an advantage for new patients for whom a slow incrementation of cannabis doses could be more appropriate and prescribed [20].

Kinetic Modelling

The amount of cannabinoids per puff decreased rapidly for both vaporisers (Fig. 3). For each puff, the sum of volatile compounds transferred into the vapour was a fraction of the total amount available in the heating chamber. Assuming that this fraction is a constant, a simple kinetic model of the quantity of vaporised cannabinoids Q_v in mg could be defined as follows:

$$\frac{dQ_v}{dP} = \left(Q_{max} - Q_v\right) k_e \quad (1)$$

where P is the number of puffs, Q_{max} is the maximal quantity in mg that can be extracted, and k_e is the extraction coefficient. The integrated form of this equation can then be written as follows:

$$Q_v = Q_{max} - Q_{max} e^{-keP} \quad (2)$$

Finally, the vaporised amount Q_v can be expressed as a percentage of the maximal quantity that can be extracted – Q_{max} in mg:

$$Q_v\% = \frac{Q_v}{Q_{max}} \times 100 = 100 - 100 e^{-keP} \quad (3)$$

Fitting our experimental data Q_v% versus the number of puffs using equation 3 allows for the estimation of the k_e parameter for both vaporisers. A linear least squares regression method was performed (Fig. 3). Here, the extraction coefficient of the DaVinci® device (k_e = 0.16) is smaller than the k_e value for the Mighty Medic® device (k_e = 0.39). The extraction coefficient can be interpreted so that the Mighty Medic® extracts about 39% of the available cannabinoids in the heating chamber per puff, while the DaVinci® vaporiser extracts only 16%. No significant difference in the k_e value was found between CBD and THC. The similar vaporisation kinetics of both cannabinoids may be due to the very close vapour pressure of THC and CBD above 140 °C and to their similar temperature of decarboxylation [47]. The heat transfer modes of the heating chamber could explain the differences in k_e. The temperature drops during a puff in the DaVinci® vaporiser could be higher than in the Mighty Medic® vaporiser where the air inlet is preheated. Although the vaporisation is faster for the Mighty Medic®, the DaVinci® allows a more gradual dosage, with 90% of the dose delivered after fifteen puffs.

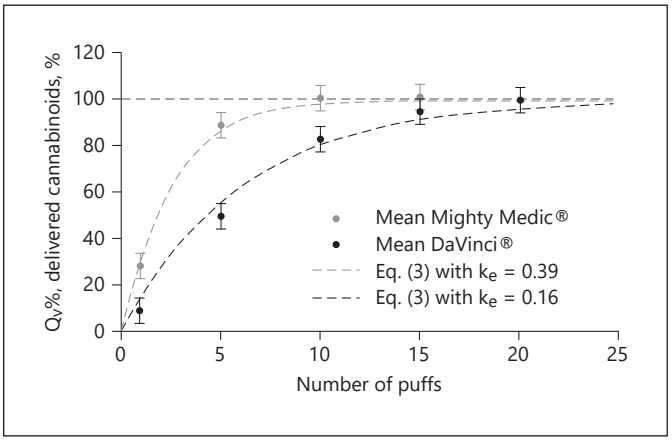

Fig. 3. Cannabinoid content in the aerosol expressed in percent of the final vaporised quantity.

In the literature, we found several attempts to design efficient vaping systems to trap cannabis aerosols. Good efficiency in collecting cannabinoids was achieved using a table vaporiser with a fibre glass filter by Hazekamp et al. [27]. Lanz et al. [47] tested five commercial vaporisers and also found that the decarboxylation efficiency was almost complete after 3 min of continuous aspiration at 420 mbar with a temperature set at 210 °C. However, their experimental design differed from ours in that they operated under continuous aspiration conditions while we used more realistic aspiration/rest cycle conditions. Hädener et al. [48] used a vaping machine but for dabbing butane hash oil, while Sheehan et al. [49] used a smoking machine to characterise the chemical and physical composition of cannabis smoke. This underlines the need to standardise experimental conditions for testing portable cannabis vaporisers.

Conclusion

An experimental setup was developed to generate vaporiser puffs under realistic conditions of use taking into account the volume, frequency, and duration of puffs.

Different sampling media and two vaporisers were compared. The glass fibre filter appeared to be the most appropriate sampling medium for THC and CBD cannabinoids, even with an airflow up to 6 L/min. From the delivery kinetics observed for the two vaporisers, a one-parameter model is proposed. We suggest that this kinetic model, based on the extraction coefficient, could be adapted for comparing devices to each other. Mighty Medic® vaporisers have an extraction coefficient of 0.39 and the DaVinci® vaporiser has an extraction coefficient of 0.16. This parameter could be a quantitative input in pharmacokinetic models of administration of volatile compounds using vaporisers.

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Statement of Ethics

The authors have no ethical conflicts to disclose.

Disclosure Statement

The authors have no financial or competing interests.

Author Contributions

C. Giroud and N. Concha-Lozano conceived and designed the experiments. L. Carrara performed the experiments. L. Carrara, C. Giroud, and N. Concha-Lozano analysed the data. L. Carrara, C. Giroud, and N. Concha-Lozano wrote the paper.

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