Chemical Analysis and Flavour Distribution of Electronic Cigarettes in Australian Schools

Caitlin Jenkins, BSc (Hons)[1,2], Fraser Powrie, M.Int.S[3], Celine Kelso, PhD[1,2,^], Jody Morgan, PhD[1,2,*,^]

[1]Molecular Horizons, University of Wollongong, Wollongong, NSW, Australia, 2522.

[2]School of Chemistry and Molecular Bioscience, University of Wollongong, Wollongong, NSW, Australia, 2522.

[3]NSW Ministry of Health, Centre for Population Health, Tobacco & E-cigarette Control Unit, NSW, Australia, 2065

^ C.K and J.M contributed equally to this work.

*Corresponding Author: Jody Morgan PhD, School of Chemistry and Molecular Bioscience, University of Wollongong, Wollongong, NSW, Australia, 2522, email: jodym@uow.edu.au

ABSTRACT

Introduction: Adolescent usage of electronic cigarettes has increased globally. Inconsistent, or absent, labelling of nicotine and other ingredients requires chemical analysis to accurately determine the chemical composition of these products.

Methods: Electronic cigarettes confiscated from public and private high school students (N=598) were provided for analysis from three regions in New South Wales, Australia. The products were examined for brand, model and flavour and a subset were further analysed for chemical composition (n=410) quantifying nicotine, synthetic cooling agents, flavouring chemicals and prohibited ingredients by gas chromatography-mass spectrometry (GC-MS).

Results: The majority of samples provided were fruity-flavoured disposable e-cigarettes across three main brands (IGET, HQD and Gunnpod). Nicotine was quantified in 97.3% of disposable samples with an average concentration of 40.0 mg/mL while one refill e-liquid was found to contain nicotine at a low concentration. Almost all samples contained the coolant WS-23 in relatively high concentrations compared to other flavouring chemicals present. Chemicals prohibited under the TGO110 (Australian e-cigarette product standard) were identified in 3.4% of the samples which were chemically analysed. This included the presence of ethylene glycol in moderately high concentrations (up to 13.2 mg/mL).

Conclusions: Australian students' preferences for fruity, disposable e-cigarettes were identified regardless of region with the vast majority containing high concentrations of nicotine. WS-23 was found in most disposable e-cigarettes, potentially to reduce the throat irritation from nicotine and other flavouring chemicals. The inhalational safety of the samples is of concern due to health risks associated with detected prohibited compounds, particularly ethylene glycol.

IMPLICATIONS

This is the first study to quantify nicotine, coolants and flavouring chemicals in e-cigarette products seized from Australian high school students and has significant implications for future policy development. Students appear to be almost exclusively using disposable e-cigarettes with high nicotine concentrations and predominately fruity flavours. WS-23 may potentially be added to disposable e-cigarettes to facilitate the uptake of these products by adolescents unaccustomed to the throat irritation from nicotine and intense flavours. The e-cigarette coils were found to have degraded over time, potentially affecting the composition of the aerosol and leaching of metals.

INTRODUCTION

Adolescent usage of electronic cigarettes (e-cigarettes or vapes) is becoming increasingly popular in many countries.[1,2] The latest data from the Australian Bureau of Statistics[3] reported that 7.6% of Australian adolescents had ever used an e-cigarette between 2020 and 2021, with recent research suggesting adolescent ever usage may be even higher.[4-6]

E-cigarettes were originally designed as an alternative type of nicotine delivery system to combustible cigarettes.[7] They contain a liquid, referred to as an e-liquid, that is vaporised to produce an aerosol for inhalation by the user. The e-liquid generally contains the carrier fluids propylene glycol (PG) and vegetable glycerine (VG), nicotine, flavouring chemicals and occasionally synthetic cooling agents (referred to as coolants).[8-10] There is little published data on the inhalational safety of the flavouring chemicals and synthetic coolants and the long term effects of e-cigarette usage is relatively unknown. Reactions between some flavouring chemicals and the carrier fluids have been observed to form acetals in situ in e-liquids, the toxicological properties of which are similarly understudied.[11-13]

In Australia, nicotine-containing vaping products are a Schedule 4 medicine, requiring individuals to obtain a prescription from a medical practitioner for purchase.[14] The standard for nicotine vaping products (TGO110)[15] establishes guidelines for the contents of nicotine-containing e-cigarette products and their labelling. There are eight ingredients (2,3-pentanedione, acetoin, benzaldehyde, cinnamaldehyde, diacetyl, ethylene glycol, diethylene glycol, and vitamin E acetate) that have been prohibited from inclusion in e-cigarette products due to associated health risks. Nicotine is the only permitted active ingredient. The presence of nicotine must be clearly labelled with the concentration of nicotine in the product within 10% of the stated concentration.[15]

