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Research Article

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Mid-Infrared Light Reduces the Nicotine Content and Detoxifies Bidis for Safer Smoking

Umakanthan[1*], Madhu Mathi[1], Umadevi[2] and Siva Rama Krishna[3]

[1]*Veterinary Hospital, India*

[2]*Assistant Professor, Department of Botany, The Standard Fireworks Rajaratnam College for Women, India*

[3]*Veterinary Assistant Surgeon, Veterinary Dispensary, India*

[*]Corresponding Author
Umakanthan, Veterinary Hospital, India.

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Abstract

Tobacco use is dangerous to health and the environment. Despite the numerous measures taken to combat the adverse effects of tobacco, fruitful results are yet to be achieved. Nicotine is the primary psychoactive (and highly addictive) chemical component in tobacco. This study aimed to lower the nicotine content and detoxify bidis (a more harmful tobacco product compared to cigarettes). We subjected the bidi packets to 2–6 µm mid-infrared (mid-IR) light generated by a specially designed pocket-sized atomizer. The smoke from such mid-IR-treated bidis blown over animate and inanimate objects was non-irritating and harmless. Spectroscopic studies revealed that the applied 2–6 µm mid-IR exerted molecular-level changes and resulted in chemical compound transformations, thus lowering the nicotine content in the bidis. Trials with smokers demonstrated that the mid-IR-treated bidis were more desirable to smoke and also retained smoking pleasure and satiety. Thus, the 2–6 µm mid-IR light can detoxify the bidis and represents a safer way for smoking than attempting complete cessation, which is highly challenging for smokers.

Keywords: MIRGA, Bidi, 2-6 µm Mid-Infrared, Nicotine Reduction, Detoxified Smoke

1. Introduction

Tobacco use is a major preventable cause of disease and death. Every year, approximately 7 and 1.2 million active and passive tobacco users die globally [1]. Tobacco smoke contains a complex mixture of 5,000 chemicals, 98 of which are hazardous and around 50 of which are carcinogens [2]. Nicotine causes significant health hazards to the heart, reproductive system, and lungs, including cancer and other chronic diseases [3-7]. Smoking reduces life expectancy by ten years, and quitting before the age of 40 reduces the chance of smoking-related fatalities by up to 90% [8,9].

Nearly 50% of smokers tried to quit smoking, but less than 10% succeeded [10,11]. The use of alternative nicotine and tobacco products was found to be more effective for facilitating sustained abstinence, which is more pleasant than other interventions [12]. 20% of smokers use safer smoking alternatives as smoking reduction/cessation aid [13]. Alternative tobacco and nicotine products, such as Electronic Cigarettes (EC), smokeless tobacco, and Nicotine Replacement Therapy (NRT), have been assessed for their potential role in smoking reduction and cessation. Studies have shown that these products can moderately reduce daily cigarette consumption and assist in smoking cessation attempts, with fewer adverse events [14].

However, it is important to note that the use of alternative tobacco products, particularly among adolescents, may lead to subsequent cigarette use and undermine tobacco control efforts. Although smoking cessation could be initially achieved with these interventions, smoking relapse is a significant challenge. Vaccines aimed to elicit antibodies to block the pharmacological effects of nicotine are not yet fully developed and face significant ethical and economic challenges. Unfortunately, no standard regimen has been proven to be effective for smoking cessation and relapse prevention.

Nicotine degradation in the blood can be achieved using the bacterial enzyme NicA2. NicA2 is an enzyme found in Pseudomonas putida and Arthrobacter nicotinovorans that can degrade nicotine through enzymatic processes [15]. It oxidizes nicotine into non-addictive compounds, such as pseudo-oxynicotine and 2,6-dihydroxy-pseudooxynicotine, which can prevent the accumulation of nicotine in the brain [16]. However, such treatment raises concerns regarding immunogenicity and cost-effectiveness. Therefore, this study aimed to develop safer smoking by detoxifying the nicotine using a laser. We chose the electromagnetic spectrum's mid-infrared (MIR) portion as the laser source. MIR is non-ionizing, biologically safe, can penetrate most of the intervening media, and is absorbed by all organic compounds [17,18]. We designed a pocket-sized 2–6 µm mid-IR generating atomizer (MIRGA) and investigated the role of MIR in reducing the nicotine content and thereby detoxifying the tobacco.

2. Materials and Methods

2.1. MIR Atomizer Equipment – "MIRGA"

MIRGA (patent no.: 401387) is a 20 mL pocket-sized atomizer containing an inorganic water-based solution containing approximately two sextillion cations and three sextillion anions. The design, specifications (Figure 1), and working principle of MIRGA were described in a study by (full design and details of MIRGA present in Supplementary Text T1) [19]. MIRGA is designed to emit energy in the 2–6 µm MIR range upon spraying Figure 1.

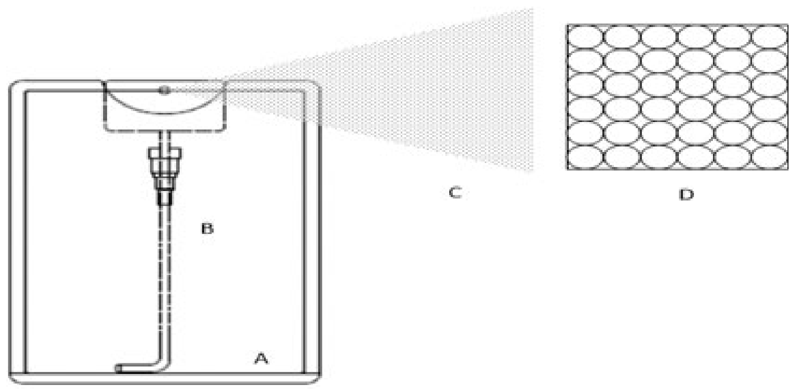


Figure 1: Schematic Representation of MIRGA Spraying A) Container B) Plunger C) MIR Spray D) Packet Containing Bidis

2.1.1. In Supplementary Text T1

MIRGA (under-patent no.: 401387) is a 20-mL capacity polypropylene plastic atomizer containing an inorganic (molar mass 118.44 g/mole) water-based solution. The sprayer unit has dimensions 86 × 55 × 11 mm, an orifice diameter of 0.375 mm, ejection volume 0.062 + 0.005 mL, and ejection time 0.2 s. The average pressure is 3900 Pa, and the cone liquid back pressure is 2000 N/m2. During spraying, approximately 1-µg weight of water is lost as mist and the non-volatile material in the sprayed liquid has a concentration of 153 mg/mL. Depending on the pressure applied to the plunger, every spraying is designed to generate 2–6 µm as estimated by an FTIR (retro-reflector) interferometer instrument (Detector type D* [cm HZ1/2 - 1] MCT [2-TE cooled]) at Light wind, Petaluma, CA, USA.

