Poll Res. 41 (3) : 1095-1105 (2022)

ISSN 0257–8050
DOI No.: http://doi.org/10.53550/PR.2022.v41i03.047

ECOFRIENDLY (GREEN) FIRECRACKERS VS OLD FIRECRACKERS AND THEIR HEALTH EFFECTS: A SYSTEMIC REVIEW

SWEETY MEHRA[1], GOVIND MAWARI[1], NARESH KUMAR[1], MRADUL KUMAR DAGA[1], M. MEGHACHANDRA SINGH[1], T.K. JOSHI[1], PRASHANT GARGAVA[3], MINAKSHI BHATTACHARJEE[4], V.K. SHUKLA[3], MANISH KUMAR JHA[1], MANASH PRATIM SARMA[3] AND AMRAPALI KUNWAR[1]

[1]*Centre For Occupational and Environmental Health, Maulana Azad Medical College, New Delhi, India*
[2]*Central Pollution Control Board, Ministry of Environment, Forest and Climate Change, New Delhi, India*
[3]*Department of Biotechnology, Assam Down Town University, Panikhaiti, Guwahati, Assam, India*

(Received 21 February, 2022; Accepted 22 April, 2022)

ABSTRACT

Fireworks are any composition or device designed to produce a visible or audible effect made out of hazardous chemicals. The key hazards involved in firework industries are toxic fumes, fire and explosion. The objective of this review is to differentiate between old firecrackers and ecofriendly/ green firecrackers and their health hazards. Published articles were searched from Med Line, Pub Med, Google Scholar and Cochrane library. It is observed that the air concentration of heavy metals found in old firecrackers was high during and after firecrackers bursting activities which lead to health effects like skin, respiratory, neurological, multiple degrees of burn etc. In ecofriendly fire crackers, the reduction in the chemicals like barium nitrate, potassium nitrate and sulphur leads to reduction in $PM_{2.5}$. Enough information is not available related to the ecofriendly firecrackers; hence, drawing a conclusion related to their health at present is difficult. The review identified many health effects as well as accidents (or incidents) related to firecrackers bursting, manufacturing and transportation. Ecofriendly/ Green firecrackers area better substitute of old firecrackers as their composition has less harmful contents. Further studies are required to conclude the effects of ecofriendly/green fire crackers as the complete list of their formulations are still not available.

KEY WORDS: Traditional/Old Firecrackers, Ecofriendly firecrackers, $PM_{2.5}$, PM_{10}, health effects

INTRODUCTION

Fireworks are any composition or device designed to produce a visible or audible effect by combustion, deflagration or detonation and which meets the definition of "consumer fireworks" or "display fireworks" used for celebration or entertainment. They have fuses, and are enclosed in a heavy paper casing so that it can contain the explosive compounds. Firecrackers, along with fireworks were originated in China.

Firework products are the combination of both fuel and oxidizing agent. The primary components used in the manufacturing of firecrackers was propellants, emitters and additives. In which the common propellant used was gunpowder or black power (potassium nitrate used as oxidizer, sulphur used as stabilizer and charcoal used as fuel), emitters being iron, aluminium, carbon, steel, magnesium/aluminium and additives are used to promote visual effects and to cheaper the composition (Russell, Michael S. The Chemistry of Fireworks, 2000)

Since the workers are continuously exposed to the chemicals, this also causes adverse health effects. The key hazards involved in firework industries are toxic fumes, fire and explosion which cause serious injuries. Firecrackers also emit pollutants harmful to human health like SO_2, CO_2, CO, NO_x and other suspended particles which can cause health problems (Ajith *et al*., 2019).

Short-term firecracker bursting alters physical and chemical properties of ambient particulate matter (PM) which can lead to a considerable increase in adverse health effects compared with non-firecracker bursting periods (Chi-Chi Lin *et al*., 2016).

Fireworks displaying activities are high-intensity human activities that cause short-term air-quality degradation. Fireworks displays mainly generates dense smoke clouds that are full of particles (e.g., total suspended particulate matter, PM_{10} and $PM_{2.5}$) with water-soluble ions and trace metals (Kulshrestha *et al.*, 2004; Drewnick *et al*., 2006; Moreno *et al*., 2007; Wang *et al.*, 2007; Vecchi *et al.*, 2008; Camilleri and Vella, 2010; Tsai *et al.*, 2012), Hirai *et al.* (2000) found that inhaling fumes from firecrackers causes cough, fever, and dyspnea, leading to acute eosinophilic pneumonia. Burning of firecrackers and sparklers increases human health effects, which was particularly severe in infants, women, and elderly people (Kannan *et al.,* 2004).

Fireworks industry is a well-known hazardous industry. Right from the initial phase of manufacturing till the transportation and storage of fireworks in the stores which is risky. Katoria *et al.,* 2013 the fireworks manufacturing process is a critical phase where workers come in direct contact with hazardous substances which leads to greater risk to their life. Some of the major problems faced by workers in the fireworks manufacturing industry are lead poisoning, ulcers and damage to the central nervous system. Inhalation injury includes breathing of hot smoke from burning of fireworks material would lead to increased inhalation of carbon monoxide (CO). When carbon monoxide enters the blood stream, carboxyhemoglobin increases in the blood and the continuous increase of carboxyhemoglobin leads to headaches, damage to the central nervous system and eventually death.

Worldwide Scenario

Explosives and fireworks are classified under the established procedures by the United Nations (UN) within the framework of international transport. The European Union Directive provides a wide framework in which the European countries adopt measures (CPCB, *CUPS/88/2017-18*, October 2017). The proposed UN numbers that exactly identify hazardous substances and articles, regarding fireworks are:

- UN0336 identifies with consumer fireworks
- UN0035 covers display fireworks

Display fireworks are classified as:

- Designed to produce visible or audible effects by combustion, deflagration or detonation.
- Classified by DOT as UN0333, UN0334 or UN0335.
- Includes solutes containing more than 130 micrograms of flash powder.
- Includes aerial shells containing more than 40 g of pyrotechnic composition.

