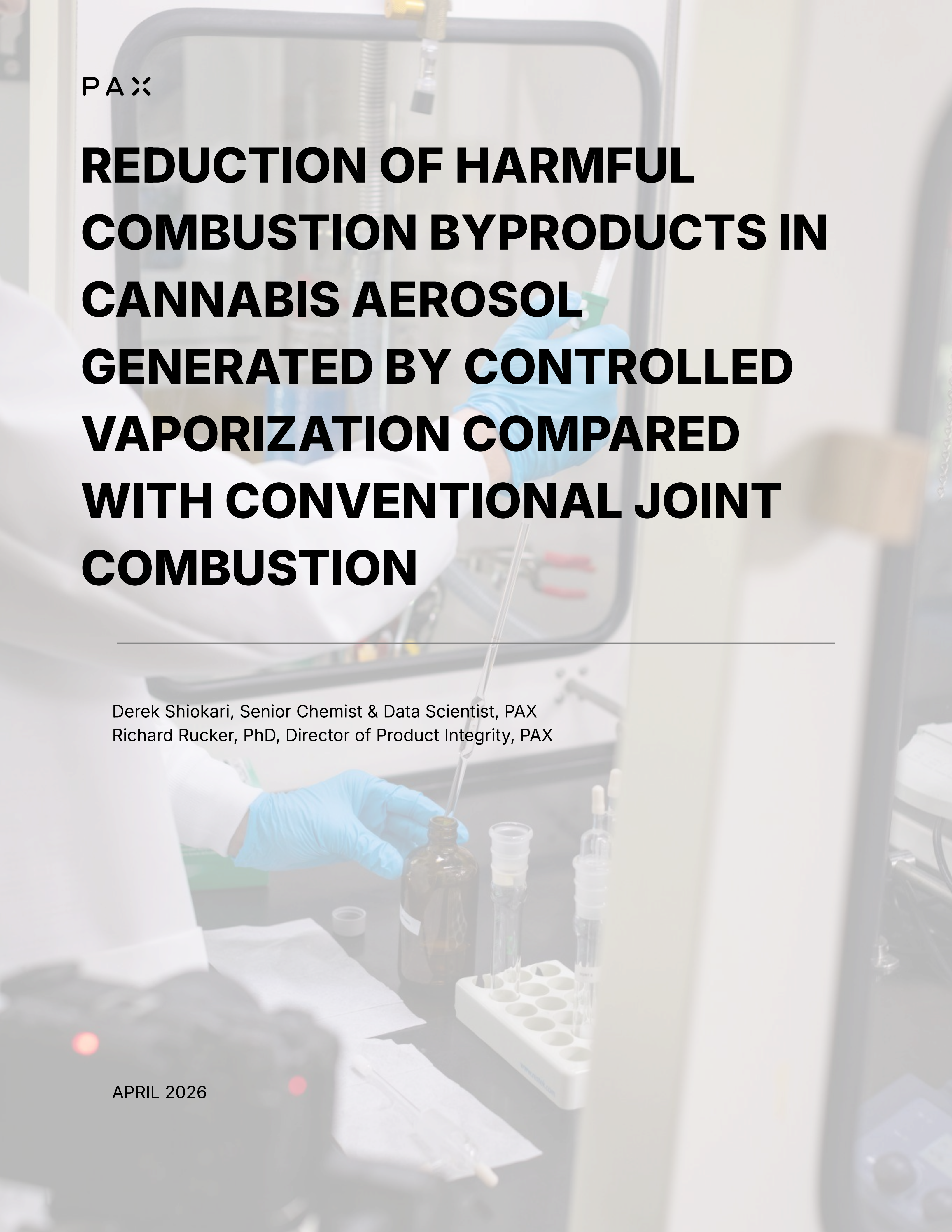

PAX

REDUCTION OF HARMFUL COMBUSTION BYPRODUCTS IN CANNABIS AEROSOL GENERATED BY CONTROLLED VAPORIZATION COMPARED WITH CONVENTIONAL JOINT COMBUSTION