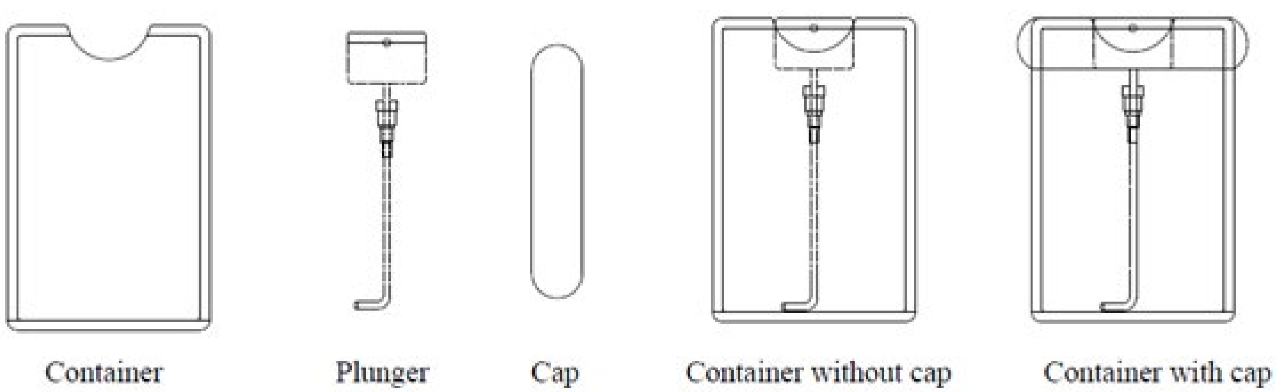


Figure 2: Parts of the MIRGA Sprayer

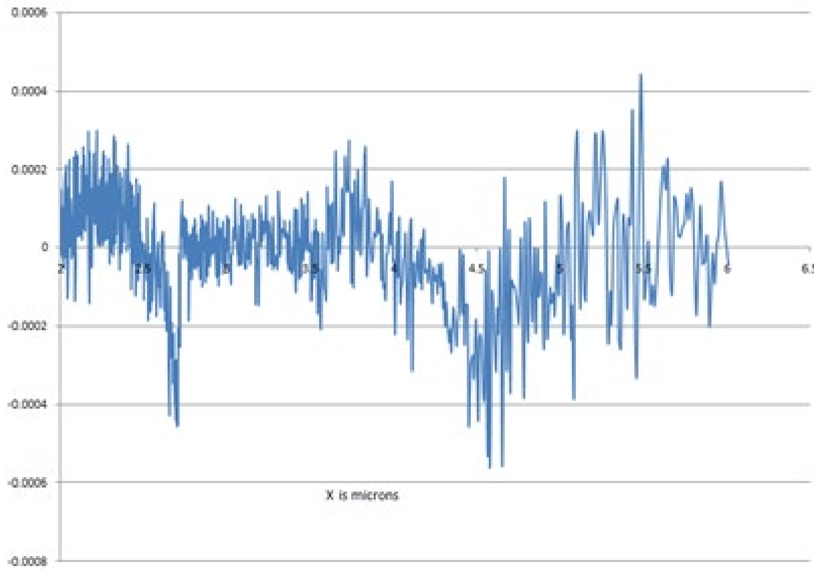


Figure 3: Estimation of 2-6 µm Mid-Infrared While Spraying MIRGA Atomizer

MIRGA spraying was externally performed from 0.25 to 0.50 m over the packets (paper, polythene, or leaf) containing bidis (Figure 2, Supplementary Video V1). This distance allowed the MIRGA solution to form ion clouds, oscillating and generating 2–6 µm MIR; closer spraying did not generate MIR. Every spray emits a volume of 0.06 mL to and fro, which contains approximately seven quintillion cations and eleven quintillion anions. The generated 2–6 µm MIR penetrated the intervening packaging material and acted on the bidis inside.

Supplementary Video V1: Method of MIRGA Spraying

Supplementary Data:

The Supplementary data for this article can be accessed using the following link: https://www.opastpublishers.com/assets/videos/method-of-spraying.mp4

2.2. Toxicity of MIRGA

Although MIRGA is sprayed externally over the packet of bidis and generates safe 2–6 µm MIR, its toxicity was assessed. An in-vitro cytotoxicity assay with A549 cells demonstrated that the MIRGA-sprayed mist was non-toxic to human cells in Figure 4 [19-21].

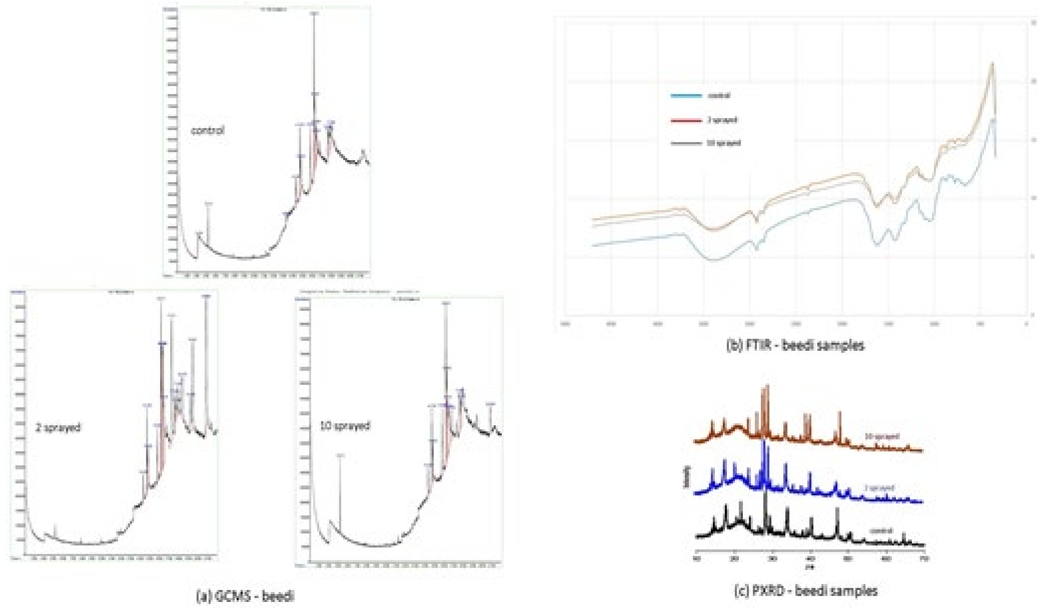


Figure 4: Instrumentations of Bidi Samples a) GC-MS b) FTIR c) PXRD

2.3. Bidis
Commercial bidi packets (20 pieces per pack) of a single brand were purchased from local retail outlets. Bidis (also known as bidis or beedis) are slim, hand-rolled, mostly unfiltered cigarettes common in South Asia. Bidis are made of raw, sun-dried, and finely ground low-grade tobacco flakes wrapped in a tendu (Diospyros melanoxylon) leaf and tied with a string.

2.4. Patient and Public Involvement
No patient involved

2.5. Experiment I
Eleven bidi packets (20 pieces per pack) were used. One packet was marked as M-0 and kept separately as a control (untreated). The remaining 10 packets were marked with M-1 to M-10, corresponding to the number of MIRGA sprayings (i.e., M-1 received one MIRGA spraying on one side of the packet, M-2 received two MIRGA sprayings (one on either side of the packet), M-3 received three MIRGA sprayings (two sprayings on one side and one on the other side of the packet), M-4 received four sprayings (two sprayings on each side), and so on. Some bidis were taken from the packets, unwrapped, and individually subjected to sensory evaluation, including smoking, by a trained expert panel (n = 8) from the bidi industry. The remaining bidis were kept for use in Experiment II.

The sensory remarks of the panelists regarding the taste and odor characteristics of the bidis were recorded as descriptions and ranked using a 9-point hedonic index:

- Dislike extremely
- Dislike very much
- Dislike moderately
- Dislike slightly
- Neither like nor dislike
- Like slightly
- Like moderately
- Like very much and
- Like extremely

Based on the sensory evaluation, the control bidis, the bidis with the highest sensory score, and the bidis with the lowest sensory score were analyzed to explain the changes that occurred due to MIR irradiation.

The following instruments were employed:
• Chemical compound transformations were identified using gas Chromatography-Mass Spectrometry (GC-MS): Agilent Technologies, 7820 GC system, 5977E MSD, DB-5 column, oven temperature of 100–270°C, MS detector, flow rate of 1-2 mL/min for helium as the carrier gas.
• Chemical bond changes were determined using Fourier-Transform Infrared Spectroscopy (FTIR): IR Affinity I–FTIR spectrophotometer, FTIR 7600, Shimadzu.
• Structural changes were measured by Powder X-ray Diffraction (PXRD): Rigaku RINT 2500 X-ray diffractometer (CuKα anode; λ = 1.541 Å).
• Particle configuration changes were detected with High-Resolution Transmission Electron Microscopy (HR-TEM): FEI Technai Spirit G2, HT 120 KV, LaB6 electron source, the Netherlands.
• ^{13}Carbon nuclear resonances were mapped using solid-state Nuclear Magnetic Resonance (^{13}C-NMR): The experiments were performed on a 600 MHz NMR spectrometer (ECZR Series, JEOL, Japan) using a 3.2 mm CPMAS probe at a 150 MHz frequency. All the samples were run at an 18 KHz spinning speed at room

temperature and with a delay of 5s.

• Contour and signal-to-noise ratio changes were assessed by 3D fluorescence spectroscopy: 3D fluorescence spectra were measured on a Hitachi F-7000 spectrophotometer in the range of 200–700 nm at 298 K. The spectral patterns were analyzed using Hitachi's original software.

2.6. Experiment II

After observing the positive outcomes of Experiments, I, M-0, and M-2 bidis were produced again and subjected to field trials with 1497 volunteer participants. Each group consisted of nearly 50 volunteers. The groups were allowed to smoke M-0 (control) bidis, followed by M-2 (2-sprayed) bidis. Interaction among them is also not permitted. All the participants met the following conditions:

- Aged 19–55 years
- Male
- Physically well without any respiratory, cardiovascular, nervous, or oral illness
- With a history of smoking of no less than a month, and
- With the habit of smoking four or more cigarettes per day.

The results were then compared.

2.7. Experiment III

In this study, control bidi smoke was blown over inanimate such as water and air and animates such as aquatics and birds. The behavioral changes were documented. The same procedure was used with 2 times MIRGA sprayed bidi smoke.

3. Results and Discussion

3.1. Experiment I

Sensory evaluation by the expert panel (Table 1) revealed that the control, M-2, and M-10 bidis were ranked as "neither like nor dislike," "like very much," and "dislike extremely," respectively. Thus, the M-2 bidis acquired a desirable sensory quality, whereas the M-10 bidis had the most undesirable sensory quality. Therefore, the M-0, M-2, and M-10 were analyzed (raw data files of Tobacco instrumentations available in Supplementary data D1). The onset of the effects occurred within 30–60 s after spraying, and the bidis retained the effects for 6–12 months.

