Plant extract as gas adsorbent to reduce smoke toxicants of cigarette

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Biological Sciences - Article

Keywords: Plant extract, Harm reduction, Toxicant, Adsorbent, Smoke

Posted Date: December 9th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-1139463/v1>

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Abstract

Cigarette smoke contains thousands of chemicals including many known toxicants and annually leads to millions of deaths worldwide. To reduce the harms of cigarette, plant extracts were applied to adsorb smoke toxicants of cigarette. Results showed that platycladus orientalis leaf extract and mulberry fruit extract particles filled into cigarette cellulose acetate filter can significantly reduce 15 major cigarette smoke toxicants emission including hydrogen cyanide (HCN), benzo[a] pyrene (B[a]P), formaldehyde, crotonaldehyde, 2-butanone, P-hydroquinone, M-dihydroxybenzene, catechol, phenol, M-P-cresol, O-cresol, N'-nitrosornicotine (NNN), 4-methylnitrosamino-1-(3-pyridyl)-butanone (NNK), (R,S)-N-nitrosoanatabine (NAT) and (R,S)-N-nitrosoanabasine (NAB) by 11.90% to 60.42% ($P < 0.01$). Platycladus orientalis leaf extract particles added in the outer cigarette filter also can adsorb other 125 kinds of chemicals most of which are harmful. Our results also indicated that plant extract has extensive gas adsorption characteristics and different plant extracts displayed different adsorption capacity to different toxicants. The adsorption capacities of five randomly selected plant extracts are all significantly higher than that of activated carbon ($P < 0.01$). These findings suggest that plant extracts are excellent cigarette smoke adsorbents.

1. Introduction

Smoking is common worldwide. Cigarette smoke contains more than 4,500 chemicals including many known toxicants (Sobus et al., 2014; Ryu et al., 2020). These toxicants are responsible for a variety of cancers and other diseases. Tobacco smoking is the key cause of lung cancer (Jassem et al., 2009; Jung et al., 2016), and a major cause of cancers of the oral cavity, larynx, oropharynx, hypopharynx, oesophagus, stomach, liver, pancreas, bladder, ureter, kidney and cervix, and myeloid leukaemia (Hecht et al., 2003; Wittel et al., 2012; Jethwa et al., 2017; Chunxia et al., 2019; Khan et al., 2020; Nocini et al., 2020). Tobacco-specific N-nitrosamines (TSNAs) are a group of carcinogens and they cause cancers of the lung, esophagus, pancreas, and oral cavity by DNA adduct formation. The most carcinogenic TSNAs in laboratory animals are 4-(methylnitrosamino)-1-(3-pyridyl)-1-butanone (NNK) and N'-nitrosornicotine (NNN) (Hecht et al., 1999; Ramírez et al., 2014). NNK has been proved to be related to lung and head and neck cancer (Xue et al., 2014; Doukas et al., 2020). NNN is one of potent carcinogenic TSNAs and it induces several malignancies including lung, esophageal, and pancreatic cancers in laboratory animals (Selvin et al., 2018). Benzo(a)pyrene [B(a)P], a polycyclic aromatic hydrocarbon, is one among the principal constituents of tobacco smoke that plays a key role in lung and breast carcinogenesis (Kasala et al., 2015; Guo et al., 2015). Hydrogen cyanide (HCN) is volatile and highly toxic with acute and chronic effects on humans (Tran et al., 2020). HCN of smoke inhibits the enzyme systems necessary for oxidative metabolism and oxygen transport at the cellular level (Silverstein et al., 1992). Unsaturated aldehyde formaldehyde is a noxious aldehyde in cigarette smoke that causes edematous acute lung injury (Cui et al., 2016) and exposure to formaldehyde has been linked to asthma, especially in children (McGwin et al., 2011). Smoking not only directly causes health harm to smokers, but also poses a health threat to non-smokers through second-hand smoke exposure (Xisca et al., 2017; Kelvin et al., 2020).

Based on the report of WHO, annually about 7 million deaths were attributable to smoking (GBD 2015 Tobacco Collaborators, 2017). The Framework Convention for Tobacco Control (FCTC) opened for signature from 2003 in Geneva has become the the most widely embraced treaty in United Nations with 168 signatories today (<https://fctc.who.int>). Although the daily smoking rate has declined, the overall number of smokers remains a rapid increase worldwide and was more than 1 billion in 2019 (Marissa et al., 2021).