BRITISH STANDARD (Fireworks) BS7114: Part 1 Classification of Fireworks, Part 2 Specification for Fireworks, Part 3 Methods of Test for Fireworks (BSI Sales Dept, Linford Wood, Milton Keynes MK146SL, UK).

In the United States, several thousand injuries, occur each year because of blasts in factories and stores as well as when consumers use fireworks (FW) out of which many are fatal (Health and Safety Executive, 2011).

In Milan, Italy it was found that elemental and organic carbon concentrations were major contributors to PM_{10} mass during a fireworks episode (Vecchi *et al.,* 2008).

Over the Bonfire Night Festivals, Birmingham, UK it was observed that polycyclic aromatic hydrocarbon concentrations were significantly elevated when fireworks activity was anticipated to be at its peak (Harrad and Laurie, 2005).

Barium nitrate which is used as pyrotechnic oxidizer and colouring agent causes barium aerosols which is a cause of pollution from fireworks utilization. The washing-out of barium-rich aerosols by snowflakes during the New Year's Eve celebrations in an Austrian village in the Alps resulted in increase in the barium concentration in snow of up to a factor of 580 compared to the blank value. An increased concentration of strontium and occasionally arsenic in snow was also observed. Snow that was visibly contaminated with smoke residues contained excessive concentrations of Ba, K, Sr, and Fe (Georg Steinhauser *et al.,* 2008).

Smith *et al.* (1975) noted that the pulmonary function monitored in nine patients (seven healthy and two with chronic respiratory disease) exposed to a six-fold increase in PM_{10} (an average of 110 µg m-3 over a 5-hour experiment, which included a 15-min peak attaining concentrations in excess of 3.8 mg m-3) from FW events showed a significant decrease in expiratory flow rate of individuals.

Indian Scenario

India is the second biggest producer of fireworks after China and whole of the production is used almost for domestic consumption. The estimated annual turnover of country's firecracker industry is more than $365million (£225m). Sivakasi, Virudhunagar a district in Tamil Nadu in South India is considered as the "fireworks capital" and also is one of the biggest centres for the manufacture of matches and fire crackers in India. 90% of Indian fireworks industries are situated in Savakasi, Tamil Nadu. There are around 750 factories and 80000 workers are employed in them (CPCB, *CUPS/88/2017-18*, October 2017). The two major occasions for celebration in India are during Dusshera and Diwali/Deepawali.

In India, SO_2 and NO_x concentrations on the day of Diwali were significantly higher compared to pre-Diwali day (Barman *et al*., 2009).

In a study by Sarkar et al. [31] it was observed that the air pollutants generated by the Diwali fireworks in India includes Ba, K, and Sr as tracers. Also, Murty, 2000 reported fireworks smoke could lead to asthma, and adversely affect thyroid functions (Wilkin *et al.*, 2007).

In a study by Sukumar *et al*. (1992) and its colleagues on workers (men and women) from a firework industry in Sivakasi, Tamil Nadu found that workers had higher levels of Cr and Mn and the workers with nervous diseases had higher levels of Cr, Mn and Pb. Female workers were found to have higher levels of Pb and lower levels of Mn as compared to the male workers. Due to the high level of exposure to Mn during the manufacturing process workers showed cases of chronic headaches, dizziness and ulcers. Respiratory tract was concluded as the main source of entry as the workers did not wear masks or gloves while working. The different types of firecrackers and their alternatives are mentioned in Figure 5.

Government guidelines

The fireworks are regulated under Explosive Act, 1884 & explosive Rules, 2008 which are applicable for regulating the manufacturing, import, export, transportation and possession for sale or use of explosives.

According to this act the explosives are categorized depending upon their pyrotechnique effect:

1. Sound emitting fireworks:
   The sound limits for the firecrackers is <125dB or <145 dB at 4 meters of distance from the point of bursting.
2. Color or light emitting fireworks:
   The fireworks which emit light or color and the sound level ≤90dB at 4m distance from the point of bursting.
3. Display fireworks:
   These firecrackers are purely assembled at the site for the purpose of display including shell of diameter exceeding 25 mm, multiple shots or cake products of any diameter exceeding 25 nos., of shots in a product

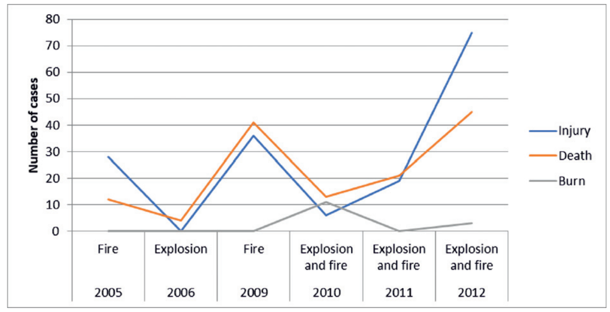

Fig. 1. Number of cases per year in a fireworks manufacturing industry

Division 2 fireworks comprises of further sub divisions, namely

- Subdivision 1 (low hazard fireworks): which does not explode violently or all at once, e.g., sparklers (serpents, etc.)
- Sub-division 2 (high hazard fireworks): these present a special hazard to a person, e.g., rockets, shells, maroons, wheels, barrages, fountains, illumination pieces, distress signals, pyrotechnic devices etc.

Marking on explosives and packages—(1) Marking on packages, the outer package shall be marked clearly visible permanent character, by means of a stamping, embossing or painting with—

- The word "EXPLOSIVES";
- The name of authorized explosive;
- The number if any of the Class and the Division including sub-division to which it belongs;
- The safety distance category of explosive;
- The name of the manufacturer;
- Identification number of the package;
- The net weight of explosives;
- Gross weight of the package;
- Date of manufacture and batch number;
- UN Classification and UN Identification number (for export packages). (The Gazette of India).