Bidi Packet No.	Number of MIRGA Spraying	Hedonic Score	Sensory Perception Description (Fool Proof)	
			Taste	Odor
M-0	Control (Non-Sprayed)	5	Regular	Regular
M-1	1	6	Reduced	Slight increased
M-2	2	8	Increased to a pleasant manner	Increased
M-3	3	7	Slightly reduced from 2 sprayed	Slightly reduced from 2 sprayed
M-4	4	5	Slightly reduced from 2 sprayed	Slightly reduced from 2 sprayed
M-5	5	4	Moderately reduced from 2 sprayed	Moderately reduced from 2 sprayed
M-6	6	3	Appreciable reduction than 2 sprayed	Appreciable reduction than 2 sprayed
M-7	7	3	Appreciable reduction than 2 sprayed	Appreciable reduction than 2 sprayed
M-8	8	2	Great reduction than 2 sprayed	Great reduction than 2 sprayed
M-9	9	2	Overall quality reduction	
M-10	10	1	Overall quality became very poor and unpalatable	

Table 1: Sensory Panel Expert Test

3.1.1. GC-MS Figure 4(a)

GCMS analysis (Table 2) shows that the control tobacco powder contained pyridine-3-(1-methyl-2-pyrrolidinyl) - (S) (nicotine), cyclopentadecanone, 13-octadecenal, naphthalene-4a, cis-9-hexadecenal, chalcone, vitamins B and E, and cis-vaccenic acid. After two sprayings, new peaks appeared, corresponding to gamma-sitosterol, 1H-purin-2-amine, and benzenepropanenitrile, but there was no nicotine peak. On the other hand, the 10-sprayed sample exhibited a unique peak of 9-octadecenal and an increased peak of nicotine. However, in both the 2- and 10-sprayed samples, the peaks of vitamins B and E, chalcone, cis-9-hexadecenal, and naphthalene-4a disappeared. Gamma-sitosterol was identified only in the 2-sprayed sample and has anti-diabetic properties and hepato-protectant [22-24].

RT (Min)	Name of Compound	% Area Present in Each Sample			Remarks
		Control	2 Sprayed	10 Sprayed	
4.233	Pyridine, 3-(1-methyl-2-pyrrolidinyl)-, (S), NICOTINE	2.99	0.0	0.0	Nicotine disappeared in 2 sprayed samples
5.217	Pyridine, 3-(1-methyl-2-pyrrolidinyl)-, (S), NICOTINE	3.1	0.0	4.16	Nicotine disappeared in 2 sprayed samples but increased in 10 sprayed samples
13.547	Oleic acid	0.68	0.92	2.94	
13.777	Hexadeconic acid	0.21	0.0	0.0	
14.35	cis-Vaccenic acid	2.57	0.0	0.0	
14.351	Oxalocyc;ododecan	0.0	0.0	3.21	
14.738	Z-8-Methyl-9-tetradecenoic acid	0.0	0.0	6.47	
14.748	Cyclopentadecanone	8.21	0.0	8.11	
14.833	6-Octadecenoic acid	6.43	0.0	4.8	
14.833	Octadecanoic acid	0.0	0.0	4.8	
15.825	7-Pentadecyne	2.98	0.0	0.0	
15.835	9,17-Octadecadienal	9.7	0.0	0.0	
16.213	Cyclopentadecanone	21.1	0.0	0.0	Most abundant peak in Control
16.213	9-Octadecenal	0.0	0.0	18.47	Most abundant peak in 10 sprayed sample
16.29	13-Octadecenal	0.0	0.0	13.97	
16.298	cis-9-Hexadecenal	9.5	0.0	0.0	
16.308	Vitamin B	7.7	0.0	0.0	
16.355	Vitamin E	11.21	0.0	0.0	
16.402	13-Octadecenal	7.73	0.0	0.0	
16.478	5-Acetamido-4,7-dioxo	6.97	0.0	0.0	
16.487	13-Octadecenal	6.21	0.0	9.54	
16.79	Benzene	0.0	0.0	3.05	
17.31	Benzenepropanenitrile	0.0	13.63	0.0	Most abundant peak in 2 sprayed sample
17.641	Chalcone	7.21	0.0	0.0	
17.641	Benzene	0.0	2.51	0.0	
17.641	2-(2-Methyl)-1H-indol-3-ylmethane	0.0	0.0	7.21	
17.792	Naphthalene-4a	6.63	0.0	0.0	
17.792	Benzene	0.0	1.08	0.0	
17.792	Butane	0.0	0.0	5.38	
17.953	1-Methyl-3-phenylindole	0.0	3.01	0.0	
17.953	13-octadecenal	7.84	8.22	0.0	
18.39	Butane	0.0	6.03	5.38	
19.293	1,2-Benzisothiazol	0.0	3.55	0.0	
19.447	1H-Purin-2-amine	0.0	9.29	0.0	
20.85	Benz-1,4-oxazepine	0.0	0.0	6.31	
20.865	gamma-Sitosterol	0.0	16.43	0.0	Most abundant peak in 2 sprayed sample

Table 2: GCMS Analysis of Tobacco Samples

3.1.2. FT-IR Figure 4(b)

The peak at 3336cm^{-1} corresponds to N-H-groups typical of capsaicin. Peaks 2924 and 2824 cm^{-1} indicate the aliphatic C-H stretching. Peak 1627 cm-1 indicates the content of C=C groups from the benzol ring, which is typical for aroma compounds and capsaicin. The peak at 3336 cm^{-1} indicates the content of N-H-groups and is typical for capsaicin. This peak decreased in the 2-sprayed sample but increased in the 10-sprayed sample; however, although it increased in the latter, it was still smaller than that in the control and corresponds to the differences in hotness. The peak at 1427 cm^{-1} indicates the content of C=C groups and is typical for aroma compounds; this peak increased a little in the 2-sprayed sample and decreased in the 10-sprayed sample and is responsible for the differences in aroma.

There are numerous odorous compounds in tobacco smoke, including carotenoid derivatives, menthol, and 1H-pyrrole-2-carboxaldehyde, 1-methyl, among others. Because of the presence of these compounds and the inherent qualitative nature of FTIR, we could not detect a marked difference in the FTIR spectra. However, the expert sensory panel reported a remarkable sensory difference among the samples.

3.1.3. PXRD Figure 4(c)

The PXRD patterns revealed that the samples had amorphous and crystalline zones. The control, 2-sprayed, and 10-sprayed samples exhibited peaks at 2θ: 14.97, 17.90, 21.74, 28.13, 33.98, 40.34, and 47.26. The areas under the peaks in the range of 10° to 48° are presented in Table 3. The results suggest that the crystallinity of the 2- and 10-sprayed samples increased by 11% and 4%, respectively, compared to the control.

Percentage Analysis of the Change in Tobacco (Bidi) Powder			
	Control	**2 sprayed**	**10 sprayed**
Peaks (degrees)	10.0 -48.0	10.0 -48.0	10.0 -48.0
Area	3786878,458	4188388,315	3933851,618
Change in area	0	401509,857	146973,16
Fraction change in the area	0	0,106026603	0,038811164
Percentage change	0	10,6	3,9

Table 3: Purity Calculation of Bidi Samples

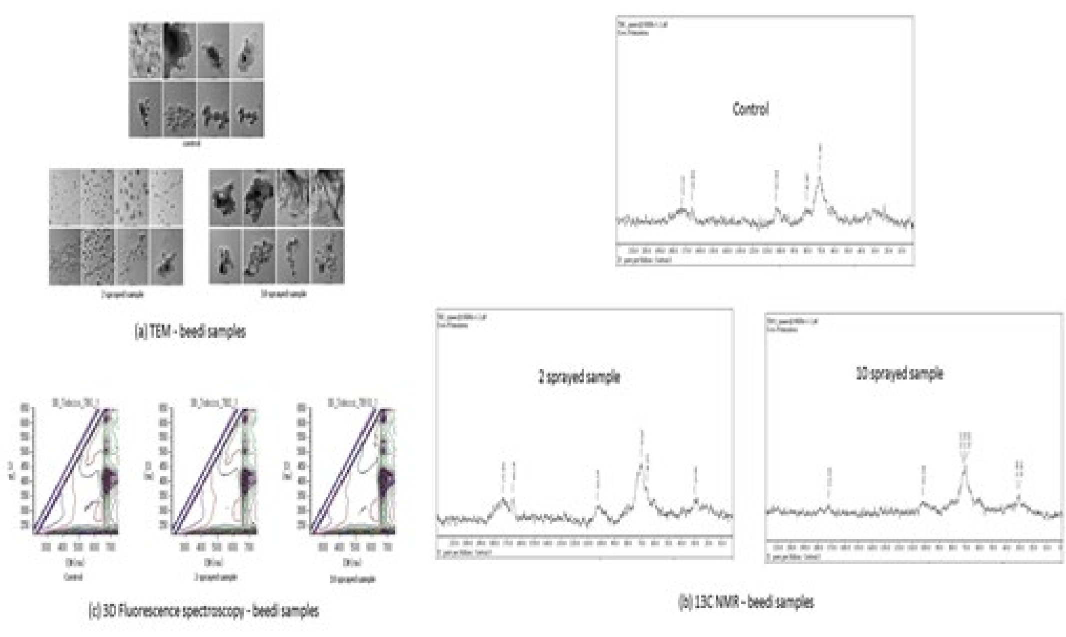


Figure 5: Instrumentations of Bidi Samples a) TEM b) 13C-NMR c) 3D Fluorescence Spectra

3.1.4. HR-TEM Figure 5(a)

In the control, the average sizes (Feret's diameters) of large particles and nanoparticles were 0.5–2 µm and 20–70 nm, respectively. Large particles show different brightness and distribution in darker areas.