For nicotine is addictive, smoking [cessation](#) is still difficult to most smokers despite ongoing legislative actions and public health efforts targeted at tobacco avoidance ([Mark et al., 2014](#); [Nicola et al., 2019](#); [Judith et al., 2019](#); [Federico et al., 2020](#)). Although in recent years electronic cigarettes (e-cigarettes) and vape devices have rapidly become the new tobacco products used by youth, most smokers are still the faithful consumers of traditional cigarettes ([Walley et al., 2019](#); [Cherian et al., 2020](#)). This compels us to adopt more measures to reduce the smoking harms of traditional cigarette. Here, we applied a kind of material- plant extract as gas adsorbent to cigarette harm reduction.

2. Material And Methods

2.1. Adsorbents preparation

In this experiment, we randomly selected five kinds of plant extracts-platycladus orientalis leaf extract(10:1, water extraction), mulberry fruit extract (10:1, water extraction), blueberry fruit extract (10:1, water extraction), pine needle extract (10:1, water extraction) and ginkgo leaf extract (10:1, water extraction) as experimental materials (Xi'an Senran Bioengineering Co., Ltd). The powder of these plant extracts was squeezed into particles with 1 mm diameter and used as adsorbents. The activated carbon of antigas mask was broken into particles with 1 mm diameter and used as control adsorbents.

2.2. Cigarette sample preparation

The total length of test cigarette(ZiYun, Hongyunhonghe Group, China) was 84 mm and the cellulose acetate filter length was 25 mm. The diameter of test cigarette was 7.8 mm. These plant extract particles were filled into the front 15 mm cellulose acetate filter of test cigarette with 1.5 mg/mm([Fig.1](#)). These cigarettes with cellulose acetate filter including plant extract particles were used as experimental cigarettes. These cigarettes with blank cellulose acetate filter were used as control cigarettes.

2.3. Outer cigarette filter preparation

The outer cigarette filter had a plastic shell embodying two cellulose acetate filters(the length is 1cm and the diameter was 7mm).There was a cavity between these two cellulose acetate filters.50mg adsorbent particles were filled into the cavity([Fig.2](#)).

2.4. Quantitative and qualitative analysis of hazard constituents in mainstream smoke

The test smoking of cigarette was carried out by a 20-port Borgwaldt RM200 rotary smoking machine (Borgwaldt, Germany). The HCN), B[a]P, [formaldehyde](#), crotonaldehyde, 2-butanone, P-hydroquinone, M-dihydroxybenzene, catechol, [phenol](#) M-P-cresol, O-cresol, N'-nitrosoanabasin (NNN), 4-methylnitrosamino-1-3-pyridyl- butanone (NNK), (R,S)-N-nitrosoanatabine (NAT) and (R,S)-N-nitrosoanabasine (NAB) emission level in mainstream cigarette smoke of cigarette were determined by commercial test according to the Chinese standard of cigarettes as described as [Cai et al \(2019\)](#)(4 replicates). In this experiment, using platycladus orientalis leaf extract particles as adsorbent in the outer cigarette filter([Fig.2](#)), changes of chemical composition of adsorbent before and after smoking were determined through gas chromatography and tandem mass spectrometry method as described as [Shen et al\(2016\)](#)(2 replicates).

2.5. The adsorption capacity comparison between the activated carbon and five kinds of plant extracts

In experiment, five kinds of plant extracts and activated carbon particles were used as adsorbents in the outer cigarette filter, the adsorbent weight changes of before and after one cigarette smoking were recorded as the adsorption capacity of one cigarette(3 replicates).

2.6. Statistical analysis

The difference of 15 major cigarette smoke toxicants emission and the difference of adsorption capacity were assessed using the ANOVA program of SPSS 22.0 for Windows (IBM SPSS Inc., New York, USA) . The significance level was set at 1% ($P < 0.01$) in all tests.

