Microchemical Journal 170 (2021) 106733

Contents lists available at ScienceDirect

Microchemical Journal

journal homepage: www.elsevier.com/locate/microc

Exposure of heat-not-burn tobacco effect on the quality of air and expiratory plume

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ARTICLE INFO

Keywords:
"Heat-not-burn" tobacco
Portable monitoring devices
Secondhand exposure
Air quality
Nicotine content

ABSTRACT

The increasing interest to avoid the consumption of regular tobacco has lead in the development of several types of devices to decrease the effects of this practice on active and bystanders. In this work, the impact of the use of new heat-not-burn (HnB) devices has been evaluated and compared with that of regular cigarettes and electronic cigarettes (e-cigs). Portable monitoring devices were employed for CO, CO_2, particulate matter (PM) and volatile organic compounds (VOCs) to evaluate the quality of indoor air and expiratory plume of both, active and passive, users during these practices. It can be noticed that the levels of VOCs in active HnB smokers expiratory air are five times lower in particular cases than those provided by regular tobacco and three times lower than those obtained for e-cigs, while the contribution of particulate matter to air pollution decreases between 200 and 600 times regarding the values obtained for e-cig vaping and regular tobacco smoking. The level of contaminants as CO decreases significantly in both, active and passive HnB smokers, in comparison with active and passive regular tobacco smokers, due to the absence of organic material combustion.

Regarding passive HnB smokers, the exposure to HnB smoke do not increases the level of VOCs in ambient air nor in expiratory plume, remaining at the basal levels, being three times lower than values obtained to an exposure to regular tobacco smoke and two times lower than exposure to e-cigs vapours. On the other hand, the use of HnB devices decreases the concentration of PM in bystanders around thirty five times in relation with values obtained for passive regular tobacco smokers. Concerning the nicotine content delivered by HnB tobacco, data shown that HnB tobacco provides values from 0.5 to 1.7 mg of nicotine to the mainstream, being these values similar to those found in conventional tobacco.

1. Introduction.

Smoking has been declared as an important cause of morbidity and mortality [1] that remains as a global health problem of our society. In addition to the associated nicotine addiction problems, smoking activities are related to diseases as heart attack, lung cancer or emphysema [2,3]. Smoking diseases are caused by toxic chemicals present in the inhaled primary smoke [4]. In this sense, there are thousands of chemicals identified in the mainstream smoke produced during tobacco combustion and corresponding pyrolysis processes [4,5]. On the other hand, second-hand smoke exposure has been categorized as a Group 1 carcinogen to humans according to World Health Organization (WHO) Framework Convention on Tobacco Control (FCTC) and the International Agency for Research on Cancer (IARC) [6,7]. As a consequence, it is mandatory in the main part of countries the control of smoking activities, especially in closed areas.

In recent years, several alternative devices were developed to reduce the hazards of tobacco combustion and to help the smoking cessation. So, in the last decade the e-cigs were developed, being thus increased exponentially the number of studies regarding the usefulness of the electronic cigarettes to reduce or eventually stop smoking [8–12] in the same way than those showing the opposite evaluation [13–15]. Moreover, it has been indicated the presence of tobacco-specific nitrosamines (TSNAs), formaldehyde, glyoxal, methylglyoxal, acrylamide, acrolein, nicotine and other volatile organic compounds in the exhaled breath of electronic cigarette users [16–19].

In the last two years, a new type of tobacco smoking device, the so called heat-not-burn (HnB), has been developed as an alternative to regular tobacco for recreative purposes. In HnB sticks, tobacco is electrically heated at temperatures below than those required to initiate the

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https://doi.org/10.1016/j.microc.2021.106733
Received 6 April 2021; Received in revised form 3 August 2021; Accepted 6 August 2021
Available online 11 August 2021
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organic material combustion (<300 °C) generating an aerosol mainly composed by water (76%), glycerine (10%) and nicotine (3%) [20], being sold the HnB devices as a technology that provides the taste of tobacco without smoke, ashes and a reduced smell [21]. In spite of the low volume of smoke produced by these new devices and the exhaustive anti-smoking legislations in many countries [22], the exposure to secondary smoke still remains as an a problem, having evidenced the exposure to toxic chemicals during the use of HnB devices [23].

Several studies can be found in the literature regarding HnB tobacco. However, published papers mainly concern the HnB mainstream smoke and the quality of air due to the primary smoke, being analyzed several toxic compounds, such as volatile organic compounds (VOCs), polycyclic aromatic compounds (PAHs), nicotine, nitrosamines, alkanes, metals and several gases. Auer et al. and Bekki et al. employed gas chromatography with flame ionization detector (GC/FID) to analyze VOCs and nicotine, and high performance liquid chromatography with fluorescence detector (HPLC/FLD) to determine PAH in HnB mainstream aerosol [24,25]. In the same way, the environmental pollution caused by HnB tobacco was studied by Ruprecht et al., determining organic and inorganic pollutants in ambient air together with the levels of particulate matter (PM) due to the smoking processes [26]. Mottier et al. used gas chromatography (GC) with mass spectrometer (MS) to analyze nicotine and VOCs; and on line, non-dispersive infrared and chemi-luminescence detectors for CO_2/CO and NO/NO_x, respectively, using smoking machines to collect tobacco mainstream [27]. So, it can be seen that all the studies found till now are focused on compounds released during primary smoking processes, without taking into account their effects on the secondhanded exposure to Hnb smoke, nor on the breath quality of active and bystanders.