The 2-sprayed sample has only nanoparticles and ultrafine particles, whereas larger particles are not observed. The nanoparticles are in the range of 10–100 nm, and the ultrafine particles are sized at 100–200 nm. Particles appeared either as individual objects or as clusters. This is a difference with respect to the control, where small particles are only observed as clusters. Two primary morphologies are observed:

- Semi-spherical with an apparently homogeneous mass distribution within the particle.
- Circular, squared, or polymorphous with a non-homogeneous mass distribution.

In the latter type, the central part of the particle appears detached from the contour, which is not observed in the control sample.

The 10-sprayed sample is more similar to the control than the 2-sprayed sample. Both large amorphous particles (top row) and Nano sized particles (bottom row) are observed. The latter are mainly organized in clusters, while individual nanoparticles are not evident. Large particles are in the micrometer range, whereas nanoparticles are sized 10–50 nm. Particle sizing is not straightforward, but particles appear strongly clustered and overlapped with each other. Moreover, the aspects (brightness, semi-spherical shape, and mass distribution within the particle) appeared to be shared by all nanoparticles. They were similar to what was observed for the control but different from the 2-sprayed sample.

Nanoparticles show comparable brightness, size, and shape (spherical or ellipsoidal), as displayed in the images in the bottom row. Moreover, nanoparticles appear organized in clusters, whereas larger particles are observed as individual objects. All available TEM images show that neither larger particles nor nanoparticles have crystalline structures. However, the PXRD patterns confirmed that the 2-sprayed and 10-sprayed samples consist of amorphous and crystalline phases, respectively.

In summary, compared to the control, the 2- and 10-sprayed samples are very different in structure. In particular, the structure of the 2-sprayed sample differed substantially, whereas the structure of the 10-sprayed sample was comparable to that of the control. The morphology and shape were substantially affected by the two sprayings, but these features returned to the initial condition (or to a condition similar to that of the control) when 10 sprayings were applied.

3.1.5. ^{13}C-NMR Figure 5(b)

The C-13 cross-polarization magic-angle-spinning (CPMAS) NMR spectra are referenced to Tetra Methyl Silane (TMS), which is the typical reference for C-13 NMR. The control sample showed low-intensity resonances around 173 ppm and 104 ppm. There was also a resonance at 71 ppm, with possible spinning sidebands at 81 ppm and 61 ppm. The key resonance at 71 ppm was assigned to the carbon present in hydroxyl, C-OH, C-OR, and alkyne RCCR2 groups. The low-intensity resonance at 173 ppm was assigned to the carbon atom in carboxylic acids (R-COH2) and esters (R-CO2R). The peak at 104 ppm was assigned to the carbon in nitrile (RCN), aromatics, and heteroaromatics. These functional group assignments are consistent with the chemistry of tobacco, as carboxylic acids (e.g., acetic acid), esters (methyl formate), aromatics (e.g., naphthalene), and heteroaromatics (e.g., pyridine) have been reported in studies of tobacco smoke.

The 2-sprayed sample spectrum shows a shoulder at 66 ppm and a resonance at about 30 ppm. The 66-ppm resonance is due to the presence of amines (C-NR2) and hydroxyl groups (C-OH). The peak at 30 ppm suggests the presence of CC=R, C-Ar, amine, alkane (C-H), and C-Cl groups. These additional peaks indicate that these compounds are at a higher concentration in the 2-sprayed sample compared to the control sample. The compounds responsible for the flavor and aroma of the 2-sprayed sample are considered to give rise to these resonances. In contrast to the spectrum of the control sample, in the spectrum of the 10-sprayed sample, the peak at 173 ppm is challenging to distinguish from the noise, and there is a resonance at around 31 ppm. The apparent disappearance of the peak at 173 ppm indicates that the 10-sprayed sample has a lower concentration of carboxylic acids and esters compared to the control sample. The apparent peak at 31 ppm was assigned to CC=R, C-Ar, amine, alkane (C-H), and C-Cl groups. These results indicate a change in the chemical composition of the 10-sprayed sample relative to the control sample, indicating that odorous compounds are affected by the spraying.

3.1.6. 3D Fluorescence Spectroscopy Figure 5(c)

By comparing the fluorescence fingerprints of all samples, the island contour (Ex = 407 nm, Em = 673 nm) of the 10-sprayed sample is larger than that of the 2-sprayed sample, which in turn is slightly larger than that of the control. The instrumentation analyses revealed that MIRGA spraying resulted in changes in relation to the chemical bonds, nanoparticles, chemical compounds, and the physicochemical and sensory characteristics of the bidis. However, only the changes in the 2-sprayed sample were desirable as they represented an improvement compared to the control. It is known that an input of excess energy in any form (e.g., heat or light) results in undesirable effects. Hence, our findings are in line with this rule, as the excessive MIR treatment of the bidis (10 sprayings) resulted in unfavorable chemical and sensory changes.

3.2. Experiment II

The observations from Experiments I and II, as well as the opinions of smokers using M-2 bidis, can be summarized as follows:

- M-2 bidis were more preferred by the participants than the control (M-0).
- The smoke from the M-2 bidis was smooth and soft to inhale, and the participants found no adverse reactions.

• Tobacco smoke odor vanished from the smoker's mouth and fingers 5–15 minutes after smoking M-2 bidis.
• M-2 bidis prevented or slowed down the discoloration of the lips and fingers caused by smoking.
• Smoking M-2 bidis maintained a smoking satiety similar to that of the control.
• Passive smokers felt less annoyed by the smoke of the M-2 bidis.
• No side effects were reported from the use of M-2 bidis for months.
• External spraying of MIRGA over the bidi packets made the smokers feel safe with respect to MIRGA.
• Participants showed interest in MIRGA spraying of other tobacco products like cigarettes.

A meta-analysis was not conducted because of the heterogeneity in this experiment, including the participants, follow-up period, and variation in smoking parameters. Therefore, we could not compile and compare the sizes and probabilities of the effects to project statistical data.

3.3. Experiment III

The result noticed in inanimate with sprayed bidi was, reduced pollution compared to control bidi, hence pollution reduction. Animates well tolerated/accepted the sprayed bidi smoke compared to control, hence disease prevention. (MIRGA's invention background, the technique used for mid-IR generation, its toxicological study, and the safety of the MIRGA-sprayed products are available in supplementary text T3)

3.4. In Supplementary Text T3: Detailed Discussion

3.4.1. Invention Background

The four observable states of matter (solid, liquid, gas, plasma) are composed of intermolecular and intramolecular bonds. The inherent characteristics of neutrons, protons and electrons are unique, however, difference in their numbers is what constitutes different atoms and how these atoms bind together develop into different molecules with unique characters. In the electromagnetic wave (EMW) spectrum mid-IR region is vital and interesting for many applications since that region coincides with the internal vibration of most molecules [25]. Almost all thermal radiation on the earth surface lies in the mid-IR region, 66% of the sun's energy we receive is infrared and is absorbed and radiated by all particles on the earth [26]. Naturally, at molecular level, interaction of mid-IR wavelength energy elicits rotational and vibrational modes (from about 4500-500 cm-1 roughly 2.2 to 20 microns) through a change in dipole movement leading to chemical bond alteration [27].

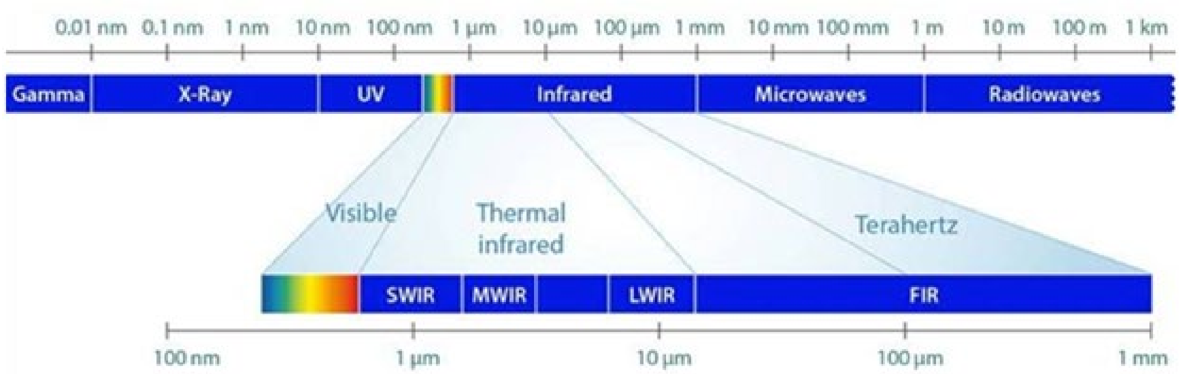


Figure 6: Electromagnetic Spectrum

During our research we observed

(A) In all objects, even though atoms always remain as atoms their chemical bond parameters are continuously prone to alteration by cosmic and physical energies (eg: EMW, heat, pressure, humidity) causing the bonds compression/stretching/bending, breaking and new bond formation [28-34]. These alterations ultimately lead to the change in the physicochemical characters of the objects.