3. Results And Discussion

3.1. The absorptive effects on fifteen smoke toxicants of cigarette smoke

Results showed that platycladus orientalis leaf extract and mulberry fruit extract added in cigarette filter can effectively adsorb 15 major toxicants in the mainstream cigarette smoke. Compared to the control(normal cigarette, no platycladus orientalis leaf extract added in cigarette filter), the test cigarette average release of HCN, B(a)P, P-hydroquinone, M-dihydroxybenzene, catechol, phenol, M-P-cresol, O-cresol, formaldehyde, crotonaldehyde, 2-butanone, NNN, NNK, NAT and NAB was effectively reduced by 21.69%, 21.47%, 11.90%, 23.00%, 23.60%, 45.00%, 39.30%, 47.10%, 14.20%, 30.80%, 13.50%, 28.29%, 15.00%, 29.29% and 16.50%, respectively ($P < 0.01$) (Fig.3) . Compared to the control(normal cigarette, no mulberry fruit extract added in cigarette filter) , the test cigarette average release average release of HCN, B(a)P, P-hydroquinone, M-dihydroxybenzene, catechol, phenol, M-P-cresol, O-cresol, formaldehyde, crotonaldehyde, 2-butanone, acetaldehyde, acetone, NNN, NNK, NAT and NAB was significantly reduced by 23.12%, 22.16%, 15.00%, 60.42%, 27.12%, 47.30%, 40.50%, 53.00%, 19.10%, 40.00%, 14.80%, 22.62%, 13.70%, 19.18% and 19.11%, respectively ($P < 0.01$) (Fig.3) .

Based on above quantitative analysis results, 15 major toxicants in the mainstream cigarette smoke were significantly reduce by 11.90% to 61.50% ($P < 0.01$). Different plant extracts displayed different adsorption capacity to different toxicants. The same plant extract showed different adsorption preference to different toxicants.

3.2. The absorptive effects on other smoke chemicals of cigarette

Platycladus orientalis leaf extract adsorbent particles added in the outer cigarette filter also showed absorptive effect to other 125 kinds of chemicals(Table 1) most of which are harmful. For example, methanethiol is a highly toxic chemical and can cause metabolic acidosis, seizures, myocardial infarction, coma and death (Maddy et al., 2020). Furan, a human carcinogen, is found in heat treated foods and tobacco smoke(Grill et al., 2015). Phenols or phenolic compounds(p-Cresol, 2-ethyl-Phenol, 2-methyl-Phenol, 2-methoxy-Phenol, 2,3-dimethyl-Phenol, 2,4-dimethyl-Phenol and 2,4,6-trimethyl-Phenol) in tobacco smoke are cardiovascular toxins, act as tumor co-promoters and show genotoxic activity(Vaughan et al., 2008). This indicated that plant extract has extensive gas adsorption characteristics.

3.3. The adsorption capacity comparison between the activated carbon and plant extracts

Due to the large specific surface area, rich porous structure, and high adsorption capacity, activated carbon adsorbents are widely used in gas purification (Zhang et al., 2015). In this experiment, we also compared the adsorption capacity to cigarette smoke between the activated carbon and plant extracts. Result indicated that the adsorption capacities of five plant extracts—platycladus orientalis leaf extract, mulberry fruit extract, blueberry fruit extract, pine needle extract and ginkgo leaf extract—are all significantly higher than that of activated carbon ($P<0.01$) (Table 2).

3.4. Implications

Most plant extracts (such as grape seed extract, hawthorn leaf extract, cyclocarya paliurus leaf extract, rosemary extract, folium artemisiae argyi extract, ginkgo leaf extract, persimmon leaf extract, sea buckthorn extract, kudzu vine root extract, buckwheat extract, etc.) are nontoxic, harmless, cheap and have wide raw material sources. They can be applied to tobacco industry simply and conveniently (Fig. 1-2). This provides a new choice for the smokers difficult in quitting smoking. We can use plant extracts as adsorbent to reduce harms of cigarette smoking.

In recent years, with rapid development of industry, the problem of air pollution arises. The air pollution derives from different resource including industrial waste gas (Cong, 2018), automobile exhaust (Guamieri et al., 2014), indoor air pollutants (Zhao et al., 2020), etc. The air pollutants include many toxic chemicals such as formaldehyde and phenols. In our experiment, plant extracts displayed excellent adsorption capacity to these toxicants and the adsorption capacities of five plant extracts are all significantly higher than that of activated carbon. This implied that we can use plant extracts as new type of adsorbents to replace activated carbon in air cleaner and anti-gas mask.

Declarations

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.

Acknowledgments

We thank Dr Hu Qun and Mr. Feng Hongtao (Yunnan Technical center of China Tobacco Industry Co., Ltd) who contributed commercial test for this work.