According to current Australian legislation, e-cigarette products cannot be purchased by anyone under 18 years of age in any state or territory, regardless of whether these products contain nicotine. Despite this, Australian adolescents are accessing e-cigarette products, reportedly from friends, online and instore, with relative ease.[4,6] An audit of online retailers that advertised delivery to the Australian city of Perth found only half required age verification for purchase, often in the form of a simple age confirmation button or input of a date of birth, which was easily falsified.[16]

Trends in e-cigarette products can be observed to change as new device types are introduced, evidenced by the introduction of JUUL pods in 2015[17] and Puff Bar disposable devices in 2019[18] in the US and their subsequent surge in popularity. Along with device trends, nicotine strength has increased in the US for disposable e-cigarettes compared to refillable e-liquids

since 2017,[19] with recent research showing a similar trend for disposable devices on the Australian market.[8]

Several recent surveys of Australian adolescents have provided insights into the current landscape of e-cigarettes amongst this population.[4-6,20] Disposable e-cigarette devices are reportedly the most popular type of e-cigarette product obtained with fruity flavours being preferred.[4-6] Notably, adolescents have expressed a preference for nicotine-containing e-cigarettes although a quarter of adolescents are unsure of the nicotine strength of their products.[5] E-cigarettes are becoming a problem in schools with surveyed students commonly reporting observing other students' e-cigarette use in school bathrooms and locker rooms.[4]

To date, only two studies have analysed the chemical composition of e-cigarette products confiscated from school students. Shamout, et al. [10] quantified nicotine, PG and VG in JUUL pod devices (n=26) from US high school students while Frinculescu, et al. [21] quantified two illicit drugs and qualitatively detected nicotine, solvents and flavouring chemicals in e-cigarette products (n=70) from UK students aged 16-18. This study is the first, globally, to focus on the analysis of disposable e-cigarette products seized from school-aged students and perform quantitative analysis of flavouring chemicals along with nicotine. This paper will examine the distribution of brands, models and flavours of devices confiscated from Australian students and report the chemical composition for a large subset of the samples including: nicotine content; compliance to TGO110; carrier fluid composition; and flavouring chemicals present.

METHODS

Materials

Standards of carrier fluids (2), nicotine, synthetic coolants (2), flavours (39), internal standard (1), additional bioactives (2) and prohibited ingredients as per TGO110 (8) were purchased for chemical analysis. All analytical standards were of at least 98% purity. List of all purchased standards and their origins is provided in supplementary information Table S1.

Study Samples

The current study investigated the brand, model and flavour of disposable e-cigarette devices (n=593, from 18 high schools) and refill e-liquids (n=5) confiscated from Australian high school students in New South Wales (NSW) from four distinct geographical regions: Western Sydney, Northern Sydney, Illawarra Shoalhaven, Central Coast. For details on the origin and collection date of the samples included in this study see supplementary information Table S2.

Device Flavour Classification

All samples (N=598) were visually examined and the brand, model and flavour were identified from the exterior labelling of the disposable devices and the two bottled samples or, where more information was required, a search of online retailers was conducted to identify the sample. Any samples which did not have any clear indication of their brand, model and/or flavour were recorded as unknown. The flavours were classified into seven categories (Beverage, Candy, Cooling, Dessert, Fruit, Tobacco and Other) based on the flavour categories established by Krüsemann, et al. [22] For flavours that would fit into two or more of the

established flavour categories, classification was based on the highest priority flavour category (see supplementary information Figure S1).

Chemical analysis

Chemical analysis was carried out using gas chromatography-mass spectrometry (GC-MS). Quantification of nicotine, flavouring chemicals, and coolant molecules within e-liquids and disposables was achieved through creation of internal calibration curves using quinoline as the internal standard (25 µg/mL). Details about instrument conditions, solution preparation and the quantitation process are provided in supplementary information Text S1. Due to an extended time between analysis, two calibration sets (referred to as Set A and Set B) were produced for accurate quantitation of all samples (see supplementary information Table S3). Acetal peaks were identified by comparing their retention time and mass spectrum to an in house database created from the analysis of acetals previously synthesised in our laboratory.[11] All samples were prepared and analysed in triplicate.