(B) The dynamic, constant, mutual influences of EMW among earth, celestials and living bodies are continuously causing alterations in the inherent physiochemical characters of earthly objects, like enhancement due to optimum dose of energy or decrease/ destruction due to more dose of energy (*detailed below*). Thus, based on these concepts, the MIRGA was developed to alter bond parameters thereby potentiate any usable natural characters.

3.4.2. MIRGA Definition

We define MIRGA as *'a harmless, economical atomizer containing an imbalanced ratio of ions suspended in water, which influence the natural potency of target substances by generating mid-IR while spraying'*.

3.4.3. Technique of mid-IR Generation from MIRGA

We designed MIRGA as to accommodate an imbalanced ratio of ions suspended in water in their fundamental state and can move as free particles. The solution has very little background frequency of detectable disintegration which is less than that of cosmic events whereas even humans have more radioactivity (around 10 microns) [35,36].

We designed MIRGA to generate energy based on various below given processes like,

(A) Spraying leads to ionization (electron getting separated from atom) and the pathway for electron re-absorption are also many, due to these two oscillatory processes energy generated.
(B) While spraying, water-based ionic solution gets excited/ charged, which in turn leads to oscillation among the imbalanced ions in their excited state, resulting in the emission of photons [37-39].
(C) Though low electromagnetic field exists between charged particles of the MIRGA's ionic solution, during spraying the induced oscillation between these charged particles produces energy [40-43].
(D) Also, in the natural rainfall process, more energy is required to break water bonds for creating smaller water droplets from the clouds [44]. Therefore, these droplets should have more stored energy and then travels down at a velocity from a specific distance thus gaining also a kinetic energy. When the rain hits the earth's surface, it forms a very thin film of mid-IR (nearly 6 micron), hence there is a net heat gain [44,45]. We simulated this rainfall's energy gaining process also in MIRGA i.e., when imbalanced ions in liquid media are atomized, the ejected smaller droplets should have higher internal energy as well as an acquired kinetic energy and the energy emitted by breaking the surface tension. From trial and experience, we calibrated an ejection pressure to obtain a desired fine mist, and minimized the evaporation rate by altering the pH and density of the solution. Also considering other facts like, the accelerated ions in the sprayed ionic clouds collide among them and generate energy, we incorporated those phenomena in our atomizer and designed in such a way to emit energy in the 2-6 µm mid-IR range [46].

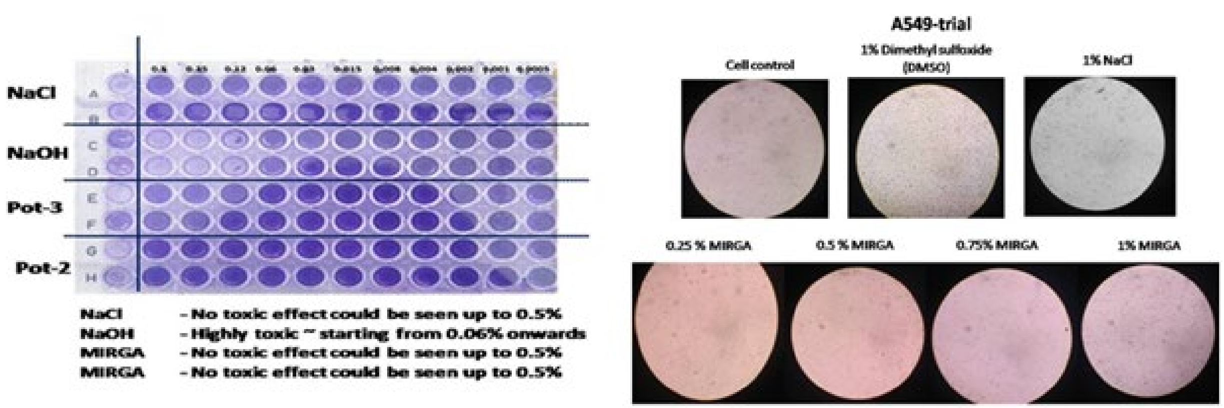
The inorganic compounds used in the generation of MIR are a perspective for biomedical applications [47,48]. It is also a new synthesis method for preparation of functional material (2-6 µm mid-IR) [49,50]. It is well known that the combination of different compounds, which have excellent electronic properties, leads to new composite materials, which have earned great technological interest in recent years [51,52].

3.4.4. Action of MIRGA Emitted 2-6 µm Mid IR on the Target Substances

While spraying MIRGA, most of the mid-IR energy scatters through the air and gets absorbed by receptors (edibles or usable) molecules. Virtually all organic compounds absorb mid-IR radiation which causes a change in molecule's vibrational state to move from the lower ground state to excited higher energy state [27]. This leads to changes in chemical bonds and these bond parameter changes led to consequent changes in target's physical and chemical characters, configuration, compound transformation depending on the dose of energy applied [30,31,53-56]. Nanostructured water layers can be triggered upon application of mid-IR radiation, since water molecules absorb in this region [57,58]. Depending on number of MIRGA spraying (energy given), a receptor's chemical bond configurations and subsequent physical and chemical characters can be altered to our desire. As displayed in the results, 2-6 µm MIR generated from the MIRGA equipment caused chemical and molecular level changes in the tobacco components. This action of the MIR is called as photodegradation which means alterations of materials by light. In this process, chemical components of the tobacco have absorbed the MIR generated by MIRGA spraying, and the absorbed MIR photons have broken the chemical bonds of nicotine molecule; thereby the nicotine molecules are degraded and transformed into another molecule/ compound, as reported in GCMS analysis.

3.4.5. Toxicological Study on MIRGA

Even though, MIRGA generates the safe 2-6 µm mid-IR energy, and moreover spraying is done 0.25–0.50 meter externally right away to packaged consumables, we also wanted to study the MIRGA's toxicity effect by cytotoxicity assay. In-vitro Vero, A549 and Human dermal fibroblast cells study proved that MIRGA sprayed mist was non-toxic in any way (Figure 7).



a) Trial with Toxicity assay of MIRGA at various concentrations

b) Trial with A549 cells

Figure 7: MIRGA's Toxicological Studies

Field studies also showed that, MIRGA spray is eco-friendly, non-toxic, non-irritant to soft tissues such as cornea, safe to infants even if sprayed directly, needs no skill but easy to handle (like perfume body spray), and highly economical (USD 0.30 per MIRGA unit which emits 300 sprayings).

3.4.6. Safety of MIRGA Sprayed Usables

In our nearly two-decades of research, we observed MIRGA induced bond altered target substances had not shown any adverse reaction upon consumption/use. As a comparison, to assure the safety of the bond altered targets' millennium long consumption by human/ living kinds; we submit that in nature,

(A) Stereochemical configuration has great influence on taste e.g. variety of mango, grapes, rice, etc [59].

(B) Cooking and digestive enzymes break chemical bonds thereby soften our edibles. And, as an example; raw rice on water-boiling to boiled rice; rice on raw heat to puffed rice; rice on boiling and drying to flat rice; rice on pressure to rice flour, each by-product has its unique aroma, taste, texture and shelf life but with same molecular formula C6H10O5) [60,61].

(C) In food industry, sensory attributes and shelf-life are enhanced by altering the food's chemical bonds using various irradiation processes like, radappertization, radicidation, raduriaztion [62].

(D) On heating, ice to water to steam manifestations are due to changes in the hydrogen bonding, where steam has negligible hydrogen bonding but chemical composition (H2O) remains the same [63,64].