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Tables

Table 1 The absorptive effect of platycladus orientalis leaf extract particles on other chemicals in outer cigarette filter

No.	Chemicals	Control	Experimental
1	Methanethiol	-	+
2	Furan	-	+
3	2,3-Butanedione	-	+
4	2-Propanone, 1-hydroxy-	-	+
5	Propanoic acid, 2-methyl-	-	+
6	Propylene Glycol	-	+
7	3-Butenoic acid	-	+
8	Pyrazine	-	+
9	Isocrotonic acid	-	+
10	1-hydroxy-2-Propanone	-	+
11	Isocrotonic acid	-	+
12	3-methyl-Butanoic acid	-	+
13	Acetamide	-	+
14	Propanoic acid, 2-oxo-, methyl ester	-	+
15	2-methyl-Pyridine	-	+
16	Furfural	-	+
17	methyl-Pyrazine	-	+
18	5-Hexenal	-	+
19	1,1'-(1,3-propanediyl)bis-Benzene	-	+
20	2-Furanmethanol	-	+
21	1,2-Ethanediol, diacetate	-	+
22	3-methyl-Pyridine	-	+
23	6-Methyl-2-(3-nitrophenyl)imidazo[1,2-a]pyridine	-	+
24	Cyclopent-4-ene-1,3-dione	-	+
25	[1,2,4]Triazolo[1,5-a]pyrimidine-6-carboxylic acid, 7-amino-, ethyl ester	-	+
26	3,4-dimethyl-Pyridine	-	+
27	1-(acetyloxy)-2-Butanone	-	+
28	Butyrolactone	-	+
29	2(5H)-Furanone	-	+
30	2-Furancarboxaldehyde, 5-methyl-	-	+

31	2-Cyclopenten-1-one, 3-methyl-	-	+
32	2,3,6-trimethyl-Pyridine	-	+
33	2-Cyclopenten-1-one, 2,3-dimethyl-	-	+
34	Benzonitrile	-	+
35	3-methyl-2(5H)-Furanone	-	+
36	2-methyl-Phenol	-	+
37	2-Cyclopenten-1-one, 2,3-dimethyl-	-	+
38	p-Cresol	-	+
39	1-(1H-pyrrol-2-yl)-Ethanone	-	+
40	Pyridine, 3,4-dimethyl-	-	+
41	2-methoxy-Phenol	-	+
42	2-Cyclopenten-1-one, 3-ethyl-2-hydroxy-	-	+
43	2-ethyl-Phenol	-	+
44	4H-Pyran-4-one, 2,3-dihydro-3,5-dihydroxy-6-methyl-	-	+
45	1H-Indene, 1-methylene-	-	+
46	Chloromethane	-	+
47	Acetic acid, methyl ester	-	+
48	Methyl vinyl ketone	-	+
49	2-methyl-Furan	-	+
50	2,3-Pentanedione	-	+
51	Acetic acid, hydroxy-, methyl ester	-	+
52	Acetoin	-	+
54	Bi-2-cyclohexen-1-yl	-	+
54	2-Butynoic acid	-	+
55	(E)-2-Butenoic acid	-	+
56	2-Pentanol, 3-chloro-4-methyl-, (R*,R*)-(./-.)-	-	+
57	1,6-Dideoxygalactitol	-	+
58	3-Furaldehyde	-	+
59	propyl-Propanedioic acid	-	+
60	Betaine	-	+
61	N,N-Dimethyl-1-propanamine	-	+
62	2-Penten-4-yn-1-ol, 3-methyl-, (E)-	-	+

63	2,5-dimethyl-Pyrazine	-	+
64	Cyclopropane, tetramethylmethylene-	-	+
65	3H-Pyrazol-3-one, 1,2-dihydro-5-methyl-	-	+
66	1-Methyl-2-methylenecyclohexane	-	+
67	cis-1-Ethoxy-1-butene	-	+
68	Bicyclo[3.1.0]hexan-2-one	-	+
69	2,6-Lutidine	-	+
70	2,4-Hexadiene, 3,4-dimethyl-, (E,Z)-	-	+
71	1,2-Cyclohexanedione	-	+
72	3-Hexen-2-one, 3-methyl-	-	+
73	1H-Pyrrole-2-carboxaldehyde	-	+
74	3,5,5-trimethyl-Cyclohexene	-	+
75	3-Pyridinecarboxaldehyde	-	+
76	2-Cyclopenten-1-one, 2-hydroxy-3-methyl-	-	+
77	Cyclopropane, ethenylmethylene-	-	+
78	2,5-Furandione, 3,4-dimethyl-	-	+
79	Benzyl alcohol	-	+
80	2,3-Dimethyl-1,4-pentadiene	-	+
81	2-methyl-4-Octyne	-	+
82	Spiro[3.4]octan-5-one	-	+
83	2,3-dimethyl-Phenol	-	+
84	Cyclopentane, (3-methylbutylidene)-	-	+
85	2,4-dimethyl-Phenol	-	+
86	1-Butanone, 1-(2-furanyl)-	-	+
87	2a,4a,6a,6b-Tetrahydrocyclopenta[cd]pentalene	-	+
88	Benzyl nitrile	-	+
89	1-methyl-2-propyl-Cyclopentane	-	+
90	Bicyclo[3.1.0]hexan-3-one, 4-methyl-1-(1-methylethyl)-	-	+
91	1,3-Benzenediol, 2,5-dimethyl-	-	+
92	1,3-Cyclopentadiene, 1,2,3,4-tetramethyl-5-methylene-	-	+
93	2-Myristynoyl-glycinamide	-	+