Nicotine is another indicator of potentially toxic pollution due smoking to activities. Nicotine has been determined previously in both, regular tobacco and e-cigs [28,29]. In the case of e-cig, the amount of nicotine can be selected by the user being available concentrations from 0 till 26 mg mL^{-1}. So, the nicotine delivered depends on the the liquid refill and the smoking habits. In the case of regular tobacco, the average content of nicotine varies from 8.2 till 11.6 mg per cigarette with differences between trademarks and types, regular, menthol or light labelled, based on the tobacco origin and mass of tobacco for cigarettes [28]. In the case of HnB sticks, nicotine has been determined by Bekki et al. [25] in the mainstream, having reported an amount around 1.2 mg per stick. However, there is a lack of information about neither the total amount of nicotine per stick nor the changes in nicotine as a function of the stick consume and the heating process. So, an additional aspect considered in this study was the evaluation of the nicotine content of HnB sticks before and after smoking.

The aims of this work has been to evaluate the impact of the use of HnB sticks on the quality of air before and after their employ in closed areas, and its effect on the expiratory plume of active and bystanders as an indication of second-hand exposure to HnB smoke. Additionally, obtained parameters were compared with those regarding regular tobacco cigarettes and e-cigs. On the other hand, it has been reported data about the content of nicotine in non-heated and heated HnB sticks.

2. Material and methods

2.1. Apparatus and samples

Two IQOS HnB identical devices, commercialized by Phillip Morris Inc. (Neuchâtel, Switzerland) acquired in a local market, were employed in this study. Three different HnB cigarettes labelled as amber, yellow and turquoise Marlboro HEETS HnB sticks were used to carry out the secondhand exposure assays.

HnB devices consist of a recharger holder were tobacco sticks are inserted (Fig. 1*A*). Fig. 1*B* shows a section of the HnB stick. The tobacco stick (i) is made of a processed cast leaf covered by a paper cover with a filtering system consisting of three parts; the inner filter (ii), the medium filter (iii) and the final filter (iv).

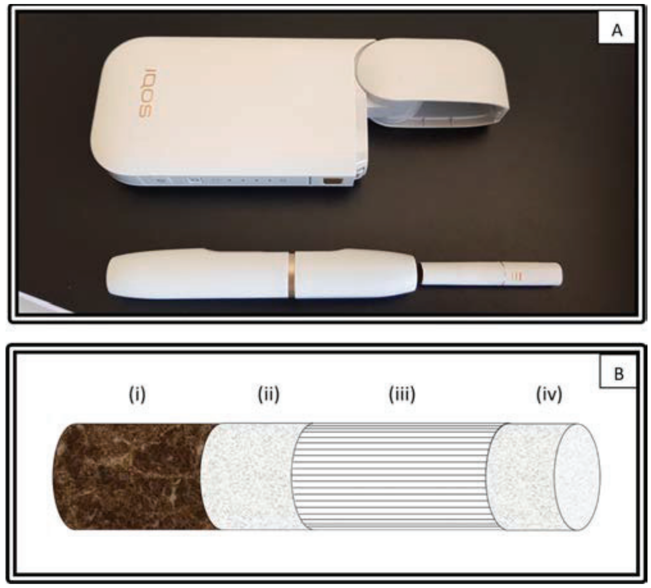

Fig. 1. Detail of HnB device employed in this study: recharger, holder and sticks (A). Section of the HnB stick: (i) tobacco, (ii) inner filter, (iii) medium filter, and (iv) final filter (B).

The quality of indoor air and the presence of analytes under study in the expiratory plume of active and passive users of tobacco devices were evaluated by employing several air monitoring systems, including: i) an airflow multi-function anemometer TA465-P from TSI (Shoreview, MN, USA) equipped with infrared spectroscopy technology for CO and CO_2 determination and a telescopic thermo-anemometer probe to measure temperature and relative humidity. ii) a CEL-712 Microdust Pro from Casella Cel (Kempston, UK) to control the concentration of particulate matter (PM). It includes a photoelectric sensor, and iii) a PhoCheck Tiger from Ion Science (Laubach, Germany) to determine VOCs based on the use of a photo-ionization detector.

All the aforementioned devices were sent previously to be calibrated and the resolutions checked by manufacturers and employed after stabilization. For calibration purposes, suppliers use referenced materials and calibrants. In this sense, and as example, particulate matter device was calibrated by employing the ISO 12103–1 A2 Fine test dust.

The CO_2 and CO device can detect a concentration range between 0 and 5000 ppm with 1 ppm resolution and from 0 to 500 ppm with 0.1 ppm resolution, respectively. Regarding the detection of PM, the photoelectric detector allows detection from 0.001 to 250 mg m^{-3} with a resolution of 0.001 mg m^{-3}, while VOCs portable device is characterized by a concentration range between 1 ppb and 10000 ppm, with a resolution of 1 ppb. This VOCs device constitutes a versatile tool that has been successfully applied in several cases such as clandestine labs, filter monitoring, general atmosphere quality monitoring for tracing chemicals or Health & Safety, STEL & TWA monitoring in confined spaces [30]. Although measurements in this work were performed in the TOTAL VOCs screening, the device allows the individual measurements of around 500 specific volatile compounds spanning molecular weights from 17 to 394 g mol^{-1}.