3.4.7. MIRGA's Primeval and Future Scope

The water based MIRGA could be the first novel pioneer potentiating technology. This type of atomizer technology also seems to be present with the extra-terrestrials for their therapeutic use during visitations [65]. In various usable, a range from 30% to 173% potentiation has been achieved by us. Even considering the least 30% in some usable have resulted in 30% economic, resource, and ecological savings as well as health benefits. But there is a knowledge gap between potentiation from 30% to at least 100% for all usable, which can be filled-up by refining MIRGA's ionic solution, concentrations, atomizer pressures, other parameters and even formulating a better solution. Using MIRGA, we conducted experiments which resulted in resource savings with edible oils, vegetables, fruits, food, coffee, tea, alcohol, tobacco, cocoa, edible salts, sugar, herbal, cement, spices, chemicals, pharmaceuticals, dairy products, liquid and gaseous fuels, and vaccine. Human and veterinary disease therapy and were included in these studies, and the results are promising. The laboratory analysis of these substances revealed the altered chemical bonds, configuration and chemical compound transformation. In foodstuffs, detoxification of agrochemical residues resulted as well as enhancement of sensory attributes and shelf life. These results are being separately submitted for publication. The individual results are about to be published.

A variety of mid-IR emitters are now available e.g. silicon photonic devices, cascade lasers (quantum and interbond), non-cascade-based lasers, chalcogenide fiber-based photonic devices and suspended-core tellurium-based chalcogenide fiber photonic devices [66-69]. These emitters are not as cost-effective as MIRGA, and useful only in astronomy, military, medicine, industry as well in the laboratory. They are much too complex in daily domestic applications for the average user. Because of MIRGA's wide range of applications, we believe that MIRGA will definitely resonate in many scientific researches such as bio photonics, therapeutics, health, ecology and many other fields. Our further research on MIRGA and its other manifestations which we developed namely MIRGA salt, MIRGA vapor and MIRGA plasma in human endeavors is dynamically now ongoing.

3.4.8. Action of MIRGA-Emitted 2–6 µm id-IR on Tobacco

While spraying MIRGA, most of the mid-IR energy scatters through the air and gets absorbed by receptor molecules in tobacco. Virtually all organic compounds absorb mid-IR radiation, which causes a change in the molecule's vibrational state from the lower ground state to the excited higher energy state [27]. This leads to changes in chemical bonds, which lead to changes in the target's physical and chemical characteristics, configuration, and compound transformation depending on the dose of energy applied [70-75]. Nanostructured water layers can be triggered upon application of mid-IR radiation because water molecules absorb in this region [76,77]. The 2–6 µm mid-IR range generated from MIRGA depends on the plunger pressure given by the user. However, we observed that any quantum of mid-IR between 2–6 µm detoxified the nicotine completely.

The 2–6 µm MIR generated by MIRGA spraying caused molecular-level changes (e.g., photodegradation) in the tobacco components. Chemical components of tobacco absorbed the MIR generated by MIRGA spraying, and the absorbed MIR photons broke the chemical bonds of the nicotine molecules; thereby, nicotine was degraded and transformed into another molecule or compound, as revealed by the GC-MS analysis. Yousif, et al., described this process as a photodissociation of molecules caused by the absorption of sunlight photons, leading to changes in the molecule's shape [78]. Similar chemical bond changes and desirable detoxification results were achieved in coffee, tea, cocoa and edible salts using MIRGA [19-21].

Similar studies have employed infrared light for the photodegradation of advanced materials but no studies on tobacco detoxification. Joselia et al., reported using Near-Infrared (NIR) light for polymeric nanoparticle degradation [79]. Yarmolenko et al., presented a new method for photodegradation of organic pollutants using visible and near-infrared light irradiation [80]. Babizhayev have shown a detox strategy using a nutraceutical formulation for inhibiting oxidative stress and inflammation and protecting from telomere attrition associated with smoking [81]. However, our study is probably the first to provide insight into laser or light sources that can be used effectively for nicotine reduction and tobacco detoxification.

Our results indicate that the bidis treated with two cycles of 2–6 µm MIR (M-2) completely lost the nicotine content, hence oral cancer prevention. Sprayed bidis had a desirable taste and odor, showed no adverse effects, preserved the organoleptic quality of the bidis with smooth smoke, and reduced irritation upon inhaling the smoke. Bidis contain higher levels of nicotine than conventional cigarettes. Rashmi et al., and Jaffar et al., are thus more hazardous [82,83]. Therefore, it is possible that the findings obtained are applicable to other tobacco products, like cigarettes, but further research is needed. Additional advantages of the specifically designed MIRGA equipment include its portable size (86x55x11mm), no need for special operational skills, ease of use (like a body spray), non-toxicity, and low manufacturing cost (one MIRGA that can be used for around 300 sprayings costs USD 0.30). MIRGA spraying can easily be used to detoxify nicotine in the tobacco product industry itself, i.e. prior to marketing.

4. Conclusion

The results obtained here suggest that 2–6 µm mid-infrared (MIR) irradiation is an economical, viable, and effective tool to detoxify tobacco products and make them safe to smoke. The 2–6 µm MIR altered the chemical compounds but retained the smoking pleasure and satiety. This technique sheds light on the chemical bond alteration of nicotine and, thus its detoxification, leading to a safer smoking product to protect human health and the environment.

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Author Contributions

Umakanthan: Conceptualization, Methodology, Supervision, Project administration, Resources, Validation.
Madhu Mathi: Investigation, Writing - Original draft preparation.
Umadevi, Sivaramakrishnan: Visualization, Data curation
Umakanthan, Madhu Mathi: Writing- Reviewing and Editing.

Ethical Considerations

Ethical statement and Informed consent: Since spraying were only external to the alcohol bottle, the institutional review board deemed sensory ethical approval unnecessary. Informed consent was obtained from all the participants.

Competing Interest

In accordance with the journal's policy and our ethical obligation as researchers, we submit that the authors Dr. Umakanthan and Dr. Madhu Mathi, are the inventors and patentee of Indian patent for MIRGA (*Patent no. 401387*), which is a major material employed in this study.

Availability of Data Materials

Supplementary Video V2 and its explanation in Supplementary text T2 is a part of our experiment. Though we also having the rights the non-technical partner is not ready to assign the rights to us now; hence, the dispute is ongoing. The editorial board and reviewers can view this for technical purposes but not for publication in a manuscript/ supplementary file.

Supplementary Video V2: Tobacco Trials Video

Supplementary Data:

The Supplementary data for this article can be accessed using the following link: https://www.opastpublishers.com/assets/videos/tobacco-research-trial.mp4

Supplementary Text T2: Explanation of the Video

With the results inferred from experiment I, the M-0 and M-2 bidis respectively evaluated as Neither like nor dislike and Like very much. M-2 bidis illustrated to have reduced nicotine content than in M-0, the bidis were smoked by a volunteer smoker. The smoke from M-0 and M-2 bidis were blown into jars each separately contained air, water, honey bees, flowers, birds, ornamental fishes and on sacrificed goat lungs. Also swabs collected from the smoker's buccal cavity. Appropriate controls maintained. The results were compared and presented. (Video V2)

1. Test 1: Into Air

The control beedi was smoked and the inhaled smoke was blown into a first clean glass jar and closed tightly. Next the S-2 beedi was smoked and the inhaled smoke was blown into a second clean glass jar and closed tightly. After a few minutes the two jars were observed. The researchers and spectators witnessed the appearance of first jar to be polluted, but the second jar appeared to be clear and pollution-free. No scientific pollution analysis was done.

2. Test 2: Into Water

The inhaled smoke from the control beedi was blown into a first jar containing water and closed tightly. Next, inhaled smoke from S-2 sprayed beedi was blown into a second jar containing water and closed tightly. After a few minutes the researchers and spectators found the water in the first jar to be polluted but water in the second jar appeared to be clear and unpolluted. No scientific pollution analysis done.

3. Test 3: On Insects and Flowers

The honey bees are reliable and good bio-indicators of pollution and toxicity (*Zhelyazkova*; Celli). The honey bees and rose flowers were kept in the first glass jar with its mouth sealed with cloth containing a small opening to blow in the tobacco smoke. The inhaled smoke from the control beedi was blown into the jar. Next, some other honey bees and rose flowers were kept in a second glass jar with its mouth was sealed with cloth having a small opening to blow-in smoke. The inhaled smoke from the S-2 beedi was blown into the second jar. The bees in the first jar were seems to show dysponea signs and some were unconscious and aroma of the rose flower found to be reduced. The bees in second jar were present unaffected, active, normal and also the aroma of the rose flower remained same.

4. Test 4: On Birds

Birds are reliable indicator and used to characterize ecosystem to monitor environmental changes and to assess the results of restoration measures (Roche). Two healthy birds were caged one in each cage. The smoke from the control beedi was blown into the first cage. The bird in that cage immediately showed dysponea signs and altered behavior. Next, the S-2 beedi smoke was blown into the second cage. The bird in the 2nd cage showed no breathing difficulty and the behavior remained normal.

5. Test 5: On Aquatics

Fishes have been widely documented as useful indicators and a good monitoring tool of environmental water quality because of their differential sensitivity to pollution (Naigaga; Chovanec). Ornamental fishes are sensitive to polluted/ contaminated water. Ornamental fishes were kept in two separate jars filled with water. The smoke from the control beedi was blown into the first jar. Immediately the swimming speed of the fish appeared to have been reduced, seen tired and has difficulty in breathing. Next, smoke from an S-2 beedi was blown into a second jar containing fish. The activities and behavior were observed to be unaffected and the swimming speed of the fish remained unchanged.