RESULTS

Refill E-liquids

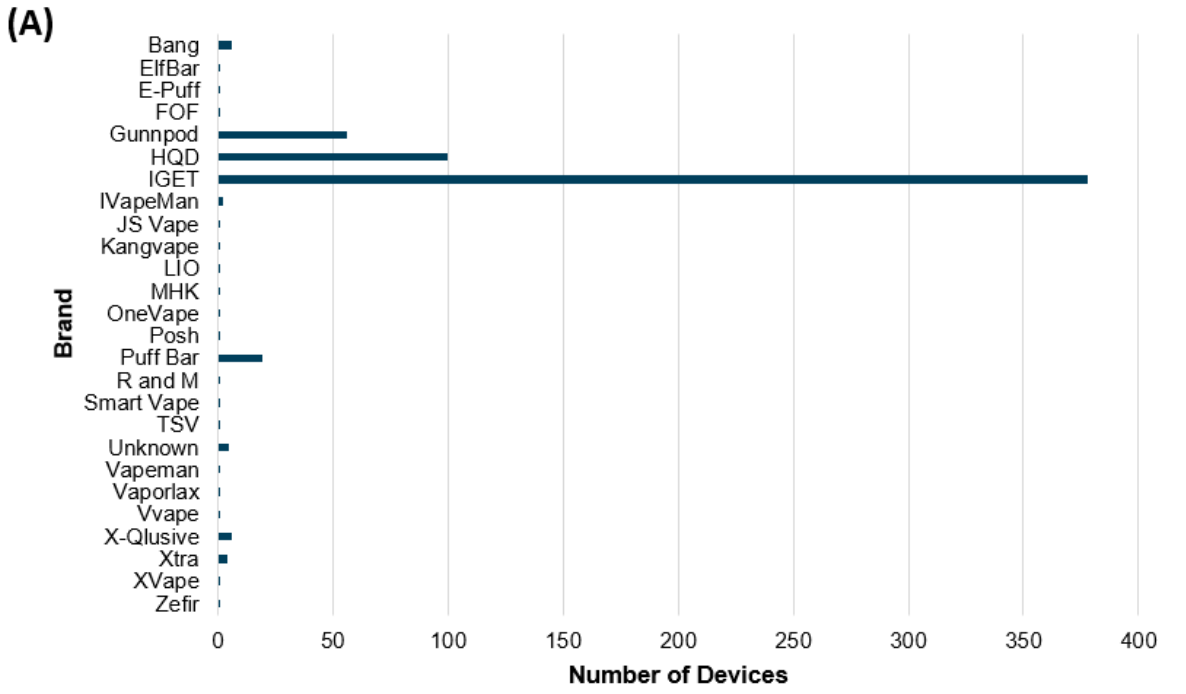
Only four refillable devices were confiscated as part of this study, three of these containing an unidentified e-liquid (SCH-007, SCH-184 and SCH-185) and the fourth in a case with two labelled e-liquid bottles (SCH-029 and SCH-030). Identification of the brand and flavour of the samples was only possible for the two refill e-liquids provided in bottles which were classified as fruit and beverage flavoured. Analysis of the chemical content of the refill e-liquids was conducted for SCH-007, SCH-029 and SCH-030. Only SCH-007 contained nicotine which was detected at a low concentration (2.27 ± 0.07 mg/mL) with no benzoic acid. This was also the only refill e-liquid that contained a cooling agent (WS-23, <LOQ). One flavouring molecule (vanillin) was detected in SCH-007 while two were detected in SCH-029 (1,3-diacetin and ethyl vanillin) all in concentrations <3 mg/mL. SCH-030 contained no detected flavouring molecules. PG and VG were detected as the carrier fluids in all refill liquids.

All results below relate to the disposable e-cigarette samples.

Brand and Model

Of the 593 disposable devices analysed, 47 different models across 26 brands were represented (models of the same name but different brands were counted separately). The number of brands (n=5) in the Northern Sydney dataset was lower than the other regions despite a larger number of samples (n=239). Across all four analysed regions (Western Sydney, Northern Sydney, Illawarra Shoalhaven and Central Coast) the same trend was observed in brand prevalence for the disposable devices; with the three most popular brands being IGET (63.7%), HQD (16.9%) and Gunnpod (9.4%) (Figure 1A). The fourth most prevalent brand overall, PuffBar (3.2%), was found in all regions except Northern Sydney. All other brands combined accounted for <7% of all samples and, excluding Bang, were different for each region. Of interest, one device (SCH-032, brand: Zefir) was advertised online as a pharmacy only product.[23] The Bar model of the IGET brand was the most common identified device (Figure 1B), though it is worth noting that this trend is not reflected in the individual

datasets. IGET Bar was the most common device for Western Sydney and Central Coast but the second most popular for Northern Sydney and Illawarra Shoalhaven. The distribution of model prevalence for HQD and Gunnpod devices was similar between all regions and is reflected in the overall data (Figure 1B). Only nine samples were provided in the original packaging, all IGET Bars from the Central Coast, and were seized from a student intending to sell on school grounds. Neither the word nicotine nor any associated concentrations were present on any of the packaging of these nine samples.