For nicotine determination in HnB cigarettes, an Agilent Technologies 7890C GC System equipped with a ZB-5MS (30 m, 0.32 mm, 0.25 μm) capillary column coupled with a 5975C inert XL EI/CI MSD simple quadrupole mass detector was employed.

For nicotine quantitation, nicotine with purity higher than 99% (GC) standard, obtained from Sigma-Aldrich (St. Louis, LO, USA) was used to prepare calibration standards. Benzocaine with a purity higher than 99%, provided by Guinama (Valencia, Spain), was employed as internal standard. n-Hexane for analysis residue, with purity higher than 98%, and sodium hydroxide, pellets reagent grade were provided by Scharlab (Barcelona, Spain). Extraction of nicotine from different parts of HnB sticks was performed with n-hexane employing an Orto-Arlesa Digicen 20 centrifuge (Madrid, Spain), a J.P. Selecta ultrasound water bath (Barcelona, Spain) and a Heidolph Multi Reax rotary agitator (Schwabach, Germany). Ultrapure water, with a maximum resistivity of 18.2 MΩ cm^{-1}, was obtained from a Milli-Q system acquired from Millipore (Bedford, MA, USA).

2.2. Indoor assay conditions

Expiratory plume assays and air monitoring were performed in a closed 40 m^3 room with a natural door ventilation intensity of 0.2 m^3 per hour without air filtration system during March to May months and with a relative humidity of 70 ± 24 % in order to recreate real and common exposition situations. Previous to each study, the room was ventilated in order to decrease the presence of contaminants. After aeration, the room was closed and the portable devices were employed to monitoring the air till complete stabilization of signals. The presence of measured parameters in air was recorded for 6 min before exposure assays. In these conditions, a bystander, performing its daily tasks, was exposed to expiratory plume of two active HnB users, being the eexposure distance no longer than 2 m. The expiratory plume of the bystander subjects were performed placing the monitoring devices at a distance of 20 ± 2 cm, according to the bibliography [31], monitoring the analytes under study for 6 min immediately before and after the smoking activities in continuous mode. VOCs and PM data were recorded every five seconds while CO and CO_2 were measured every ten seconds by using the portable devices. Regarding the expiratory plume monitoring of HnB active users, sampling process was performed in the same conditions as for passive subjects.

Once finished the eexposure assays, the ambient air was monitorized in the same conditions to determine the effect of HnB smoking activities.

2.3. Volunteers characterisation

The experiments were performed by a set of 7 volunteers including 3 HnB users and 4 non-smokers bystanders. In all the cases, the volunteers were previously informed of the experiments and the corresponding consent form was signed by them. The volunteers participating in the experiments 4 men and 3 women in an age range between 20 and 61 years.

2.4. Determination of nicotine in HnB sticks

The nicotine determination was based on the methodology proposed by Farsalinos *et al.* [32]. 200 mg of tobacco, from HnB tobacco stick, were mixed with 2 mL NaOH 8 M and 4 mL nanopure water. The solution was allowed to stand for 15 min. Then 10 mL of n-hexane were added and solutions were well mixed by rotary agitation for 45 min. Mixed phases were sonicated for 15 min. The supernatant layer, corresponding to the organic phase, was separated by centrifugation employing 4000 r.p.m. for 10 min. Nicotine extract was transferred to a glass vial and appropriately diluted with n-hexane before analysis. One microliter of the hexane diluted phase was injected in splitless mode at 250 °C employing a constant flow of 1.1 mL min^{-1} helium as carrier gas. Oven programme used was 70 °C, increased at a rate of 25 °C min^{-1} up to 230 °C, and finally held for 3 min. The transfer line and source temperatures were 280 and 276 °C, respectively. Acquisition and quantification of nicotine was performed in the selected ion monitoring (SIM) using the mases 84 and 120 m/z as quantification mass for nicotine and internal standard, and the mases 165, 133 and 162 as qualitative mases for nicotine and internal standard.

3. Results and discussion

The air and expiratory plume of active and bystanders monitoring depends on the concentration ranges and the resolution characteristic for each one of employed devices indicated in the experimental part.

For monitoring, a set of 8 to 14 individual measurements of parameters under study were performed. Obtained results were averaged from all sampling sessions and the standard deviation was obtained in order to provide representative values that include all the variability found in individual measurements.

3.1. The quality of indoor air

Table 1 shows the averaged results obtained for the monitoring of analytes under study in ambient indoor air before and after smoking amber and yellow HnB tobacco sticks, corresponding to different sessions and with 3 different HNB users. These values were employed to evaluate the impact of the HnB tobacco smoking on the ambient air.

As it can be seen, only values obtained for CO_2 increased significantly after smoking in both cases, from 600 to 1150 ppm, presenting a high variability. Due to this high variability, the difference between both situations is not significant. Similar behaviour can be observed in the results obtained by Meišútovič-Akhtarieva *et al.* [33], where the average value increases with high variability. Due to those results obtained after and before use were statistically comparable. The same conclusions can be extracted from Savdie *et al.* [34], were results for controls and assays in HNB studies were statistically comparable attending to the high variability of measurements. In all the cases, the apparent increase seems to be due to the breathing of the users, being representative of a real situation in which there is not a high rate of air renewal. CO values were under the limit of detection of portable device, fixed at 0.1 ppm, while in [33] CO concentration in air was 0.1 ppm along the study.