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ABSTRACT

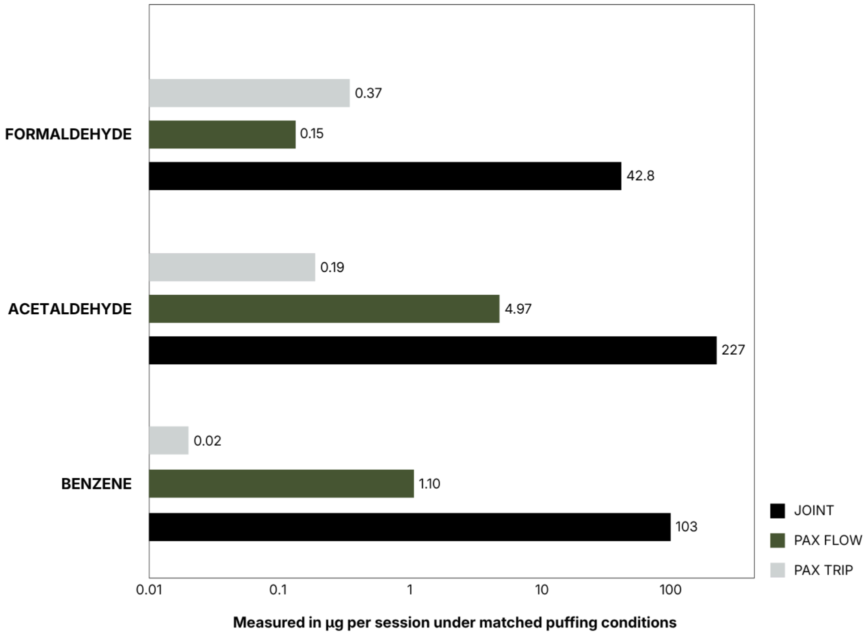
Combustion of cannabis flower produces smoke—a complex aerosol containing toxic byproducts formed through high-temperature pyrolysis and oxidation. Vaporization, by contrast, heats cannabis below the point of combustion, aiming to deliver cannabinoids and terpenes while minimizing formation of these harmful compounds.

In this study, we compared mainstream aerosol generated by PAX's dry herb vaporization device (FLOW) and all-in-one oil vaporization device (TRIP) with smoke from combusted cannabis joints under matched puffing conditions. Particulate and gas-phase emissions were collected using Cambridge filter pads and cryogenic solvent trapping, then analyzed for sixteen harmful and potentially harmful compounds (HPHCs), including benzene, toluene, p-xylene, and a range of carbonyl compounds.

Across all measured analytes, vaporization reduced harmful byproducts by up to 99% compared to joint smoke. Qualitative GC-MS analysis further revealed substantially greater chemical complexity in joint smoke, including toxicants such as ethylbenzene, styrene, p-cresol, and m-xylene that were not detected in vapor aerosol.

These results demonstrate that combustion—not cannabis itself—is the primary driver of harmful inhalation byproducts, and that controlled vaporization can significantly reduce exposure to these compounds.

VAPORIZATION REDUCES KEY TOXIC COMPOUNDS BY UP TO 99% COMPARED TO JOINT SMOKE



1. INTRODUCTION

Cannabis is commonly consumed through combustion of plant material in joints or similar smoking devices. Combustion processes expose cannabis flower to temperatures exceeding 900 °C, initiating pyrolysis reactions that lead to burning which produce a complex mixture of gases and particulate matter. During combustion, cannabinoids, terpenes, lipids, proteins, and carbohydrates present in the plant material undergo thermal degradation and oxidation. These high-temperature processes result in the formation of solid carbonaceous particulate matter in the smoke aerosol.

These reactions also generate numerous secondary compounds including:
- volatile organic compounds (VOCs)
- carbonyl compounds (aldehydes and ketones)
- aromatic hydrocarbons
- nitrogen-containing compounds
- oxidized plant metabolites

Several of these compounds, including benzene, formaldehyde, and acetaldehyde, are commonly monitored in tobacco smoke due to their inhalation toxicity. Cannabis vaporization technologies aim to reduce formation of these byproducts by heating cannabis to temperatures sufficient to volatilize cannabinoids and terpenes (typically 160–230 °C) while avoiding combustion. Although previous studies have examined emissions from cannabis vaporization devices, direct comparisons under matched puffing conditions are necessary to isolate the effects of combustion chemistry.

The objective of this study was therefore to compare the chemical composition of mainstream aerosol under identical puffing conditions, as produced by:
1. Combusted cannabis joints
2. Vaporized cannabis flower in a PAX vaporization device

2. METHODOLOGY

2.1 CANNABIS MATERIAL

The same batch of ground flower was used for both combustion and vaporization testing to ensure consistency in plant material composition. Cannabis flower used for all experiments:
- Cultivar: Lemon Cake Batter
- Producer: Humboldt Farms

2.2 JOINT CONSTRUCTION

For combustion experiments, ~750 mg of ground cannabis flower was loaded into RAW Classic unbleached hemp cone wraps. The packing density was standardized to provide an average pressure drop of 1.67 +/- 0.05 kPa at 2 liters per minute (LPM) of flow. Each joint was puffed individually until the combustion front reached the crutch.

Observed puff counts per joint:
- 18 puffs
- 19 puffs
- 15 puffs

2.3 VAPORIZATION DEVICE

For vaporization experiments, approximately 300 mg of ground cannabis flower was loaded into PAX FLOW vaporization devices. Devices were operated using fourth petal organic heating mode. Four devices were puffed in sequence across three collection ports, with each port capturing aerosol from 80 puffs (20 puffs per device session). Multiple vaporization sessions were aggregated to produce sufficient aerosol mass for chemical analysis.