(B)

IGET	HQD	GUNNPOD
Bar (148)	Cuvie (47)	Normal (52)
XXL (106)	Cuvie Plus (39)	Lite (2)
Shion (85)	Maxx (7)	G-Shot (1)
King (14)	Box (4)	Meta (1)
Legend (13)	King (2)	
Mega (5)	Super (1)	
Max (2)		
GOAT (2)		
Plus (2)		
Super (1)		

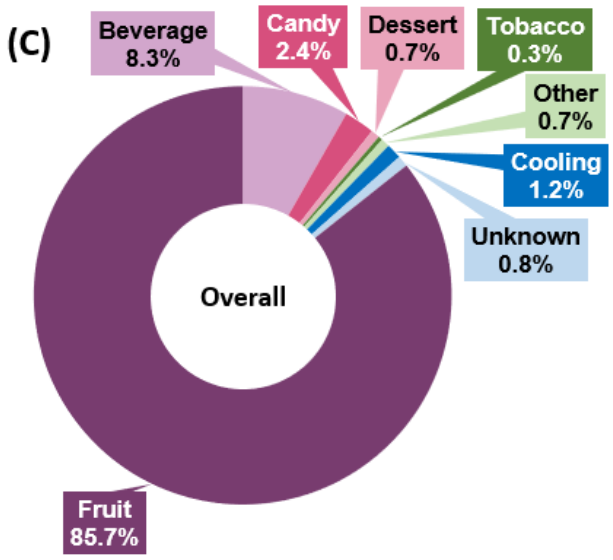


Figure 1. Distribution of (A) brands for disposable e-cigarettes (n=593); (B) model distribution for the top three brands (n=534); and (C) flavour categories from e-cigarette labelling (n=593). Full details of Brand, Model and flavours are provided in the supplementary information Table S4.

Labelled Flavour

A total of 132 unique flavours were recorded with fruity flavours being the most prevalent accounting for 85.7% of all products (Figure 1C). Tobacco flavours were the least prevalent and were only present in the Northern Sydney and Central Coast samples. Dessert flavours were only identified in the Western Sydney samples. Beverage flavours were present in all of the datasets but were higher in the Illawarra Shoalhaven samples (17.9%). Almost half (n=267, 45.0%) of all flavours contained a cooling component in their flavour name (e.g. “ice”, “iced”, “frozen” or “cool”). Only 7 samples (1.2%) were classified in the cooling category based on the flavour priority list (see supplementary information Figure S1 and Table S4, flavours such as “Apple Ice” were classified as fruit according to the priority list).

Nicotine

Nicotine was detected in 396 disposable e-cigarettes (n= 407, 97.3%) with concentrations ranging between 16.5 ± 0.4 mg/ml (SCH-006) and 63 ± 2mg/mL (MOH-328) and a mean of 40.0 mg/mL (Table 1). Figure 2A shows the distribution of nicotine concentrations for all analysed e-cigarette samples. Nicotine was confirmed as the nicotine benzoate salt in all samples except SCH-039 (99.75%). A total of 11 disposable e-cigarette samples (2.7%) were identified as being nicotine-free. Of the 11 nicotine-free samples, six were identical in brand, model, flavour and packaging to at least one other nicotine-containing sample in this study (for an example see Figure 2B and 2C). Two of these six devices appeared to have been opened previously, indicating that the contents of the device, including the e-liquid, may have been tampered with. Comparison of nicotine concentrations between any identical devices (brand, model and flavour) where four or more were present generally exhibited large variations in nicotine concentration (>5 mg/mL).

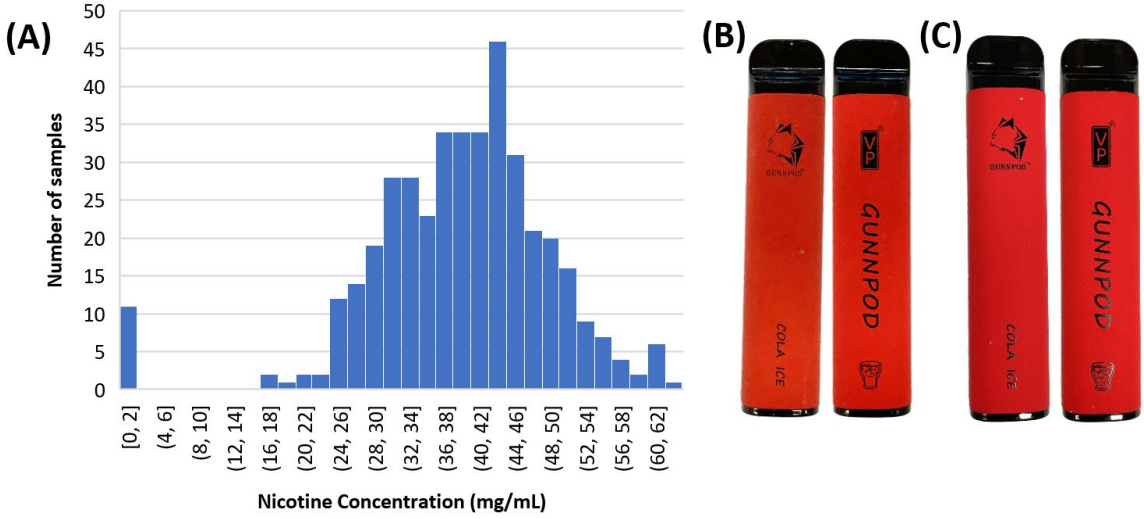


Figure 2. (A) Distribution of nicotine concentration in disposable e-cigarettes (n=407) and comparison of (B) nicotine-free (MOH-649) and (C) nicotine-containing (MOH-300) devices of the same brand, model and flavour. Detailed measurements for each analysed sample are provided in the supplementary information Table S5 along with a short list providing the list of samples that were found to be nicotine free (Table S6).