Regarding VOCs, results obtained agree well with those reported for indoor air [35–38], and are in good agreement with those reported by Meišútovic-Akhtarieva *et al.* in 2019 for a study of the impact of exhaled aerosol from usage of tobacco heating system inside a chamber [33]. Similar to data found in this study, the concentration of volatile compounds does not present significant variations in the indoor air, being found average values before the use of HNB within the confidence interval of those obtained after use. . On the other hand, particulate matter, with an averaged value of 0.02 mg m^{-3} showed a variability in the same order than the average obtained value. On the other hand, there is not any significant difference in the VOCs concentration in ambient air after smoking the two types of HnB sticks employed.

3.2. Analysis of active users breath before and after smoking

The expiratory plume of active users of HnB devices with amber and

Table 1
Indoor air parameters measured before and after HnB consumption in a closed room.

	Amber HnB sticks		Yellow HnB sticks	
	Before	After	Before	After
VOC (ppm)	0.10 ± 0.02 (n = 8)	0.13 ± 0.04 (n = 8)	0.12 ± 0.01 (n = 9)	0.11 ± 0.01 (n = 9)
PM (mg m^{-3})	0.02 ± 0.02 (n = 8)	0.03 ± 0.02 (n = 8)	0.02 ± 0.02 (n = 9)	0.04 ± 0.02 (n = 9)
CO_2 (ppm)	650 ± 80 (n = 8)	1000 ± 200 (n = 8)	600 ± 100 (n = 9)	1200 ± 200 (n = 9)
CO (ppm)	<LOD*	<LOD*	<LOD*	<LOD*

Note: Data were acquired in a 40 m^3 room in which two HnB were used in the presence of one bystander. Data are the average of the number n of independent sessions indicated between brackets performed by 3 different HnB users.
*: CO portable device LOD: 0.1 ppm

yellow sticks was evaluated and compared with those obtained for vaping and conventional cigarettes. Table 2 summarizes the obtained values for the analytes under study.

It can be observed that the levels of PM in active smokers expiratory plume is of the same order than those registered for the indoor air, not been increased due to smoking activity in any case. These results agree with those obtained by Meišútovic-Akhtarieva *et al.* [33]. Regarding the CO_2, in both cases, before and after HNB use, the expiratory plume values of shows that the use of these devides do not increase when compared with those obtained for the expiratory plume background. It must be noticed that the levels of CO increased in expiratory plume of users before and after HNB use while the concentration of CO in ambient air was under the limit of detection of the portable device. Similar results were reported in the bibliography. In this sense, Meišútovic-Akhtarieva *et al.* [33] obtained averaged values for CO_2 around 644 ± 65 ppm in the expiratory plume after HNB use while expiratory plume background values were 620 ± 58 ppm. In a similar way, literature reported CO values were 0.74 ± 0.29 mg m^{-3} in the air after HNB use with a 0.45 ± 0.33 mg m^{-3} obtained value in the control [34] while the study of Meišútovic-Akhtarieva *et al.* preported CO values of the same order than those obtained for the human background [33].

It cannot be detected significant variations in the concentrations of VOCs, being the values obtained of the same order than those present in the ambient air. So, it can be concluded that, although active smokers will exhale some amounts of VOCs, the indoor air concentration is not affected due the low concentrations emitted and their high dilution. Additionally it seems that the use of yellow HnB sticks do not provide any significant difference respect to the use of amber sticks.

Regarding the expiratory user plume, the Fig. 2 shows an example of the monitoring of active for the controlled parameters in a single session. From these recordings it can be noticed the low precision of measurements and the increase of concentrations in smoker expiratory plume after using HnB sticks.

Fig. 2 shows that the smoking process increases the averaged basal levels of analytes under study present in the expiratory plume after smoking. However, it should be mentioned that monitoring processes are subjected to the variability of breathing, which is reflected in the average values reported in Table 2.

3.3. Analysis of passive expiratory plume

The passive exposure to the smoke of HnB devices has been evaluated through the analysis of VOCs, PM, CO_2 and CO in the expiratory plume of a passive subject that remained in the closed room while two active subjects smoke HnB tobacco. Table 3 summarizes the results obtained in several sessions for the analytes under study before and after exposure.

The concentration of CO_2 in bystander expiratory plume is around two times the levels found in the ambient air before to start the experiments although results are similar to those obtained for the plume background, being probably it due to the intensification of breathing as a result of puffing on the tobacco stiks. Although measurements present a high variability, values of concentration in bystanders assays are of the same order, and higher than those obtained for the ambient air, due to the presence of the two active smokers in the room during measurements. CO was not present in expiratory plume of bystanders, showing that the heating of tobacco only has consequences on the active expiratory plume. Regarding VOCs, their concentration remains practically constant taking into account the averaged values of all experiences, due to the dilution of VOCs concentration in the ambient air. The same behaviour was observed for the levels of PM.Once again there was not observed any difference between the use of amber or yellow sticks.

Fig. 3 shows an example of an individual monitoring of passive HnB smoker expiratory plume for the target analytes, obtained before and after exposure. Fig. 3 illustrates clearly that the exposure to HnB could increase the presence of contaminants in expiratory plume but tend to stabilize. It must be noticed that while the basal levels for VOCs remains practically constant around a 0.1 ppm concentration before smoking, the concentration exhaled gradually increased till reach values of 1.4 to 1.5 ppm. Similarly happens for CO_2, where concentrations increase gradually from averaged values of 1000 ppm to reach values around 2000 ppm which are in good agreement with results found in other studies [38]

In summary, the averaged values indicate that a small impact of passive inhalation of HnB smoke. However, in particular cases it can increase the pollutant levels for VOCs and CO_2.