94	4-Hydroxybenzamidine	-	+
95	2,4,6-trimethyl-Phenol	-	+
96	5-Iodo-nonane	-	+
97	(1-Methylenebut-2-enyl)benzene	-	+
98	2-quinoxalinamine, 3-chloro-N-ethyl-	-	+
99	Hexanoic acid, tridec-2-ynyl ester	-	+
100	1-methyl-Naphthalene	-	+
101	Octadecane	-	+
102	1H-Inden-1-one, 2,3-dihydro-	-	+
103	2,1-benzisoxazole-4-carboxylic acid, 1,3-dihydro-3-oxo-, ethyl ester	-	+
104	(isocyanomethyl)-Benzene	-	+
105	1-methyl-4-(1-methylethylidene)-Cyclohexane	-	+
106	4-ethenyl-1,2-dimethyl-Benzene	-	+
107	Cyclooctane	-	+
108	3-methyl-Cyclohexanone	-	+
109	exo-Norbornanol,heptafluorobutyrate (ester)	-	+
110	Verbenol	-	+
111	1,2-Cyclopentanedione, 3-methyl-	-	+
112	2-Propanol, 1-[(1-ethynylcyclohexyl)oxy]-	-	+
113	Pyrrolo[3,4-c]pyrazole-4,6(3H,5H)-dione, 5-(2-fluorophenyl)-3a,6a-dihydro-6a-methyl-	-	+
114	Benzene, [(octyloxy)methyl]-	-	+
115	Methyl ethyl cyclopentene	-	+
116	1,3-Dimethyl-3,4,5,6-tetrahydro-2(1H)-pyrimidinone	-	+
117	3-ethenyl-Cyclohexanone	-	+
118	2-Pyrrolidinone	-	+
119	Dicyclobutylidene oxide	-	+
120	Phenol, 2,6-dimethyl-	-	+
121	endo-2-Methylbicyclo[3.3.1]nonane	-	+
122	2-Azetidinecarboxylic acid, 1-nitroso-	-	+
123	Cyclohexane, 1-methyl-4-(1-methylethylidene)-	-	+
124	2-methoxyethyl-Benzene,	-	+

-, No detected; +, Detected

Table 2 The adsorption capacity comparison between the activated carbon and plant extracts

Adsorbent (100mg)	Activated carbon	Platycladus orientalis leaf extract	Mulberry fruit extract	Blueberry fruit extract	Pine needle extract	Ginkgo leaf extract
Adsorption capacity of 1cigarette(mg)	15.60±0.50 ^A	67.40±0.70 ^B	77.40±1.10 ^B	76.20±1.20 ^B	66.50±0.90 ^B	63.50±0.70 ^B

Note: Data in the table are least square means±standard error. Values with different capital case superscripts are significantly different at *P*<0.01.

Figures

Figure 1

Platycladus orientalis leaf extract and mulberry fruit extract were used as adsorbents in cellulose acetate filter to reduce harms of cigarette smoking(☐Plant extract particles were filled into the cellulose acetate filter; ☐Cellulose acetate filters were assembled into cigarettes; ☐Smoking; ☐Plant extract particles adsorb the harmful gas and turn black.).

Figure 2

Platycladus orientalis leaf extract was used as adsorbent in outer filter to reduce harms of cigarette smoking(⑤ Plant extract particles were filled into the outer filter; ⑥ Cigarette was insert into filters; ⑦ Smoking; ⑧ Plant extract particles adsorb the harmful gas and turn black.).

Figure 3

Platycladus orientalis leaf extract(Experimental1) and mulberry fruit extract (Experimental2)adsorbents in cellulose acetate filters can effectively reduce the major carcinogens in mainstream cigarette smoke. Control, cigarette with no additives in cellulose acetate filter; Experimental 1 cigarette with platycladus orientalis leaf extract added in cellulose acetate filter; Experimental 2 cigarette with mulberry fruit extract added in cellulose acetate filter.