Table 1. Summary of analysed disposable e-cigarettes (n=407) for detected compounds.

Chemical name (and its associate flavour*)	Number of samples containing this chemical	% of samples containing this chemical	Number of samples with quantifiable concentration	Average concentration (mg/ml)	Minimum concentration (mg/ml)	Maximum concentration (mg/ml)
Nicotine						
Nicotine	396	97.3	396	40.0	16.5 ± 0.4	63 ± 2
Flavour Chemicals						
***p*-Anisaldehyde ("butter almond")**	10	2.5	6	0.37	0.18 ± 0.02	0.67 ± 0.02
Benzyl alcohol ("cherry, floral")	136	33.4	49	1.26	0.406 ± 0.004	6.8 ± 0.1
Benzyl benzoate ("faintly fruity")	25	6.1	11	0.34	0.069 ± 0.002	0.75 ± 0.01
Butanoic acid ("pungent, acidic")	11	2.7	2	1.41	1.03 ± 0.05	1.78 ± 0.05
δ-Decalactone ("coconut, creamy")	6	1.5	0	-	-	-
γ-Decalactone ("fruity, peach")	153	37.6	73	0.28	0.0612 ± 0.0009	0.93 ± 0.01
1,2-Diacetin ("fatty, buttery")	195	47.9	182	4.40	0.048 ± 0.005	23.9 ± 0.6
1,3-Diacetin ("fatty, buttery")	225	55.3	192	11.8	0.090 ± 0.005	101 ± 4
Diethyl succinate ("winey")	7	1.7	1	0.18	0.176 ± 0.004	0.176 ± 0.004
Ethyl butanoate ("pineapple")	7	1.7	1	0.86	-	-
Ethyl maltol ("sweet, caramel")	173	42.5	78	3.25	0.718 ± 0.009	18.1 ± 0.4
Ethyl vanillin ("vanilla")	30	7.4	16	1.00	0.29 ± 0.01	2.06 ± 0.04
***cis*-3-Hexene-1-ol ("green, grassy")**	114	28.0	68	0.42	0.171 ± 0.004	1.51 ± 0.05
Isoamyl acetate ("banana")	4	1.0	2	0.47	0.46 ± 0.01	0.48 ± 0.04
Isoamyl isovalerate ("fruity, apple")	1	0.2	0	-	-	-
Maltol ("sweet, candy")	11	2.7	1	4.77	-	-
Menthol ("mint")	100	24.6	51	0.74	0.40 ± 0.02	1.81 ± 0.05
Methyl cinnamate ("cinnamon")	84	20.6	33	0.21	0.097 ± 0.005	0.66 ± 0.01
3-Methyl-1,2-cyclopentanedione ("caramel, maple")	2	0.5	1	0.60	-	-
γ-Nonalactone ("sweet, vanilla")	12	2.9	12	5.09	4.0 ± 0.2	6.1 ± 0.5
Piperonal ("cherry, spicy")	3	0.7	0	-	-	-
Sulfurol ("meaty, roasted, nutty")	6	1.5	1	2.54	-	-
γ-Undecalactone ("fatty, creamy")	98	24.1	44	0.22	0.078 ± 0.009	0.74 ± 0.05
Vanillin ("vanilla")	175	43.0	110	1.33	0.23 ± 0.02	8.2 ± 0.3
Coolants						
WS-23	405	99.5	403	14.2	0.278 ± 0.006	32.5 ± 0.7
WS-3	63	15.5	60	1.15	0.250 ± 0.007	2.70 ± 0.04
Prohibited Compounds						
Acetoin ("buttery")	2	0.5	0	-	-	-
Benzaldehyde ("almond")	3	0.7	2	0.31	0.30 ± 0.01	0.310 ± 0.009
Cinnamaldehyde ("cinnamon")	5	1.2	1	2.23	-	-
Ethylene glycol (odorless, "sweet tasting")	4	1.0	3	9.22	3.35 ± 0.08	13.2 ± 0.2

* Chemical flavours associated with this chemical as identified from Good Scents database[24]

Flavour chemicals which were not identified in any samples: 4-acetylanisole, 2-acetylpyridine, p-anisyl alcohol, p-dimethoxybenzene, ethyl hexanoate, furfural, guaiacol, 1-methylnaphthalene, valeraldehyde, veratraldehyde. Prohibited compounds which were not identified in any samples: diacetyl, diethylene glycol, 2,3-pentanedione, vitamin E acetate.

Other bioactive compounds

Cannabidiol (CBD) and ∆-9-tetrahydrocannabinol (THC) were included as standards for the chemical quantification of all analysed samples. Neither of these bioactive compounds were detected in any samples in this dataset (see supplementary information Table S5).