2.4 PUFFING PROTOCOL

Both delivery systems were tested using identical puffing conditions[1]. These puff parameters were selected to simulate realistic inhalation conditions while maintaining experimental consistency.

PARAMETER	VALUE
PUFF DURATION	2.0 seconds
FLOW RATE	2.1 L/min
PUFF VOLUME	~70 mL
INTER-PUFF INTERVAL	30 seconds

2.5 AEROSOL CAPTURE

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[1] [1]Standardized puffing conditions proposed by Desjardins et al. 2007.

Mainstream smoke and aerosol were captured using Cambridge filter pads (CFPs) upstream of bubblers filled with methanol and held under cryogenic conditions at -78 °C. For vaporizer testing, aerosol from multiple sessions was collected across several CFPs to obtain sufficient analyte mass. Captured particulate matter on the CFP was desorbed in its port-specific bubbler methanol prior to chemical analysis. In some samples, insoluble material precipitated during storage at 0 °C. Residual material was subsequently reconstituted in dichloromethane (DCM) for further analysis.

2.6 TARGETED CHEMICAL ANALYSIS

The port-specific methanolic extract from aerosol capture was filtered using 0.22 um Nylon syringe filters. From this bulk filtrate, subsamples were taken and treated according to the analyte class under investigation.

The monocarbonyls subsample was derivatized in 18 mM Dinitrophenylhydrazine (DNPH) in 80:20 acetonitrile (MeCN) : water and sonicated for 15 mins; appropriate molar ratios in this procedure were confirmed with 100 ppm formaldehyde spike recoveries in excess of 95%. The reaction mixture was neutralized with 1 wt% Trizma base (aq) after derivatization.

Fresh aliquots of bulk extract were transferred into separate vials for GC-MS analysis of aromatic VOC content.

Target analytes included:

Aromatic VOCs
- Benzene
- Toluene
- p-Xylene

Carbonyl compounds
- Formaldehyde
- Acetaldehyde
- Acetone
- Propionaldehyde
- Crotonaldehyde
- 2-butanone
- Valeraldehyde
- Hexanal
- Additional carbonyls included in the Supelco ERA-028 certified reference mixture

2.7 UNTARGETED CHEMICAL ANALYSIS

Untargeted compound identification was performed using single-quadrupole gas chromatography–mass spectrometry (GC-MS). Chromatographic subtraction methods were used to compare joint smoke and vapor aerosol chromatograms, enabling identification of compounds unique to each aerosol stream.

3. RESULTS

3.1 REDUCTION IN HARMFUL COMBUSTION BYPRODUCTS

Across the sixteen quantified HPHCs, vapor aerosol contained up to 99% lower concentrations compared with joint smoke. These results demonstrate dramatic reductions in key combustion markers including aromatic hydrocarbons and aldehydes. Representative compound concentrations are shown below.

Table 1. Selected HPHCs Measured in Joint Smoke and Vapor Aerosol

ANALYTE	DELIVERY SYSTEM	IN SESSION (MG/SESSION)	EXPOSURE REDUCTION (%)
FORMALDEHYDE	Joint	42.8 ± 8.99	—
	PAX Flow	0.145 ± 0.074	99.66%
	PAX Trip	0.37 ± 0.17	99.13%
ACETALDEHYDE	Joint	227 ± 33.5	—
	PAX Flow	4.97 ± 0.115	97.81%
	PAX Trip	0.19 ± 0.18	99.91%
ACETONE	Joint	518.6 ± 45.8	—
	PAX Flow	4.60 ± 0.781	99.11%
	PAX Trip	0.52 ± 0.69	99.90%
PROPIONALDEHYDE	Joint	12.3 ± 2.03	—
	PAX Flow	Non-detect	>99.99%

	PAX Trip	Non-detect	>99.99%
CROTONALDEHYDE	Joint	39.6 ± 1.09	—
	PAX Flow	Non-detect	>99.99%
	PAX Trip	0.16 ± 0.083	99.60%
2-BUTANONE	Joint	47.5 ± 4.72	—
	PAX Flow	Non-detect	>99.99%
	PAX Trip	0.28 ± 0.31	99.42%
METHACROLEIN	Joint	Non-detect	—
	PAX Flow	Non-detect	—
	PAX Trip	Non-detect	—
BUTYRALDEHYDE	Joint	Non-detect	—
	PAX Flow	Non-detect	—
	PAX Trip	Non-detect	—
BENZALDEHYDE	Joint	9.57 ± 0.22	—
	PAX Flow	Non-detect	>99.99%
	PAX Trip	Non-detect	>99.99%
VALERALDEHYDE	Joint	7.48 ± 1.85	—
	PAX Flow	0.328 ± 0.009	95.61%
	PAX Trip	Non-detect	>99.99%
M-TOLUALDEHYDE	Joint	Non-detect	—
	PAX Flow	Non-detect	—
	PAX Trip	Non-detect	—
HEXANAL	Joint	9.34 ± 3.61	—
	PAX Flow	Non-detect	>99.99%