3.4. Comparison between regular tobacco, e-cigarettes and HnB tobacco

Values obtained for VOCs, PM, CO_2 and CO in expiratory plume of active and passive HnB smokers were compared with those obtained for regular and e-cigs reported in a previous study made in similar conditions [31], (see Fig. 4).

As can be seen, the comparison between concentration values obtained for VOCs in active smokers decreases from 1 ± 0.1 ppm in active tobacco smokers to 0.19 ± 0.14 ppm for active HnB smokers. In this case, e-cigs present an intermediate situation, providing an average value of 0.55 ± 0.04 ppm. PM levels in expiratory plume of active regular tobacco smokers is between nine hundred and five hundred times higher than values in expiratory plume of active amber HnB

Table 2
Comparison of the descriptive statistics expiratory plume quality parameters during the use of HNB, vaping[a] and conventional cigarettes[a] (CC) obtained from *n* independent experiments, being n from 12 to 14 assays performed by 3 different HNB users and in the same conditions.

		Plume background (Mean ± SD)	Mean ± SD	median	95% conf. Interval	Min value	5th percentil	25th percentil	75th percentil	95th percentil	Max value
VOC (ppm)	HNB	0.13 ± 0.03	0.19 ± 0.14	0.175	0.115	0.01	0.03	0.12	0.27	0.37	0.4
	Vaping	0.47 ± 0.03	0.55 ± 0.04	0.55	0.045	0.51	0.51	0.53	0.57	0.59	0.59
	CC	0.52 ± 0.02	1.0 ± 0.1	1	0.1	0.9	0.91	0.95	1.05	1.09	1.1
PM (µg m^{-3})	HNB	25 ± 15	35 ± 33	30	26.2	0	2.5	12.5	47.5	80	90
	Vaping	24 ± 3	5130 ± 1100	5134	1240	4038	4148	4586	5682	6120	6230
	CC	32 ± 18	18589 ± 640	18589	723	17950	18014	18269	18908	19164	19228
CO_2 (ppm)	HNB	2150 ± 430	2000 ± 346	2000	277	1500	1575	1825	2175	2425	2500
	Vaping	1992 ± 410	1502 ± 134	1502	152	1368	1381	1435	1569	1623	1636
	CC	1793 ± 690	1505 ± 82	1505	93	1423	1431	1464	1546	1579	1587
CO (ppm)	HNB	0.2 ± 0.2	0.4 ± 0.2	0.35	0.19	0	0.05	0.22	0.55	0.6	0.6
	Vaping	0	0.58 ± 0.13	0.58	0.15	0.45	0.46	0.51	0.64	0.70	0.71
	CC	0.13 ± 0.07	8 ± 5	8	5.7	3	3.50	5.50	10.50	12.50	13

[a]: Data obtained from Casanova-Cháfer *et al.* [32].
NOTE: Data for HNB are related to both, amber and yellow sticks which are statistically comparable.
[a]: Data obtained from 8 till 9 independent assays with 4 non-smoker volunteers.

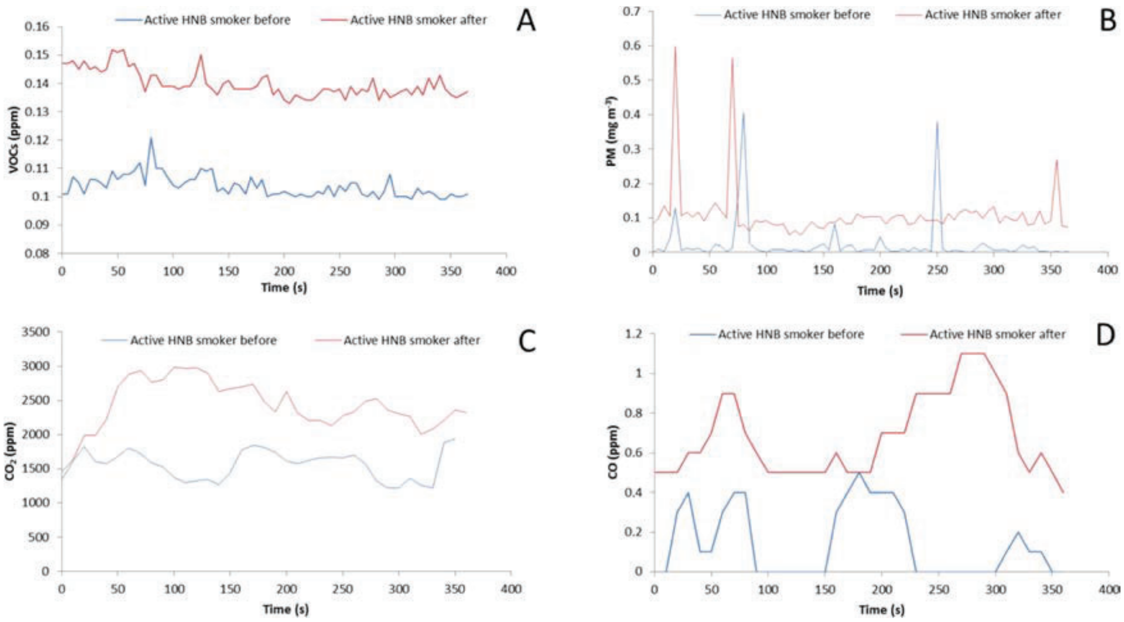

Fig. 2. Continuous monitoring of VOCs (A), PM (B), CO_2 (C) and CO (D) in active HnB smoker bexpiratory plume before and after using amber sticks in a single session for one of the active smokers.