Flavour Chemicals

There was a large variation observed in the frequency of appearance and concentration of flavours detected among the samples (Table 1). The most commonly detected flavouring chemicals were 1,3-diacetin (55.3%), 1,2-diacetin (47.9%), vanillin (43.0%) and ethyl maltol (42.5%). The most concentrated flavouring chemical was 1,3-diacetin with concentrations as high as 101 ± 4 mg/mL (MOH-269). With the exception of 1,3-diacetin, flavour concentrations were, on average, present in all samples either in low concentrations (<2 mg/mL) or moderate concentrations (2-6 mg/mL). Raspberry ketone, triethyl citrate and ethyl-3-methyl-3-phenylglycidate were detected but not quantified in 82 (20.1%), 40 (9.8%) and 32 (7.9%) of samples respectively. The composition of flavouring chemicals in identical devices (brand, model and flavour) where four or more were present were different, however large variations (>5 mg/mL) were generally only observed for flavouring chemicals in high concentrations. The large variation value was selected as an appropriate range due to the large spread in concentrations for different flavouring molecules. Concentration measurements for each sample analysed are provided in the supplementary information Table S7. PG and VG were detected as the carrier fluids in every sample with an average ratio of 30%PG/70%VG.

Coolants

WS-23 was detected in 405 of the samples (99.5%), of which 63 also contained WS-3, with average concentrations of 14.20 mg/mL and 1.15 mg/mL respectively (Table 1, with full details provided in supplementary information Table S7). There was no correlation between the inclusion of a cooling component in the flavour name and the presence of a coolant. WS-23 was, on average, the second most concentrated ingredient in the disposable e-cigarettes and more concentrated than most flavouring chemicals. Comparison of WS-23 concentrations between any identical devices (brand, model and flavour) where four or more were present generally exhibited large variations (>5 mg/mL).

Prohibited compounds

Four compounds prohibited by the TGO110 were detected in disposable e-cigarettes in this study. A total of 14 samples (3.4%) contained one prohibited compound, no samples contained more than one prohibited substance. The detected prohibited compounds were acetoin (n=2), benzaldehyde (n=3), cinnamaldehyde (n=5) and ethylene glycol (n=4) (Table 1, with full details provided in supplementary information Table S8 and S9). Two of these samples (MOH-304 and MOH-649) did not contain any nicotine and therefore their content is not required to abide by TGO110.

Acetals

The PG acetal of p-anisaldehyde and the PG and VG acetals of vanillin and benzaldehyde were detected in this study. Formation of acetals was only detected in six samples (1.5%) (see

supplementary information Table S10), all of which were shown to also contain the original flavouring molecule.

Coil degradation

Coils in the disposable e-cigarettes were observed in various stages of degradation via the blackening of the metal coil and scorching of the surrounding fabric (Figure 3). The degree of blackening was considerably different between samples with some showing little to no blackening and some where the coil was indistinguishable from the scorched fabric (Figure 3). A greater degree of blackening was generally found in devices with lower volumes of e-liquid remaining or tampered devices.

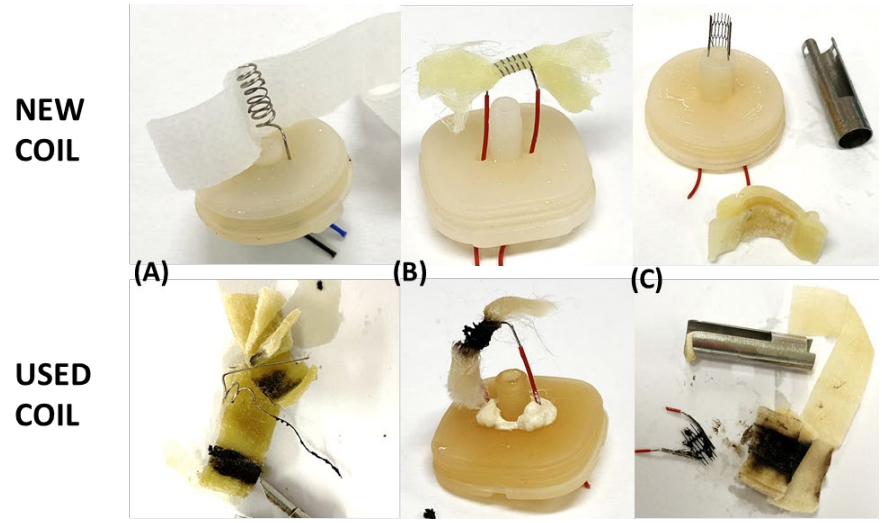


Figure 3. Comparison of new (top) and used (bottom) metal heating coils of types (A) vertical coil in a new device and MOH-646, (B) horizontal coil in a new device and SCH-022 and (C) mesh coil in a new device and MOH-633.