6. Test 6: On Goat's Lung

Two goat lungs slaughtered a few minutes ago were purchased (from Government licensed slaughter house) and trialed. The smoke from control beedi was pumped into the first lung. The moisture content of the first lung was found to have reduced and appeared discolored. Next the smoke from an S-2 beedi was pumped into a second lung. The second lung appeared to be unaffected and its features remained unchanged.

7. Test 7: From the Smoker's Buccal Cavity

First, after smoking a control beedi an oral swab was taken. Later, after smoking an S-2 beedi an oral swab was taken from the same smoker. Both were stained and compared. The cell pathology was noticed in control. In S-2, cells were normal and without pathology. These tests were presented in the supplementary file as *Video S1*, in which the 'MIR-treated bidis' were called formerly as 'Genno-treated bidis'.

References

1. WHO fact sheet. (2019). Tobacco.
2. Li, Y., & Hecht, S. S. (2022). Carcinogenic components of tobacco and tobacco smoke: A 2022 update. *Food and Chemical Toxicology, 165,* 113179.
3. Hackshaw, A., Morris, J. K., Boniface, S., Tang, J. L., & Milenković, D. (2018). Low cigarette consumption and risk of coronary heart disease and stroke: meta-analysis of 141 cohort studies in 55 study reports. *Bmj, 360.*
4. O'Keeffe, L. M., Taylor, G., Huxley, R. R., Mitchell, P., Woodward, M., & Peters, S. A. (2018). Smoking as a risk factor for lung cancer in women and men: a systematic review and meta-analysis. *BMJ open, 8*(10).
5. Saji, S., Patil, S. S., Alleyn, M., Lockey, R., & Kolliputi, N. (2020). Nicotine in E-cigarette smoke: cancer culprit?. *Journal of Cell Communication and Signaling, 14,* 127-128.
6. Weiger, C., Moran, M. B., Kennedy, R. D., Limaye, R., & Cohen, J. (2022). Beliefs and characteristics associated with believing nicotine causes cancer: a descriptive analysis to inform corrective message content and priority audiences. *Nicotine and Tobacco Research, 24*(8), 1264-1272.
7. Cuomo, R. E., Mackey, T. K., & Purushothaman, V. (2023). Tobacco/nicotine dependence as a risk factor for substance use disorders and related mental health conditions among cancer patients. *Psycho-Oncology, 32*(9), 1395-1400.
8. Kingston, A., Byles, J., Kiely, K., Anstey, K. J., & Jagger, C. (2021). The impact of smoking and obesity on disability-free life expectancy in older Australians. *The Journals of Gerontology: Series A, 76*(7), 1265-1272.
9. Prinz, A. L., & Richter, D. J. (2023). The impact of smoking, overweight, and fine particulate matter air pollution on life expectancy: Estimations with county-level matched data for Germany. *EUR J ENV PUBLIC HLT. 2023; 7* (2): em0130.
10. Creamer, M. R., Wang, T. W., Babb, S., Cullen, K. A., Day, H., Willis, G., ... & Neff, L. (2019). Tobacco product use and cessation indicators among adults—United States, 2018. *Morbidity and mortality weekly report, 68*(45), 1013.
11. Buchanan, T., Magee, C. A., & Kelly, P. J. (2020). Smokers who do not quit: Can the precaution adoption process model help identify hard-core smokers?. *Journal of Smoking Cessation, 15*(1), 6-13.
12. Hajek, P., Phillips-Waller, A., Przulj, D., Pesola, F., Myers Smith, K., Bisal, N., ... & McRobbie, H. J. (2019). A randomized trial of e-cigarettes versus nicotine-replacement therapy. *New England Journal of Medicine, 380*(7), 629-637.
13. Villalobos, R. E., Ambrocio, G. P. L., & Fernandez, L. (2019). Electronic cigarettes for smoking cessation: an individual patient meta-analysis of randomized controlled trials.
14. Zakiyah, N., Purwadi, F. V., Insani, W. N., Abdulah, R., Puspitasari, I. M., Barliana, M. I., ... & Suwantika, A. A. (2021). Effectiveness and safety profile of alternative tobacco and nicotine products for smoking reduction and cessation: a systematic review. *Journal of multidisciplinary healthcare*, 1955-1975.
15. Constant, S., Bo, V, Engelen., Thomas, Thisted., Matthew, W., Kalnik. (2019). Nicotine degradation in smokers: will a new and potent enzymatic approach work where nicotine vaccines have failed? *Preventive Medicine and Community Health, 1*(4): 1-4.
16. Liu, G., Wang, W., He, F., Zhang, P., Xu, P., & Tang, H. (2020). Structural insights into 6-hydroxypseudooxynicotine amine oxidase from Pseudomonas geniculata N1, the key enzyme involved in nicotine degradation. *Applied and Environmental Microbiology, 86*(19), e01559-20.
17. Pereira, M. F., & Shulika, O. (Eds.). (2011). *Terahertz and mid infrared radiation: generation, detection and applications.*
18. Hatakeyama, K., Murata, Yuusuke., Kawabe, Yasunori., Namai, Hayato., Miura, Takuya. (2019). Infrared absorbing composition.
19. Mathi, M. (2022). Decaffeination and improvement of taste, flavor and health safety of coffee and tea using mid-infrared wavelength rays. *Heliyon, 8*(11).
20. Thangaraju, U., & Mathi, M. (2023). Quantitative reduction of heavy metals and caffeine in cocoa using mid-infrared spectrum irradiation. *Journal of the Indian Chemical Society, 100*(1), 100861.
21. Umakanthan, T., & Mathi, M. (2023). Increasing saltiness of salts (NaCl) using mid-infrared radiation to reduce the health hazards. *Food Science & Nutrition.*
22. Izu, G. O., Adeyi, A. O., Erukainure, O. L., & Islam, M. S. (2022). Gamma-sitosterol–rich fraction from the methanolic extract of Ficus exasperata restores diabetes associated