Table 3
Comparison of the descriptive statistics of bystanders expiratory plume quality parameters during the use of HNB, vaping[a] and conventional cigarettes[a] (CC) obtained from *n* independent experiments, being n from 8 till 9 assays performed by 4 different HNB bystanders and in the same conditions.

		Plume background (mean ± SD)	Mean ± SD	Median	95% conf. Interval	Min value	5th percentil	25th percentil	75th percentil	95th percentil	Max value
VOC (ppm)	HNB	0.130 ± 0.014	0.20 ± 0.09	0.2	0.07	0.1	0.1	0.125	0.275	0.3	0.3
	Vaping	0.47 ± 0.03	0.47 ± 0.02	0.47	0.02	0.45	0.45	0.46	0.48	0.488	0.49
	CC	0.488 ± 0.06	0.61 ± 0.05	0.614	0.06	0.56	0.57	0.59	0.64	0.66	0.66
PM (μg m^{-3})	HNB	25 ± 19	0.04 ± 0.03	0.027	0.02	0.01	0.01	0.014	0.045	0.08	0.09
	Vaping	24 ± 3	21 ± 7	21	7.92	14	14.7	17.5	24.5	27.3	28
	CC	15 ± 4	1269 ± 295	1269	334	974	1003.5	1121.5	1416.5	1534.5	1564
CO_2 (ppm)	HNB	1450 ± 513	1650 ± 378	1700	303	1000	1125	1525	1950	2000	2000
	Vaping	1992 ± 410	3327 ± 910	3327	1029	2418	2509	2872.5	3781.5	4145	4236
	CC	1320 ± 469	2050 ± 611	2050	691	1439	1500	1744.5	2355.5	2600	2661
CO (ppm)	HNB	0	0.05 ± 0.08	0	0.07	0	0	0	0.075	0.175	0.2
	Vaping	0	0	0	0	0	0	0	0	0	0
	CC	0	1.3 ± 0.2	1.3	0.23	1.1	1.1	1.2	1.4	1.5	1.5

[a]: Data obtained from Casanova-Cháfer *et al.* [32]
NOTE: Data for HNB are related to both, amber and yellow sticks which are statistically comparable.

tobacco. For CO values it was found an average of 8 ± 5 ppm for active regular tobacco users while values of 0.58 ± 0.13 and 0.4 ± 0.2 ppm were found for e-cigs and HnB active tobacco users. Furthermore, the low variability shown in e-cig and HnB measurements can indicate a similar way of heating, far from the variability obtained for regular tobacco expiratory plume data. In the last case CO production strongly depends on smoking habits.

Regarding CO_2, similar data were provided for active and passive device users. It can be attributed to the strong dependence of measuring conditions on the respiration of subjects.

On the other hand, the comparison of VOCs in passive expiratory plume shows that the use of HnB devices decreases around 2.5 times the concentrations in passive users as compared to values obtained for passive regular tobacco and e-cigs exposed. The comparison between concentration values obtained for PM in passive exposed subjects decreases from 1269 ± 295 μg m^{-3} in passive tobacco smokers to an average between 0.04 ± 0.03 μg m^{-3} for amber and yellow HnB tobacco. In this case, e-cigs provided an average value of 21 ± 7 μg m^{-3}. CO is only present at relatively high levels in regular tobacco bystanders expiratory plume and the absence of complete combustion of organic material for both, e-cgis and HnB tobacco, provided values near the LOD of the monitoring device, fixed in 0.1 ppm.

As in active smokers expiratory plume, CO_2 shows very low differences between the results obtained with the different devices, showing a high variability.

In comparison with data previously reported, the obtained results regarding the presence of pollutants in expiratory plume of users and bystandings are in agreement with the behaviour of pollutants in air before and after the use of smoking devices use [33,34]. In this sense, the use of HNB systems provides lower values of pollutants than those obtained with traditional cigarettes, being the use of vaping systems an intermediate situation between them.

3.5. *Analysis of nicotine in HnB sticks*

Linearity of the GC nicotine determination was assessed using a calibration curve from 0.8 to 5 μg mL prepared in n-hexane. Determination coefficient values (R^2) obtained in different sessions of