Types of firecrackers

- Old firecrackers

- Ecofriendly firecrackers (green firecrackers)

Traditional/old fire-crackers

The chemistry of fireworks is based on the combustive features of its ingredients used and the lighting effects that they generate. Based on the literature survey the key ingredients that are used in the manufacturing of firecrackers are:

1. Fuel: Charcoal i.e., black powder is the most common fuel used in fireworks.
2. Oxidizing Agent: It produces oxygen needed to burn the mixture within the fireworks. E.g. Nitrates, chlorates or per-chlorates etc.
3. Reducing agents: It burns the oxygen provided by the oxidizing agents. The most common reducing agents are sulphur and charcoal which reacts with oxygen to form sulphur dioxide (SO_2) and carbon dioxide (CO_2) respectively.
4. Regulators: These are metals (like aluminum, titanium, copper, strontium, barium etc.) that are added to regulate the speed of the reaction and the coloring agent.
5. Binders: These are used to hold the mixture of the fireworks together in a paste like mixture. The most commonly used binder is dextrin (a type of starch).
6. Coloring Agents: Different chemicals are used for the production of different colors in firecrackers mentioned in Figure 3.

The detailed composition of the chemicals used in old firecrackers their uses and their environmental and human health hazards are mentioned in Figure 2 and Table 1.

Ecofriendly/Green fire-crackers

These firecrackers are produced using less harmful raw materials and additives which reduce emissions by suppressing dust. The new formulations have reduced the emission of light and sound named as SWAS, SAFAL and STAR; have 30% reduction in particular matter using potassium nitrate (KNO_3) as oxidant**.** The approval for the production of new or improved formulation crackers was given to NEERI and PESO. The key Features of ecofriendly/green firecrackers in comparison with the old firecrackers (CSIR-NEERI) are given below in Table 2.

The ecofriendly firecrackers were launched on 5th Oct, 2019 in India to resolve the crisis of air pollution. A Raw Materials Compositional Analysis (RACE) facility was launched in Sivakasi to facilitate manufacturers for testing their raw materials and chemicals. About 530 emissions testing certificates

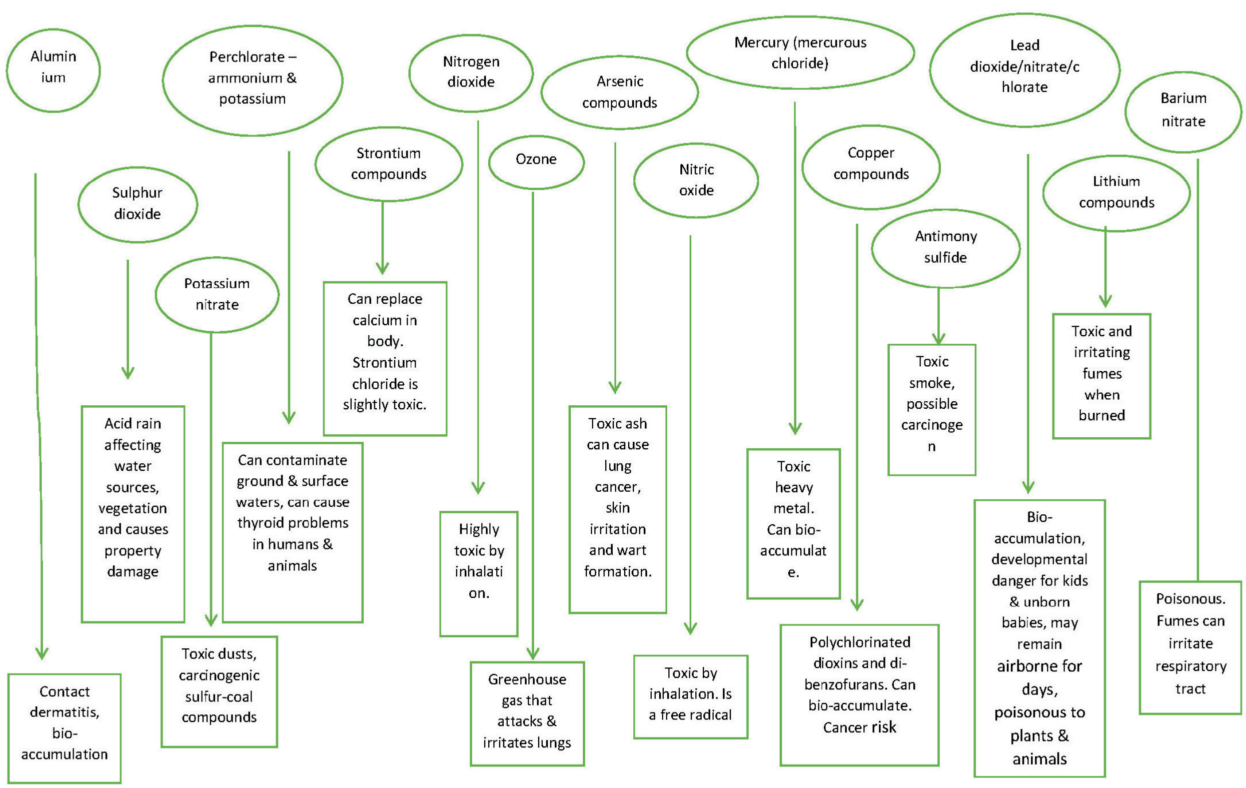

Fig. 2. Chemical compounds in firecrackers and their environmental and human health effects

Table 1. Old firecrackers: chemicals used and their environmental and human health effects

Color producing compounds	**Color**	**Environmental and Human health hazard**
Strontium salts and lithium salts	Red	Strontium replaces calcium in body, lithium produces toxic and irritating fumes
Calcium salts	Orange	Burning sensation, shortness of breath, eye and skin redness
Incandescence of Iron or charcoal	Gold	Metallic taste, cough
Sodium compounds	Yellow	Produces sulfur dioxide as byproduct
White hot metal (BaO)	Electric white	Poisonous fumes (*source*: ATSDR)
Barium compounds with chlorine	Green	Causes nose, eye and throat irritation (*source*: ATSDR)
Copper compounds and chlorine	Blue	Can bio-accumulate
Mixture of strontium and copper compounds	Purple	Highly toxic, replaces calcium in body
Burning aluminum, titanium or magnesium powder	Silver	Bio-accumulation, eye irritation, chest congestion (*source*: ATSDR)
Sound producing compounds	**Major use**	**Hazardous nature**
Potassium nitrate (oxidizers)	Used as component of black powder. Also used in safety fuses and lift chargers	Toxic dust, carcinogenic sulfur-coal compounds
Barium nitrate (oxidizers)	Used as an oxidizer as well as a green color agent	Poisonous. Fumes can irritate respiratory tract.
Aluminum (fuel)	Most widely used fuel. Produces brilliant flames and white sparks	Contact dermatitis, bioaccumulation.
Sulfur (fuel)	Used for white and colored smoke composition, flash and sound blends. Component of black powder	Acid rain from sulphuric acid affecting water sources, vegetation and property damage