DISCUSSION

Australian high school students were found to primarily use disposable e-cigarette products with high concentrations of nicotine regardless of region or type of school (public vs private), some of which contained potentially harmful compounds. These results are consistent with several recent surveys of Australian adolescents where they expressed preferences for nicotine-containing, fruity flavoured disposable e-cigarettes.[4-6] High school students in NSW, Australia are generally between the ages of 12 and 18, with almost all students below the minimum legal age to purchase e-cigarettes.

Refillable e-cigarette devices accounted for <1% of samples in this study suggesting that these types of e-cigarette products are uncommon among high school students in NSW. The small number of refill e-liquids analysed were more likely to be nicotine free and coolant free compared to the disposable devices analysed. Whilst the sample size for refillable e-liquid analysis was small, these results are consistent with previous research comparing Australian refillable e-liquids and disposable e-liquids.[8] Reports that disposable e-cigarettes will be banned under future legislation in Australia[25] may have a significant effect on youth vaping as the vast majority of students currently use disposable devices.

Trends in brands and flavours of disposable e-cigarettes were similar across the four datasets with slight differences in the distribution of models. One disposable device in this study was identified as the brand Zefir, which was advertised on the website as a prescription vape available from pharmacies around Australia.[23] The three most popular brands were IGET, HQD and Gunnpod which accounted for 90% of all disposable samples. The most common device overall, the IGET Bar, comprised a quarter of all samples. PuffBar products, which were identified by Pettigrew, et al. [4] as the most popular brand among Australian 15-21 year olds only accounted for 3.2% of the samples confiscated from high school students in this study. Additionally, JUUL, which was reported by Pettigrew, et al. [4] as the third most common brand among this age group was not present among the confiscated samples. JUUL is known to be a common brand in the US[17] and the term 'JUULing' is sometimes used interchangeably with 'vaping'.[26,27] It is possible that students are self-reporting the term 'JUUL' to describe any disposable vaping device rather than identifying a specific brand. Alternatively, differences between this study and Pettigrew, et al. [4] could reflect broader variations in the Australian market following the regulatory changes in October 2021.

Consistent with the literature,[4,5] fruity flavours were the most popular and accounted for the majority of samples (85.7%). Tobacco flavoured devices were the least common flavour category identified (2 devices, 0.3% overall) and were only found in two of the four datasets. These results provide further confirmation that tobacco flavours are unpopular amongst adolescents while fruity flavours are preferred.[4,5,28] An online search (August 2023) of the two most popular models from this study, the IGET Bar and XXL, identified a wide range of fruity flavours available for purchase but no tobacco flavours.[29,30]

Chemical analysis was only conducted on one of the tobacco flavoured devices which was found to contain mainly "sweet" flavouring chemicals (3-methyl-1,2-cyclopentanedione, ethyl maltol, vanillin and ethyl vanillin) and the "meaty" flavouring chemical sulfurol.[24] These sweet flavouring chemicals were observed in concentrations similar to or exceeding that of the fruity flavoured disposable e-liquids. Recommendations to restrict e-cigarette flavours, such as those in Australia,[25] often recommend allowing tobacco to remain available and some research has found that tobacco flavours may be less appealing.[28] However, without limitations on what flavouring chemicals comprise tobacco flavours, and evidence here of sweet flavouring chemicals, it is unclear how effective this would be in eliminating fruity and sweet flavours.

Virtually all of the disposable e-cigarettes confiscated from high school aged students contained nicotine in salt form (97.1%) at relatively high concentrations. Conversion of nicotine to its salt form via the addition of acid reduces the throat harshness associated with its inhalation and allows for higher concentrations of nicotine to be tolerated.[31] Additionally, the coolant WS-23 was detected in >99% of the disposables analysed at concentrations higher than most of the other flavouring chemicals present. The only two disposable devices which did not contain WS-23 were a Watermelon Mint Ice flavoured device, which contained menthol, and a Classic Tobacco flavoured device. WS-23 may be added to disposable e-cigarettes to further reduce the throat irritation associated with high nicotine concentrations and intense flavours among naïve users.[8] A recent survey suggested that more than half of adolescents who reported e-cigarette ever-use had never previously smoked and would therefore be unaware and unaccustomed to the throat irritation.[6] The high concentrations of WS-23 observed throughout this study are noteworthy as previous research

has found comparable concentrations to be unsafe based on in vitro studies and may adversely impact the inhalational safety of these products.[32,33]

Current Australian product guidelines for nicotine vaping products (TGO110) requires the labelling of nicotine, its concentration and warning statements on the packaging. Additionally it is a requirement that the nicotine concentration is within 10% of the labelled concentration.[15] While no details were provided from the origin of these samples (how/where these products were purchased/obtained), it cannot be excluded that these devices were legally obtained via one of the currently available pathways, therefore all samples containing nicotine were compared against the TGO110 requirements to assess compliance. Of all the samples tested, only 21 devices (3.5%, 19 Puff Bar, 1 MHK and 1 Xtra) were labelled with any type of concentration, shown as "5%", all without the inclusion of the word nicotine. Eighteen of these "5%" labelled products were analysed for content and none of them met the ±10% criteria outlined in the TGO110.