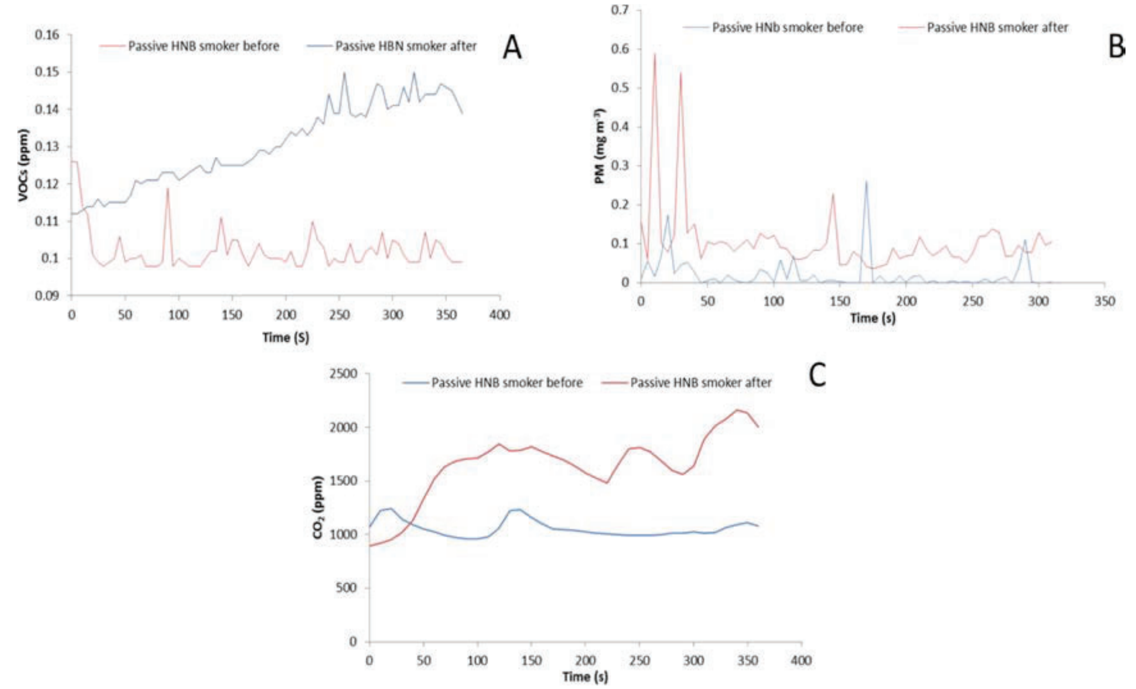

Fig. 3. Continuous monitoring of VOCs (A), PM (B), and CO_2 (C) in passive smoker expiratory plume before and after exposition to HnB smoke.

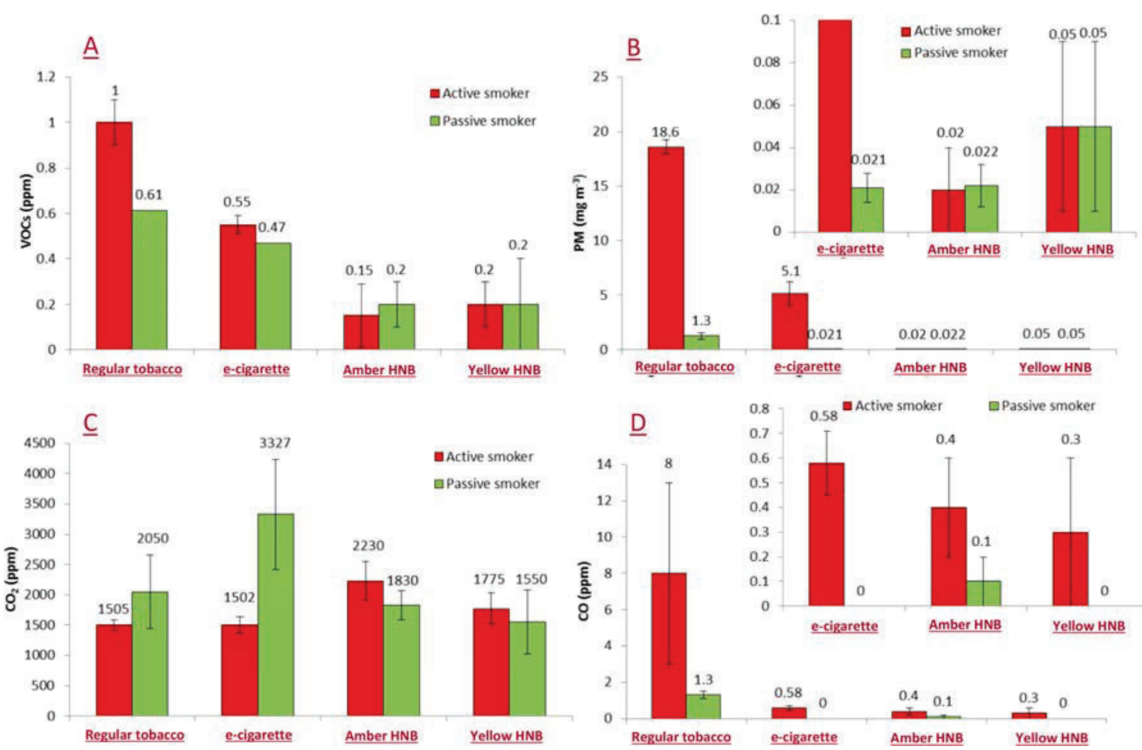

Fig. 4. Comparison of VOCs (A), PM (B), CO_2 (C) and CO (D) levels in expiratory plume of active and passive smokers after exposition to regular tobacco, electronic cigarettes and two types of HnB tobacco. Inserts in Fig. 3B and 3D: extended scale for e-cig and HnB devices.

measurement ranged from 0.996 and 0.994. Precision was established for the lowest nicotine standard (n = 5), as 3 % relative standard deviation (RSD), and RSD values ranged between 3 and 39% in non-smoked and smoked tobacco for the determination of nicotine in HnB sticks and filters. On the other hand, limits of detection (LOD) and quantification (LOQ) were calculated as 3 and 10 times the standard deviation of intercept of calibration line divided by the obtained slope,; providing a LOD of 5 µg and a LOQ of 16 µg nicotine per stick.