have been issued to fireworks manufactures for new and improved formulations meeting the stipulated guidelines of ecofriendly/green crackers. To develop ecofriendly/green fireworks, eight labs participated, CSIR-NEERI, CEERI, IITR, IICT, NCL, CECRI, NBRI and CMERI, with CSIR NEERI

Table 2. Key features of Ecofriendly/Green firecrackers (developed by CSSIR-NEERI) in comparison with the old firecrackers

S.No.	**Key Features of Ecofriendly/Green firecrackers in comparison with the old firecrackers**
1.	Reduction in the size of shell compared to the old firecrackers.
2	Reduction in elimination of ash usage
3.	Reduction in the usage of raw materials in the compositions, of uniform acceptable quality, and/or use of additives as dust suppressants to reduce emissions with specific reference to particulate matter (PM), SO_2 and NO_2 as • A minimum PM reduction of 30% • A minimum PM reduction of 20% and the rest 10% of gaseous emission (mass of gases emitted based on composition) or more reduction of gaseous emission (mass of gases emitted based on composition)
4.	In light emitting firecracker Fe_2O_3 is used as an additive in place of Barium (used in the old firecracker)
5.	Knowhow based on novel concept of exploiting exothermic heat of materials (zeolite, clays, silica gel, lime and AI) for bursting of crackers
6.	Overcome issues of particulate and gaseous emissions
7.	PM reduction by more than 80% for peroxidase based crackers.
8.	PM reduction by 30% for water based crackers.
9.	Significant NO_X and SO_x reduction is anticipated.
10.	Reduction in cost due to reduction of KNO_3 and S.
11.	They release water vapor and don't allow the dust particles to rise.

coordinating the entire exercise (PIB. India launches "Green Firecrackers". 5th Oct 2019)

Types of Ecofriendly/Green Firecrackers: (Figure 4)

1. SWAS (light emitting cracker)
2. STAR (sound emitting cracker)
3. SAFAL (Safe Minimal Aluminium)

Exothermic compounds used in Ecofriendly/Green Firecrackers:

Zeolites

Zeolites are crystalline alumino-silicates which consist of three-dimensional frameworks of SiO4 and AlO4 tetrahedra linked through oxygen bridges (Dessalegne *et al.*, 2016). These zeolites have a porous structure which can accommodate a wide variety of cations, such as Na^+, K^+, Ca^{2+}, Mg^{2+} and others. They are considered as irritant dusts which may evoke pulmonary changes leading to irritation of the respiratory tract. Pulmonary inflammatory responses, particularly those caused by natural occurring zeolites, can lead to fibrosis.

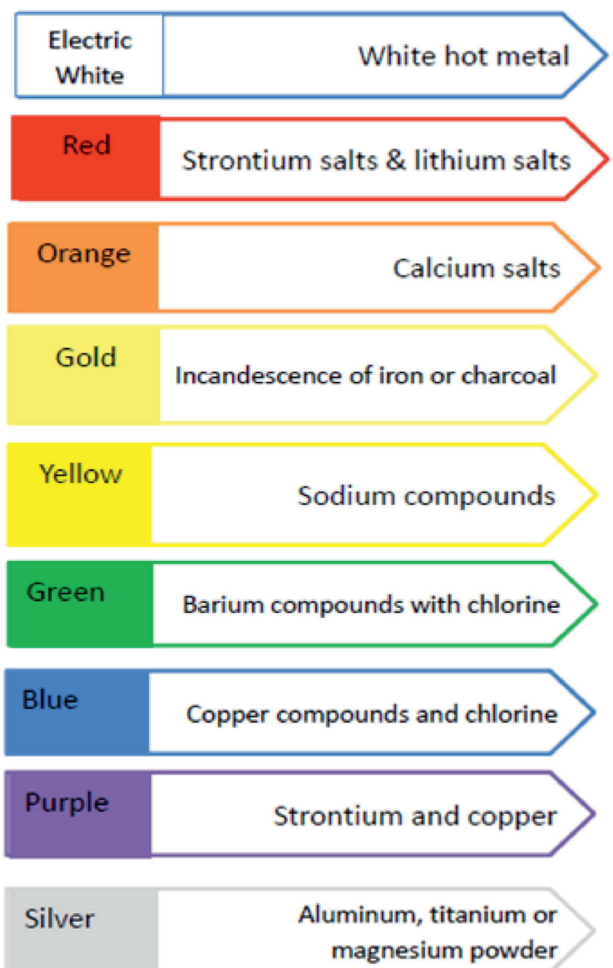

Fig. 3. Metal and its compounds and the colours they produce

Synthetic zeolite structures, usually cuboidal, produce irritation of the eyes and mucous membranes, but there is no evidence of significant pathologic changes in the lungs. Few non-pulmonary toxic changes are produced by either the natural or synthetic zeolites (Toxicological Assessment of Zeolites JOHN A. THOMAS and BRYAN BALLANTYNE).

Clay: Clay minerals can have an adverse effect on human health when they are inhaled over a very long period. Inside the lung, clay minerals can cause diverse pathologies include cancer or pneumoconiosis, but the toxicity of these minerals is generally related to both the presence of quartz or asbestos from mining works, or with the geological conditions of formation. (Chapter 11.5 Clays and Human Health)

Silica gel: Silica gel is a colloidal form of silicon dioxide (SiO_2) which is made by partial dehydration of metasilicic acid (H_2O_3Si). Silica gel is most commonly used in everyday life as beads in a small paper packet. It is used as a drying agent to control local humidity to avoid spoilage or degradation of some goods. (Mika Sillanpää, 2015, Chapter 7, NOM Removal by Adsorption).