pathophysiological alterations in an alloxan-induced diabetic rats. *Biokemistri, 33*(1).
23. Sekar, G., Merlin, G., Krishnan, M., Babu, S., Padmini, K., Konduru, P., & Mangai, S. (2022). Effect of β-sitosterol on insulin resistance & protein expression of insulin signalling molecules in quadriceps muscle of high fat diet-induced type-2 diabetic rats. *Bioinformation, 18*(11), 1098.
24. Abo-Zaid, O. A., Moawed, F. S., Ismail, E. S., & Farrag, M. A. (2023). β-sitosterol attenuates high-fat diet-induced hepatic steatosis in rats by modulating lipid metabolism, inflammation and ER stress pathway. *BMC Pharmacology and Toxicology, 24*(1), 1-10.
25. CORDIS, European commission. New advances in mid-infrared laser technology, Compact, high-energy, and wavelength-diverse coherent mid-infrared source.
26. Aboud, S. A., Altemimi, A. B., RS Al-HiIphy, A., Yi-Chen, L., & Cacciola, F. (2019). A comprehensive review on infrared heating applications in food processing. *Molecules, 24*(22), 4125.
27. Girard, J. (2013). *Principles of environmental chemistry. Jones & Bartlett Publishers*.
28. Alvarez A, Prieto M, 2012. Fourier Transform Infrared spectroscopy in Food Microbiology, Springer Science & Business Media, p3.
29. Smith, B. C. (2018). *Infrared spectral interpretation: a systematic approach. CRC press.*
30. Dwivedi, R. S. (2017). *Remote sensing of soils* (Vol. 497). Berlin/Heidelberg, Germany: springer.
31. Jag, M. (2000). Organic spectroscopy: principles and applications.
32. McMakin, C. (2011). *Frequency specific microcurrent in pain management.* Elsevier Health Sciences.
33. Moss D, 2011. Biomedical Applications of Synchrotron Infrared Microspectroscopy: A Practical Approach, Royal Society of Chemistry, UK, 58.
34. Raven P H, Berg L R, Hassenzahl D M, 2012. Environment, John Wiley & Sons, Inc., USA, p45.
35. Ashcroft, F. (2002). *Life at the extremes: the science of survival.* Univ of California Press.
36. Sanders, R. H. (2014). *Revealing the Heart of the Galaxy*. Cambridge University Press.
37. Verheest, F. Waves in dusty space plasmas. Kluwer Academic Publishers, Dordrecht, 2000. xiv+ 264p.
38. Keping, S., & Yu, G. (2004). Recent developments in applied electrostatics (ICAES2004). In *Proceedings of the Fifth International Conference on Applied Electrostatics. Elsevier, UK* (p. 87).
39. Fauchais, P. L., Heberlein, J. V., & Boulos, M. I. (2014). *Thermal spray fundamentals: from powder to part.* Springer Science & Business Media.
40. Wendisch, M., & Brenguier, J. L. (Eds.). (2013). Airborne measurements for environmental research: methods and instruments. John Wiley & Sons.
41. Singh, K. C. (2009). Basic Physics, PHL Learning Private Limited, p413.
42. Prasad, M. (2017). Soul, God and Buddha in Language of Science, Notion Press, Chennai.
43. Pople, S. (1999). Complete Physics, Oxford University Press, p166.
44. Barry, R. G., & Chorley, R. J. (2009). *Atmosphere, weather and climate*. Routledge.
45. Eniday
46. Krishnakumar, T. (2019). Application of microwave heating in food industry. 1-20.
47. Tishkevich, D. I., Korolkov, I. V., Kozlovskiy, A. L., Anisovich, M., Vinnik, D. A., Ermekova, A. E., ... & Trukhanov, A. V. (2019). Immobilization of boron-rich compound on Fe3O4 nanoparticles: stability and cytotoxicity. *Journal of Alloys and Compounds, 797*, 573-581.
48. Dukenbayev, K., Korolkov, I. V., Tishkevich, D. I., Kozlovskiy, A. L., Trukhanov, S. V., Gorin, Y. G., ... & Molardi, C. (2019). Fe3O4 nanoparticles for complex targeted delivery and boron neutron capture therapy. *Nanomaterials, 9*(4), 494.
49. Kozlovskiy, A. L., Alina, A., & Zdorovets, M. V. (2021). Study of the effect of ion irradiation on increasing the photocatalytic activity of WO 3 microparticles. *Journal of Materials Science: Materials in Electronics, 32,* 3863-3877.
50. El-Shater, R. E., El Shimy, H., Saafan, S. A., Darwish, M. A., Zhou, D., Trukhanov, A. V., ... & Fakhry, F. (2022). Synthesis, characterization, and magnetic properties of Mn nanoferrites. *Journal of Alloys and Compounds, 928, 166954.*
51. Kozlovskiy, A. L., & Zdorovets, M. V. (2021). Effect of doping of Ce4+/3+ on optical, strength and shielding properties of (0.5-x) TeO2-0.25 MoO-0.25 Bi2O3-xCeO2 glasses. *Materials Chemistry and Physics, 263,* 124444.
52. Almessiere, M. A., Algarou, N. A., Slimani, Y., Sadaqat, A., Baykal, A., Manikandan, A., ... & Ercan, I. (2022). Investigation of exchange coupling and microwave properties of hard/soft (SrNi0. 02Zr0. 01Fe11. 96O19)/(CoFe2O4) x nanocomposites. *Materials Today Nano, 18,* 100186.
53. Yi, G. C. (Ed.). (2012). *Semiconductor nanostructures for optoelectronic devices: Processing, characterization and applications.* Springer Science & Business Media.
54. Esmaeili, K. (2015). Viremedy, homeopathic remedies, and energy healing remedies as information—Including remedies; A synopsis [Revision Aug 2015; E-pub.: Aug. 2015] (First Pub: 2013) (p. 43).
55. Atkins, P. W., Ratcliffe, R. G., de Paula, J., & Wormald, M. (2023). *Physical chemistry for the life sciences*. Oxford University Press.
56. Datta, S. N., Trindle, C. O., & Illas, F. (2013). *Theoretical and computational aspects of magnetic organic molecules.* World Scientific.
57. Sommer, A. P., Caron, A., & Fecht, H. J. (2008). Tuning nanoscopic water layers on hydrophobic and hydrophilic surfaces with laser light. *Langmuir, 24*(3), 635-636.
58. Sommer, A. P., Zhu, D., Mester, A. R., & Försterling, H. D. (2011). Pulsed laser light forces cancer cells to absorb anticancer drugs–the role of water in nanomedicine. *Artificial Cells, Blood Substitutes, and Biotechnology, 39*(3), 169-173.

59. Williamson, K. L., & Masters, K. M. (2012). *Techniques Labs for Macroscale and Microscale Organic Experiments*. Cengage Learning.
60. Scanlan, N. (2011). *Complementary medicine for veterinary technicians and nurses*. John Wiley & Sons.
61. Kowtaluk, H. (2006). Food for today 9E, 9th edition. Tata McGraw-Hill Publishing Company Limited, New Delhi, p456.
62. Sivasankar, B. (2002). *Food processing and preservation*. PHI Learning Pvt. Ltd.
63. Day, T. (2014). *Ecosystems: Oceans.* Routledge.
64. Raymond, K. W. (2008). *General, organic, and biological chemistry: an integrated approach.* Wiley.
65. Blue planet project: Alien Technical research–25, Westchester Camp, Office of the Central Research #3. CODE: ARAMISIII–ADR3-24SM, p80-81
66. CMOS Emerging Technologies. CMOSET 2012: Abstracts, p49.
67. Jung, D., Bank, S., Lee, M. L., & Wasserman, D. (2017). Next-generation mid-infrared sources. *Journal of Optics, 19*(12), 123001.
68. Sincore, A., Cook, J., Tan, F., El Halawany, A., Riggins, A., McDaniel, S., ... & Schepler, K. L. (2018). High power single-mode delivery of mid-infrared sources through chalcogenide fiber. *Optics Express, 26*(6), 7313-7323
69. Wu, B., Zhao, Z., Wang, X., Tian, Y., Mi, N., Chen, P., ... & Wang, R. (2018). Mid-infrared supercontinuum generation in a suspended-core tellurium-based chalcogenide fiber. *Optical materials express, 8*(5), 1341-1348.
70. Morichika, I., & Ashihara, S. (2020, June). Bond-breaking and adsorption of molecules at plasmonic hot-spots initiated by infrared vibrational excitation. In *Optical Manipulation and Structured Materials Conference 2020* (Vol. 11522, pp. 130-132). SPIE.
71. Nunes, C. M., Pereira, N. A., Reva, I., Amado, P. S., Cristiano, M. L., & Fausto, R. (2020). Bond-breaking/bond-forming reactions by vibrational excitation: infrared-induced bidirectional tautomerization of matrix-isolated thiotropolone. *The Journal of Physical Chemistry Letters, 11*(19), 8034-8039.
72. Alwi, H., Zain, N. S. M., Abidin, H. Z., Jaafar, J., & Hamid, K. H. K. (2019). Far-infrared drying effects onto the physical characteristics of Aquilaria malaccensis leaves. *Key Engineering Materials, 797*, 196-201.
73. Yablonskaya, O., Voeikov, V., Buravleva, E., Trofimov, A., & Novikov, K. (2021). Physicochemical effects of humid air treated with infrared radiation on aqueous solutions. *Water, 13*(10), 1370.
74. Manyatsi, T. S., Al-Hilphy, A. R., Majzoobi, M., Farahnaky, A., & Gavahian, M. Effects of infrared heating as an emerging thermal technology on physicochemical properties of foods. *Critical reviews in food science and nutrition*, 1-20.
75. Lu, A., Li, Y., Wang, C., & Ding, H. (2023). Infrared Effect of Minerals. In *Introduction to Environmental Mineralogy* (pp. 237-265). Singapore: Springer Nature Singapore.
76. Yang, R. Y., Huo, P. Y., Zhang, Q. L., Jiang, Y., & Jiang, W. Z. (2023). Strong amplification of mid-infrared radiation absorption in nanotube-confined water. *Physics of Fluids, 35*(5).
77. Zhu, Z., Chang, C., Shu, Y., & Song, B. (2019). Transition to a superpermeation phase of confined water induced by a terahertz electromagnetic wave. *The Journal of Physical Chemistry Letters, 11*(1), 256-262.
78. Yousif, E., & Haddad, R. (2013). Photodegradation and photostabilization of polymers, especially polystyrene. *SpringerPlus, 2*(1), 1-32.
79. Furtado, J. B. D. M., Furtado Filho, P. A., Oliveira, T. P., Caetano, M. R. D. S., Araujo, I. M. D. S., Figueiredo, F. C., & Santos Júnior, J. R. D. (2020). Enhancement of the photodegradative potential of polymer composites containing babassu fiber. *Materials Research, 23.*
80. Yarmolenko, M. A. E., Rogachev, A. A., Liu, Y., Rogachev, A. V., Gao, L., & Ma, Z. (2022). Features of polymer materials degradation under influence of short-wave laser radiation. *Problemy Fiziki, Matematiki i Tekhniki (Problems of Physics, Mathematics and Technics),* (1), 49-54.
81. Babizhayev, M. A. (2014). The detox strategy in smoking comprising nutraceutical formulas of non-hydrolyzed carnosine or carcinine used to protect human health. *Human & experimental toxicology, 33*(3), 284-316.
82. Datta, R., Singh, S., Joshi, A., & Marwah, V. (2022). Concept of BIDI years: Relevance to the perioperative period. *Lung India: Official Organ of Indian Chest Society, 39*(4), 337.
83. Sangawe, V. V., Saraf, S. A., & Shaikh, J. D. Assessment of some physico-chemical parameters of water sample from Jayakwadi dam, Aurangabad, MS, India.