An additional requirement of the TGO110 is the prohibition of eight specific chemicals which have been banned in nicotine-containing e-cigarettes due to health risks.[15] Four prohibited compounds (acetoin, benzaldehyde, cinnamaldehyde and ethylene glycol) were detected in 14 of the disposable e-cigarettes (3.4%, n=407). All four of these compounds were prohibited due to their potential inhalational health risks; including possible lung damage, respiratory failure, cytotoxicity and depression of the central nervous system.[15] Of particular concern, ethylene glycol was found in moderate to high concentrations in two samples (11.1 ± 0.2 mg/mL in MOH-325 and 13.2 ± 0.2 mg/mL in SCH-070). Ethylene glycol has been found to cause respiratory irritation and is a toxicological hazard.[34,35] Whilst ethylene glycol has been observed in e-cigarette products previously,[35] this is the first study to identify and quantify it in Australian e-cigarette products. It is worth noting that two of the 14 samples that contained prohibited compounds did not contain nicotine and consequently their contents are not required to abide by current Australian legislation which applies only to nicotine vaping products.

Nine disposable e-liquids from the Central Coast region were included for chemical analysis. These samples were packaged and unused when confiscated from a student who was intending to sell them. These samples followed the trends observed throughout this study being fruity-flavoured IGET Bars. All of these unopened devices contained nicotine with no mention of nicotine on the packaging or appropriate warning messages. This supports previous findings that some adolescents are sourcing their nicotine e-cigarettes from a friend or associate and provides evidence that this is occurring within school cohorts.[4-6] Moreover, reports that a quarter of adolescents are unaware of the nicotine concentration of their e-cigarette products is likely due to a lack of information on the packaging of these devices.[5]

The large variation in the number and concentration of flavouring chemicals in each sample and frequency of appearance reflect the large range of unique flavours analysed. Two of the four most commonly detected flavours were sweet flavours,[24] vanillin and ethyl maltol, reflecting the overwhelming number of fruity and sweet flavoured samples in this study. 1,3-Diacetin and 1,2-diacetin were the most common flavouring chemicals and 1,3-diacetin was, on average, at least double the concentration of any other flavouring chemical.

The samples were provided at different stages of use (new vs empty) which prevented the chemical analysis of some samples due to low e-liquid yield and may have affected the composition of the collected e-liquids. Volatile flavouring molecules were detected in low concentrations in some identical devices (<2 mg/mL) and were absent in others. This is possibly due to preferential vaporisation of these compounds resulting in low concentrations or their absence at the end of the device life.[8] However, this does not necessarily account for the large differences in nicotine and WS-23 concentrations in many of the identical devices. It is more likely that this is reflective of irregularity in the manufacturing of these devices[32] or student tampering replacing the original e-liquid.

Many of the samples from this study had coils with differing levels of blackening, occurring over time as the coil undergoes repeated heating and cooling cycles to vaporise the e-liquid. Figure 3 shows the excessive blackening on some coils and additional scorching of the surrounding fabric. The level of blackening differed, likely due to the different stages of usage of the samples. Degradation of e-cigarette coils and loss of metals, possibly into the aerosol, has been found previously[36,37] and may contribute to the observed coil blackening. This is an important issue for future research as it is unclear how this degradation may affect the composition of the aerosol and the inhalational safety of e-cigarettes. The blackened coils were generally observed in samples with low e-liquid volumes remaining or evident tampering, suggesting that these devices are being used beyond the expected puff capacity of the coils leading to substantial degradation.

While a large number of samples were analysed, this study is limited by the fact all samples were confiscated by high school staff and all regions of study were within NSW. Similar research should be conducted across Australia to confirm if the results of this study are reflected in high schools across the country. The specific dates the e-cigarettes were confiscated were not provided for the majority of the samples, preventing the analysis of broader trends over time. The e-cigarette market is rapidly changing and requires regular research to identify potential variations over time, particularly as legislation is modified.

The present study provides the first analysis of e-cigarette products confiscated from Australian students. The findings of this study indicate that Australian adolescents are using fruity flavoured disposable e-cigarette devices, most commonly the IGET Bar, that generally contain high concentrations of nicotine and WS-23. Compounds prohibited due to their associated inhalational health risks were found in 3.4% (n=14) of the chemically analysed samples. Four of these samples were found to contain the prohibited ingredient ethylene glycol, the first quantified identification of this compound in Australian e-cigarette products. Future policy should focus on preventing adolescents from accessing disposable e-cigarettes. Potential flavour limitations should be approached cautiously as the flavouring chemicals that are present in the fruity products appear to also be present in comparable abundance in tobacco flavoured products.

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DECLARATION OF INTEREST

The authors have no conflicts of interest to declare.

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