Iron (III) oxide or Ferric Oxide (Fe_2O_3): The experimental results show that iron oxide catalyzed the thermal decomposition of potassium perchlorate. The thermal decomposition of potassium perchlorate was studied by Differential scanning calorimetry (DSC) (TAN, *et al.*, 2007).

METHODS

Search Strategy

We used Pub Med, MEDLINE, Google Scholar and Cochrane library and concerned national sites upto October 2021 to identify the relevant citations. The searched keywords were 'firecrackers', 'ecofriendly or green firecrackers', 'human health impacts and hazards'. All the data related to ecofriendly firecrackers was extracted from national government site. The search topics were "firecrackers". We also extracted information on selected keywords like manufacturing, transportation, air quality issues related to firecrackers.

Inclusion Criteria

Only those studies were included in this review which met all of the following criteria; shows relevant information related to firecrackers and its effects on human health as well as on environment. All the data from Newspaper clips, printing media were excluded. The only exception was data from national government sites.

RESULTS

Out of 6730 abstracts only relevant literature articles were selected which were of primary relevance related to fire crackers and its impact on human as well as environment. These studies showed the major health concerns related to the manufacturing and bursting of firecrackers as they cause permanent hearing loss, contact dermatitis and accidents/ incidents because of human error. Short term effects includes allergy, skin irritation, eye irritation and inflammation, headaches, fever, chills, chest tightness, coughing, etc. Long term health effects include permanent hearing loss, bio-accumulation (specific to organ system) which can lead to prolonged problems. Reduction in SO_x, NO_x in green firecrackers can help in regulating the air quality during Diwali.

A case study shows that within 1 hour of fireworks displays levels of Strontium in the air increased 120 times, Magnesium 22 times, Barium 12 times, Potassium 11 times, and Copper 6 times more than the amount present in the air before the event. The heavy metal found to have risen significantly during the fireworks event is strontium (Sr) which was much lesser during non-fireworks duration. This indicates that this rise in Sr is the result of fireworks activity (Vecchi *et al*., 2008).

In a study by Moreno *et al*. 2007 it was found that firework activities spiked suspended particles, Nitric oxide (NO), Sulfur dioxide (SO2), which created and dispersed an aerosol cloud presenting a range of metallic elements. Although the "recreational pollution" from fireworks is temporary in nature, the pollutants emitted are highly concentrated which add significantly to the total yearly metal emissions and the particles on average are small enough to be easily inhaled which poses a health risk to sensitive individuals.

Researchers have found that fireworks can create a cloud of ozone which is an extremely reactive greenhouse gas molecule that can irritate the lungs. The ozone is believed to be caused by ultraviolet light released by chemicals in fireworks which in this study were sparklers (Attri *et al.*, 2001) as mentioned in Figure 2.

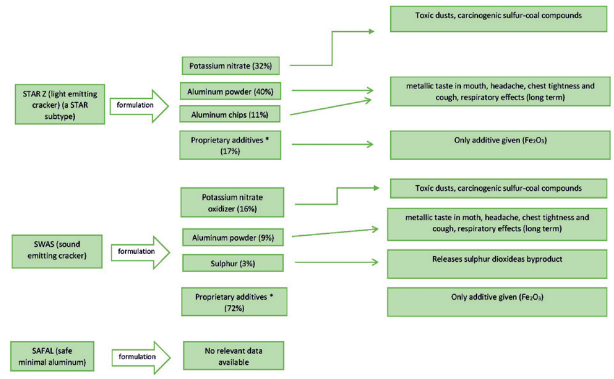

Fig. 4. Ecofriendly/Green firecrackers their chemical composition and human health and environmental effects

London recorded two major festivals celebrated with pyrotechnic events and found that they were marked by increase in the pollutant levels of Nitric oxide (NOx) and Sulfur dioxide (SO2), elevated PM concentrations, as well as trace metal concentrations, specifically Strontium (Sr), Magnesium (Mg), Potassium (K), Barium (Ba), and Lead (Pb) in a 3-week study. These changes in air quality were then related to the oxidative activity of daily PM samples by assessing their capacity to drive the oxidation of physiologically important lung antioxidants. Because of the elevated PM concentrations caused by firework activity and the increased oxidative activity of this PM source, the researchers believe more work needs to be done in examining if exposure to firework derived PM is related to acute respiratory outcomes.

A study from 2010 attempts to estimate the probable health impact of exposure to the pollution caused by fireworks. Using risk data from epidemiological studies conducted in USA, it was estimated that when exposed to air pollution from fireworks the relative risk of cardiovascular mortality would increase as high as 125.11% and the relative risk for cardiovascular morbidity was found to increase to or by 175.16% over a regular winter day (Thakur, 2010).

Influence of burning of fireworks on particle size distribution of PM_{10} and associated barium (Ba) were studied at a congested residential as well as commercial area of Nagpur city, India. Cascade impactor having 50% cut-off aerodynamic diameters of <10, 9, 5.8, 4.7, 3.3, 2.1, 1.1, 0.7, and <0.4 μm was used for sampling 2 days before Diwali, during Diwali, celebrations of marriage functions, and New Year's Eve. A significant increase in levels of PM10 and Ba were observed during Diwali as compared to days before Diwali and other activities. PM10 levels were increased by four to nine times whereas Ba levels were increased by 8 to 20 times in alveolar region, when compared with the levels observed before Diwali. Probability of deposition of Ba in alveolar region varied between 14 and 27 ng/h with higher deposition when the burning of fireworks activity was lower near the site (Khaparde, *et al.*, 2012).

Sr, Ba and Cu compounds are used to give red, green, and blue fireworks, respectively (Kulshrestha *et al.*, 2004; Wang *et al.*, 2007; Moreno *et al.*, 2007) mentioned in figure 3.