The amount of nicotine present in HnB sticks was determined in non-smoked and smoked amber and yellow HnB sticks in order to evaluate the percentage of nicotine inhaled by users. In the same way, the amount of nicotine retained in HnB filters was determined in the whole filter as well as in the three constituents of the filtering section, the inner filter (close to tobacco), the medium filter and the final filter, close to users mouth (see Fig. 1). The content of nicotine in non-used HnB sticks (n = 4) was determined too, varying from 6.3 ± 0.3 mg for orange sticks till 4.5 ± 0.2 mg for yellow sticks, being an average value of 4.8 ± 0.5 mg per stick for turquoise sticks, which contains also menthol.

Table 4 shows the results obtained for nicotine remaining content in used HnB sticks for amber and yellow sticks and nicotine retained in the whole filters. From these data it seems clear that the remaining amount of nicotine in amber HnB sticks is statistically higher than in yellow ones. However, the repeatability of the aforementioned data is very low and strongly depends on the smoking habits, the temperature reached in the heating process and the cleanliness of HnB device. In addition, the amount of nicotine retained by the filtering system components, employing yellow HnB sticks was analyzed in order to determine their nicotine retention (See Table 5).

Nicotine is strongly retained by non-heated tobacco (results shown in Table 4). Additionally, the different parts of filters employed in HnB sticks present similar efficiency, Table 5. Major retention is performed in the middle part of the filter, with an average of 0.4 mg per filter followed by 0.3 and 0.2 mg retained in the other two parts. In short, data reported for nicotine in HnB tobacco indicates an average delivery to mainstream of approximately 1.7 mg nicotine for amber HnB sticks and 0.5 mg for yellow ones. These results are in good agreement with those reported in the mainstream for the HnB tobacco [32].

Table 4
Nicotine remaminig content in heated HnB sticks and nicotine retained by whole filters.

		mg nicotine (heated stick)	average ± SD	mg nicotine (whole filter)	average ± SD
Amber	S1	3.64	3.4 ± 0.6	1.31	1.42 ± 0.13
	S2	2.90		1.63	
	S3	2.95		1.40	
	S4	3.05		1.32	
	S5	3.53		1.35	
	S6	4.55		1.51	
Yellow	S1	3.65	2.6 ± 0.8	0.98	1.2 ± 0.4
	S2	2.41		2.14	
	S3	2.51		1.04	
	S4	1.80		0.89	
	S5	1.42		1.00	
	S6	3.70		1.23	
	S7	3.06		1.31	
	S8	1.67		1.05	

Table 5
Nicotine concentration retained by filtering system parts in yellow HnB devices.

	mg nicotine	average ± SD
HnB filter yellow inner part	0.30	0.32 ± 0.04
	0.29	(0.8 cm × 0.7 cm Ø)
	0.37	
	0.31	
HnB filter yellow medium part	0.35	0.4 ± 0.1
	0.48	(1.8 cm × 0.7 cm Ø)
	0.29	
	–	
HnB filter yellow final part	0.23	0.23 ± 0.09
	0.11	(0.7 cm × 0.7 cm Ø)
	0.33	
	0.23	

Note: The dimensions of the filtering system parts are indicated in brackets down the average mg of nicotine retained.

4. Conclusions

The new HnB devices do not reduce the nicotine consumption as compared with regular tobacco, being found concentrations in the devices and remaining amounts of nicotine, in the non-smoked tobacco and filters, that agree with usual levels in classical cigarettes. So, the regular use of HnB devices does not contribute to the smoking cessation and maintains the level of nicotine of users.

The use of HnB has positive consequences on the gaseous composition in active and bystander expiratory plume and the quality of the ambient air.

The comparison between HnB, e-cigs and regular tobacco active smokers expiratory plume reveals that the use of new devices decreases drastically the emission of contaminants. The VOCs level decreases in active smokers between 70 and 80% as compared with the use of e-cigs and regular tobacco. PM and CO levels are reduced remaining at residual levels.

On the other hand, the expiratory plume of HnB bystanders does not increased the levels of VOCs, PM or CO. However, levels of CO_2 are two times higher than previous ones in indoor air.

Furthermore it has been evidenced that portable monitoring provides fast, green and powerful tools in the analysis of indoor air and to evaluate the effect of smoking practices on the environment and breath of active and bystanders.

5. Novelty Statement

This paper proposes, for the first time, the evaluation of secondhand exposure of HnB tobacco practices as an indicator of pollution of indoor ambient air and its effects on the expiratory plume of active and passive smokers. Data obtained by using portable air monitoring devices to control volatile organic compounds (VOCs), CO_2, CO and particulate material (PM) were compared with results previously found for the use of classical tobacco and electronic cigarettes. In short, it can be concluded that HnB sticks provide comparable nicotine levels than regular tobacco. However, the new smoking devices strongly minimize, in all cases, the concentration of PM and CO in breath, reducing also the VOCs in the breath of passive smokers.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

Authors gratefully acknowledge the financial support of the Ministerio de Economía y Competitividad (Project CTQ 2014 52841-P and Project CTQ-2016-78053-R).

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