	PAX Trip	0.60 ± 0.39	93.54%
BENZENE	Joint	103 ± 17.7	—
	PAX Flow	1.10 ± 0.078	98.93%
	PAX Trip	Non-detect	>99.99%
TOLUENE	Joint	193.6 ± 37.3	—
	PAX Flow	1.46 ± 0.516	99.25%
	PAX Trip	0.081 ± 0.032	99.74%
P-XYLENE	Joint	64.7 ± 23.5	—
	PAX Flow	Non-detect	>99.99%
	PAX Trip	Non-detect	>99.99%

3.2 EXCEEDANCE OF INHALATION LIMITS IN JOINT SMOKE

During a single joint session (~17 puffs), concentrations of several toxic compounds exceeded inhalation exposure thresholds established by Pax toxicologists based on peer reviewed data. These included benzene, formaldehyde and acetaldehyde. In contrast, vapor aerosol concentrations remained substantially lower, far below these important safety thresholds.

3.3 CHEMICAL COMPLEXITY OF JOINT SMOKE

Qualitative analysis of the methanolic extract from joint smoke using single-quadrupole GC-MS surveying revealed substantial chemical complexity. Approximately 189 compounds were detected in mainstream smoke generated from a single joint session. Many of these compounds are consistent with burning of plant material. Detected compound classes included:

- Nitriles
- Phenolic compounds
- Pyridine derivatives
- Oxidized plant hormones
- Fatty acid amides
- Terpenoid oxidation products

- Polycyclic Aromatic Hydrocarbons (PAHs)

This analysis allowed for the tentative identification of additional toxicants in joint smoke which are also found in cigarette smoke. These include ethylbenzene, p-cresol, m-xylene, styrene, and other combustion byproducts.

3.4 SMOKE SEMI-INSOLUBLE RESIDUE ANALYSIS

Some captured smoke constituents exhibited poor solubility in methanol, forming a semi-insoluble residue when concentrated. These compounds likely originate from incompletely combusted plant material and may contribute to particulate smoke composition. Dichloromethane (DCM), an aggressive organic solvent, was used to analyze this residue. Following solvent evaporation and partial reconstitution in DCM, GC-MS analysis of this residue revealed additional compounds including:

- Sesquiterpenoids
- Oxidized plant hormones
- Fatty acid esters
- Diterpenes

The presence of insoluble constituents even in the reconstituted DCM extract of joint smoke was consistent with the presence of soot, tar, and insoluble solid particulate matter produced by combustion of cannabis.

3.5 VAPORIZER AEROSOL COMPOSITION

In contrast to joint smoke, vaporizer emissions chromatograms showed substantially fewer secondary compounds. Few nitrogen-containing or aromatic combustion products were observed.

Detected compounds primarily consisted of:
- Cannabinoids
- Monoterpenoids
- Sesquiterpenoids

4. DISCUSSION

The results of this study highlight the fundamental role of combustion chemistry in generating harmful inhalation byproducts during cannabis smoking. When cannabis is combusted in a joint, temperatures exceeding 900 °C in the combustion zone initiate a cascade of thermal degradation reactions including:

- Pyrolysis of organic plant components
- Oxidation of lipids and terpenes
- Fragmentation of carbohydrates and proteins

These reactions generate a complex aerosol containing hundreds of secondary compounds. In contrast, vaporization devices heat cannabis to temperatures sufficient to volatilize cannabinoids and terpenes while avoiding combustion. The substantially lower levels of carbonyl compounds and aromatic hydrocarbons observed in vapor aerosol are therefore consistent with the expected chemical differences between combustion and controlled heating. The >95% reduction in quantified HPHCs observed in this study reflects this fundamental difference in chemical processes.

5. LIMITATIONS

This study focused on a single cannabis cultivar and a limited set of targeted harmful compounds. Future work could expand upon these findings by examining:

- Additional cannabis cultivars
- Varying vaporization temperatures
- Broader untargeted and targeted chemical panel, including acrolein
- Long-term exposure metrics

6. CONCLUSION

Combustion of cannabis plant material produces a complex aerosol containing numerous harmful byproducts generated through pyrolysis and oxidation. Under matched puffing conditions, vaporization of cannabis flower reduced exposure to these harmful compounds by up to 99% compared with joint smoke. These findings demonstrate that combustion is the primary source of toxic chemical exposure during cannabis smoking, and that vaporization technologies can substantially reduce formation of these byproducts.