Compounds, such as organic dyes (for smoke generation), metal salicylates (for noise effects), and chloride salts or chlorinated organics (for color enhancement), can be added for specialized functions (Shimizu, 2004). Iron (Fe) facilitates the production of sparks, whereas calcium (Ca) enhances the colors produced by other compounds (Kulshrestha *et al.*, 2004).

Smith *et al.* (1975) presented the first direct evidence that air pollution caused by fireworks activities in Honolulu can alter pulmonary function in susceptible people. They also speculated that 26% decrease in forced expiratory volume (FEV 25-75%) in susceptible people was the result of an SO2-KCl aerosol interaction.

Another study by Beig *et al.* (2013), SAFAR showed increase in mortality and morbidity attributed to effective exposure to $PM_{2.5}$ and PM_{10} mass concentrations within areas of 2 km radii associated with the fireworks activity. It also indicates the excess number of cases for total, cardiovascular and respiratory mortalities and hospital admissions may be related to inhalation of large number of smaller particles ($PM_{2.5}$) rather than the inhalation of larger particles (PM10–2.5).

Exposure to high levels of metals can induce severe health effects, such as neurological and hematological effects, on exposed populations, particularly the effect of Pb on children, the carcinogenic effects of inhaled Cd and Ni on humans with chronic lung diseases, the toxic and carcinogenic effects of Cr on the bronchiole epithelium, increased neurotoxic impairment from Mn, and respiratory irritation from increased Cu levels (Benoff *et al.*, 2000; Santos-Burgoa *et al.*, 2001; ATSDR, 2002; Hu, 2002; Manalis *et al.*, 2005).

Sarkar *et al*. (2010) estimated that chronic exposure to Diwali pollution is expected to cause at least a 2% increase in non-carcinogenic hazard index associated with Al, Mn and Ba in the exposed subjects. Yang *et al.* (2014) also indicated that exposure to metals found in $PM_{2.5}$ may pose a serious public health risk in their study area and that the non-carcinogenic elemental inhalation risk is greatly increased due to the burning of firecrackers.

DISCUSSION

Exposure to loud sounds can lead to temporary or permanent anatomical and physiological changes in the cochlea. These may cause hearing loss characterized by threshold shifts, the loss of speech comprehension and tinnitus.

Barman *et al.* 2009 conducted air quality test similar to the previous researchers to determine NO_x, SO_2 and ten trace metals related with PM_{10} such as Calcium (Ca), Iron (Fe), Zinc (Zn), Copper (Cu), Lead (Pb), Manganese (Mn), Carbon monoxide (Co), Chromium (Cr), Nickel (Ni) and Cadmium (Cd). Results showed that during the night of Diwali, PM_{10} increased by 446.8%, SO_2 by 289.3% and NO_x by 121.3%. These levels were higher when compared to National Ambient Air Quality Standards (NAAQS) which were 100, 80 and 80 μg/m^3 respectively. The concentration of Cu, Ni, Cr, Zn and Cd were high in air when compared to other metals.

The inhaled particles which have an aerodynamic diameter of less than 10 μm, are a crucial part of the atmosphere. When present at a level of over 50 μg/m^3, PM_{10} has an adverse effect on Human health (World Health Organization, 2006); an epidemiological study by Pope (2004) suggested that even a low level of exposure leads to an increased risk of cardiopulmonary disease, stressed respiratory physiology, mortality, and morbidity. Higher concentrations of PM_{10} in inhaled air increase the chances of these particles reaching deep into the lungs. Previous studies have suggested that these effects presented an increase in mortality with each incremental increase of PM10 by 10 μg/m^3. People who are elderly or have past history of lung or heart disease may be more likely to the adverse effects of PM_{10} (Dockery *et al.*, 1993; Schwartz *et al.*, 1996).

In another study it was observed that the air concentrations of sulfur, zinc, antimony, copper, titanium and barium were as high as 45.64 μg/m^3, 2.32 μg/m^3, 0.05 μg/m^3, 0.36 μg/m^3, 1.25 μg/m^{3}and 34.55 μg/m^{3}respectively on the day of Diwali as compared to pre and postfestival days in Pitampura, New Delhi, India (Mradul *et al.*, 2019). It was seen that PM_{10} was highest in the area with 324 µg/m³ post-Diwali. Chlorine is a potent irritant to the eyes, the upper respiratory tract, and lungs. On Diwali day, the value of chlorine in $PM_{2.5}$ was 19.73 µg/m3 compared to days before and after Diwali in Pitampura area. General complaints by participants post Diwali revealed that 27.3% and 43.4% of participants of Pitampura complained about abnormal breathing and eye problems respectively. The data on hospital admission pre and post Diwali were collected from twenty hospitals of Delhi reported cardiac problems, stroke, respiratory problems, and burns increased in post Diwali hospital admission in 10 (50%) hospitals.

Methodological issues

No studies are available that can differentiate between the old firecrackers and the ecofriendly firecrackers. Hence, to draw a concrete difference between their formulations and their health effects is challenging. All the data related to ecofriendly firecrackers is extracted from CSIR-NEERI.

CONCLUSION

This review identifies the difference between the traditional/old and ecofriendly (green) firecrackers with respect to their formulations and their health effects respectively. Scant data is available related to the formulations of ecofriendly firecrackers and no studies are available related to its use and outcomes. This review is the first review that shows the importance of ecofriendly firecrackers and the improvements required for the betterment of ecofriendly firecrackers. This review also identifies hazards and adverse health effects related to fireworks/firecrackers bursting, manufacturing and transportation. The chemicals found in old firecrackers are extremely toxic and hazardous which can lead to health effects like bio-accumulation, skin and eye irritations, respiratory problems, neurological problems (long term effect), burn with multiple degrees and many more. Due to the reduction in the amount of chemicals used in the ecofriendly firecrackers there is expected reduction in the emissions of particulate matter. Particulates emitted are a major concern as they can travel down to the blood stream via inhalation. Barium nitrate is partially substituted by potassium nitrate and strontium nitrate; new formulations made for oxidizers, fuel and additives are expected to reduce the concentration of ambient $PM_{2.5}$, and PM_{10}. Reduction in the usage of potassium nitrate (KNO_3) and sulphur (S) leads to the reduction in overall cost of manufacturing.

The data from studies also shows that the workers in the fireworks manufacturing industry are exposed to many chemicals as they do not wear any masks or gloves making their respiratory tract the primary route of exposure. The workers are also exposed to many accidents related to the fireworks manufacturing industry as shown in Figure 1.

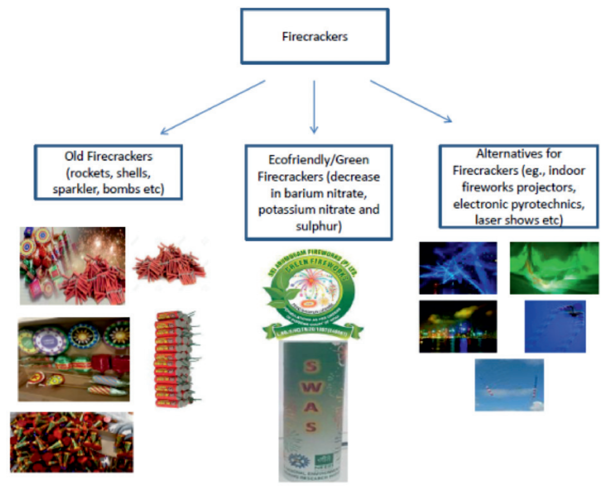

Fig. 5. Showing different types of firecrackers and their alternatives

Studies showed that barium nitrate is hazardous during processes like weighing, mixing and filling; hence, reduction in barium nitrate will reduce accidents that happen during the manufacturing process.

Further studies are required to unravel the effects of ecofriendly (green) fire crackers as the complete list of their formulations are still not available. More attention should be given to the improvement of the composition of the ecofriendly firecrackers for further reducing the health effects caused by them as well as reduce accidents related to firecracker bursting and manufacturing. Further large-scale air sampling should be done to characterize the $PM_{2.5}$. According to all the data drawn from all the search engines and the national government sites related to old firecrackers and the ecofriendly (green) firecrackers it can be concluded that the ecofriendly/green firecrackers can be a better substitute for the old firecrackers as their composition is less harmful to human beings. Further studies are needed on control measures for firework displays which can help reduce the probable health hazards and replacement by ecofriendly firecrackers is needed to study the effects of the new formulations introduced by CSIR-NEERI.

Limitations

Enough information is not available related to composition of ecofriendly firecrackers. Hence, demonstrating the overall health impact of chemicals released from the ecofriendly firecrackers is difficult.

Funding

No financial support obtained

ACKNOWLEDGEMENT

None

Conflict of Interest

All authors have declared that they have no conflict of interest.

REFERENCES

Attri, A. K., Kumar, U. and Jain, V. K. 2001. Microclimate: Formation of ozone by fireworks. *Nature*. 411(6841):1015. https://link.gale.com/apps/doc/A187996606/AONE?u=anon~ea353cbf&sid=googleScholar&xid=fb327b47

Ajith, S., Sivapragasam, C. and Arumugaprabu, V. 2019. A review on hazards and their consequences in firework industries. *SN Appl. Sci.* 1: 120. https://doi.org/10.1007/s42452-018-0129-1

ATSDR (Agency for Toxic Substances and Disease Registry), 2002. Toxicological profile of Copper. Atlanta, GA, USA, Division of Toxicology.

Thakur, B. 2010. Air pollution from fireworks during festival of lights (Deepawali) in Howrah, India - a case study. *Atmï¿½sfera.* 23(4).

Barman, S.C., Singh, R., Negi, M.P. and Bhargava, S.K. 2009. Fine particles (PM2.5) in ambient air of Lucknow city due to fireworks on Diwali festival. *J Environ Biol.* 30(5): 625-632.

Pope CA 3rd, Burnett RT, Thurston GD, et al. Cardiovascular mortality and long-term exposure to particulate air pollution: epidemiological evidence of general pathophysiological pathways of disease. *Circulation.* 2004; 109(1): 71-77. doi:10.1161/01.CIR.0000108927.80044.7F

Chi-Chi Lin, 2016. A review of the impact of fireworks on particulate matter in ambient air. *Journal of the Air & Waste Management Association.* 66(12): 1171-1182, DOI: 10.1080/10962247.2016.1219280

D. W. Dockery, C. A. Pope, X Xu, J. D. Spengler, J. H. Ware, M. E. Fay, B. G. Ferris Jr and F. E. Speizer, 1993 Dec 9. An association between air pollution and mortality in six U.S. cities. N. Engl. J. Med. 329(24): 1753-1759. doi:10.1056/NEJM199312093292401

Drewnick, F., Hings, S.S., Curtius, J., Eerdekens, G. and Williams, J. 2006. Measurement of 21 fine particulate and gas-phase species during the New Year's fireworks 2005 in Mainz, Germany. *Atmos. Environ.* 40: 4316-4327. doi:10.1016/j.atmosenv.2006.03.040

Beig, G., Chate, Sachin, D. M., Ghude, D., Ali, K., Trupti, Satpute, S. K. Sahu, Neha Parkhi and H. K. Trimbake, 2013. Evaluating population exposure to environmental pollutants during Deepavali fireworks displays using air quality measurements of the SAFAR network. *Chemosphere.* 92(1): 116-124. doi:10.1016/j.chemosphere.2013.02.043

Georg Steinhauser, Johannes H. Sterba, Michaela Foster, Friedrich Grass and Max Bichler, 2008. Heavy metals from pyrotechnics in New Years Eve snow. Atmospheric Environment. 42(37): 8616-8622. https://doi.org/10.1016/j.atmosenv.2008.08.023

Harrad, S. and Laurie, L. 2005. Concentrations, sources and temporal trends in atmospheric polycyclic aromatic hydrocarbon in a major conurbation. *Journal of Environmental Monitoring.* 7: 722-727.

Health & Safety Executive (HSE), 2011. Explosives Incidents Database Advisory Service. http://www.hse.gov.uk/explosives/eidas.htm.

Hirai, K., Yamazaki, Y., Okada, K., Furuta, S. and Kubo, K. 2000. Acute eosinophilic pneumonia associated with smoke from fireworks. *Intern. Med.* 39: 401-403. doi:10.2169/internalmedicine.39.401

Hu, H. 2002. Human health and heavy metals exposure. In: Life Support: The Environment and Human Health Michael McCally (ed), MIT Press (Chapter 4).

Kannan, G.K., Gupta, M. and Kapoor, J.C. 2004. Estimation of gaseous products and particulate matter emission from garden biomass combustion in a simulation fire test chamber. *Atmos. Environ.* 38: 6701-6710. doi:10.1016/j.atmosenv. 2004.09.041

Khaparde, V.V., Pipalatkar, P.P., Pustode, T. Chalapati Rao C V, Gajghate G D. 2012. Influence of burning of fireworks on particle size distribution of PM10 and associated Barium at Nagpur. *Environ Monit Assess.* 184: 903-911. https://doi.org/10.1007/s10661-011-2008-8

Kulshrestha, U.C., Rao, T.N., Azhaguvel, S. and Kulshrestha, M.J. 2004. Emissions and accumulation of metals in the atmosphere due to crackers and sparkles during Diwali festival in India. *Atmos. Environ.* 38: 4421-4425. doi:10.1016/j.atmosenv.2004.05.044

Manalis, N., Grivas, G., Protonotarios, V., Moutsatsou, A., Samara, C. and Chaloulakou A. 2005. Toxic metal content of particulate matter (PM10), within the Greater Area of Athens. *Chemosphere.* 60(4): 557-566. doi:10.1016/j.chemosphere.2005.01.003

Moreno, T., Querol, X., Alastuey, A., Minguillòn, M.C., Pey, J., Rodriguez, S., Mirò, J.V., Felis, C. and Gibbons, W. 2007. Recreational atmospheric pollution episodes: inhalable metalliferous particles from firework displays. *Atmos. Environ.* 41: 913-922. doi:10.1016/j.atmosenv.2006.09.019

Mradul Kumar Daga, Govind Mawari, Dipu Bharali, Himanshi Banker, Priya Mehar, Prachi Saluja, Diksha Kumar, Dikshant Kumar, Manish Kumar Jha and Prashant Gargava, 2019. Assessment of the air quality and its impact on health and environment in India. *Indian Journal of Medical Specialities.* 10. 117. 10.4103/INJMS.INJMS_15_19. 10(3): 117-125

Murty, O. P. 2000. Diwali toxicity. Journal of Forensic Medical and Toxicity, 17: 23-26.

Russell, Michael S. The Chemistry of Fireworks. 2000. DOI. https://doi.org/10.1039/9781847552037

Sarkar, S., Khillare, P.S., Jyethi, D.S., Hasan, A. and Parween, M. 2010. Chemical speciation of respirable suspended particulate matter during a major firework festival in India. *J. Hazard. Mater.* 184: 321-330. doi:10.1016/j.jhazmat.2010.08.039

Schwartz, J., Dockery, D.W. and Neas, L.M. 1996. Is daily mortality associated specifically with fine particles? *J. Air. Pollut. Assoc.* 46: 927-939. doi:10.1080/10473289.1996.10467528

Shimizu, T. 2004. Chemical composition of fireworks compositions, in: Kosanke, K. et al. (Eds.), Pyrotechnic Chemistry, Pyrotechnic Reference Series No. 4, *Journal of Pyrotechnics* (Whitewater, CO).

Sillanpää, Mika and Bhatnagar, Amit, 2015. Chapter 7. NOM Removal by Adsorption. In: *Natural Organic Matter in Water.* 213-238. DOI: 10.1016/B978-0-12-801503-2.00007-0.

Smith, M.R. and Dinh, V.D. 1975. Changes in forced expiratory flow due to air pollution from fireworks. Preliminary report. *Environ. Res.* 9: 321-331. doi:10.1016/0013 9351(75)90012-2

Sukumar, A. and Subramanian, R. 1992. Trace elements in scalp hair of manufacturers of fireworks from Sivakasi, Tamil Nadu. *Sci Total Environ.* 1992;114:161-168. doi:10.1016/0048-9697(92) 90422-o

TAN, H. P. and XUE, J. G. 2007. Catalyzed Thermal Decomposition of Potassium Perchlorate. *Journal of Central South University of Forestry & Technology.* 6: 114-116 Changsha 410004, Hunan, China.

Tsai, H.H., Chien, L.H., Yuan, C.S., Lin, Y.C., Jen, Y.H. and I.R. Ie. 2012. Influences of fireworks on chemical characteristics of atmospheric fine and coarse particles during Taiwan's Lantern Festival. *Atmos. Environ.* 62: 256-264. doi:10.1016/j.atmosenv.2012.08.012

Vecchi, R., Bernardoni, V., Cricchio, D., D' Alessandro, A., Fermo, P., Lucarelli, F., Nava, S., Piazzalunga, A. and Valli, G. 2008. The impact of fireworks on airborne particles. *Atmospheric Environment.* 42: 1121-1132. doi:10.1016/j.atmosenv.2007.10.047

Wang, Y., G. Zhuang, C. Xua, and Z. An. 2007. The air pollution caused by the burning of fireworks during the lantern festival in Beijing. Atmos. Environ. 41:417-431. doi:10.1016/j.atmosenv.2006.07.043

Wilkin, R. T., Fine, D. D. and Burnett, N. G. 2007. Perchlorate behavior in a municipal lake following fireworks displays. *Environmental Science & Technology.* 41: 3966-3971. https://doi.org/10.1021/es0700698

World Health Organization, 2006. WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide.

Yang, L.X., Gao, X.M., Wang, X.F., Nie, W., Wang, J., Gao, R., Xu, P.J., Shou, Y.P., Zhang, Q.Z. and Wang, W.X. 2014. Impacts of firecracker burning on aerosol chemical characteristics and human health risk levels during the Chinese New Year Celebration in Jinan, China. *Sci. Total. Environ.* 476-477:57-64. doi:10.1016/j.scitotenv.2013.12.110