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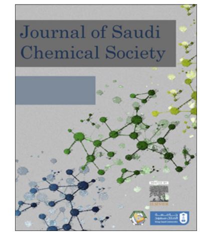

ORIGINAL ARTICLE

Chemical composition and potential health risks of raw Arabian incense (Bakhour)

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Abstract Burning Arabian incense (Bakhour) is a common indoor practice in the Middle East and the Arabian Gulf region. However, the chemical composition of this substance has never been studied. Three different Bakhour brands were selected for this study. A complete chemical profile for the raw samples was determined using carbon, hydrogen, and nitrogen elemental analysis, inductively coupled plasma optical emission spectroscopy, scanning electron microscopy coupled with energy dispersive X-ray spectroscopy and gas chromatography mass spectrometry techniques. A wide range of elements and compounds were identified, many of which are hazardous to health. Nitrogen was found in all samples which should raise concerns due to the known health implications of amines, nitrogen oxides and nitrites. In addition toxic metals such as cobalt, copper, iron, nickel, lead, and zinc were also determined in all samples. The amounts of these metals are equivalent to those in raw tobacco, where they are known to pose health risks. Three types of solvents (acetone, dichloromethane and toluene) were used for the extraction of organic compounds. Carcinogens, toxins and irritants were found along others of different health implications. Isolation of these compounds provides preliminary evidence on the harmful consequences of being exposed to Bakhour.

1. Introduction

Bakhour, traditional Arabian incense, is commonly used in the Middle East and North Africa to perfume houses, shops, clothing, and in various ceremonies and worship homes [1,2]. Bakhour is traditionally burned to purify the surroundings from evil spirits, create a pleasant atmosphere or eliminate undesirable odors in an indoor environment [3–8]. Bakhour is therefore one of the most common sources of indoor smoke in the Arabian Gulf region to which individuals are exposed to

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on a weekly basis in most homes [3,4]. Bakhour can vary in composition, but it usually contains a wide variety of natural ingredients such as agarwood (oud), woodchips, musk and sandalwood that are soaked in scented oils [1,2]. The ingredients are mixed and formed into small bricks which are burned in charcoal, gas or electric burners to produce the scented smoke [9].

A few studies on Bakhour suggest that the smoke produced from burning the raw material is a potential health hazard [3,4,10–15]. An indoor air pollution study conducted in the United Arab Emirates (UAE) in 2012 on 628 homes of Emirati nationals found that the burning of Bakhour on a daily basis is associated with increased headaches, difficulty in concentration and forgetfulness [3]. A community survey conducted in Oman revealed that Bakhour burning triggered wheezing among asthmatic children [10]. Clinical studies have also reported noticeable cell inflammatory responses upon the exposure of individuals to components in Bakhour smoke, such as particulate matters smaller than 2.5 μm ($PM_{2.5}$), carbon monoxide (CO), sulfur dioxide (SO_2), oxides of nitrogen (NO_x), formaldehyde (HCHO), and carbonyls [3,10]. Research on rats and mice indicated that continuous exposure to Bakhour smoke results in reduced lung weight, necrosis and degradation of epithelial bronchioles, and ultra-structural pulmonary changes known to impair respiratory efficiency [12–14]. Although there is accumulating evidences to suggest the potential harm that may be associated with burning Bakhour, very little is known about the chemical composition of the raw material [3,4,10–15]. For instance, the *Aquilaria malaccensis* plant's woodchips that are processed to make Bakhour were found to sequester high amounts of metals such as cadmium (Cd), nickel (Ni), copper (Cu), zinc (Zn), iron (Fe), and lead (Pb) from soils [16]. The presence of such metals and their salts in the raw Bakhour could pose a serious health risk. Cadmium is a poisonous metal that can severely affect the lungs, kidneys, and bones [17]. Cadmium oxide (by-product of pyrolysis and combustion) is a carcinogen and can also cause tracheobronchitis and pulmonary edema [17]. Lead is toxic and known to cause heart and kidney failure in humans [17]. In addition, nickel (Ni)-containing compounds are known to cause asthma as well as to be a "Group 1" carcinogen [17].

Few studies on incense products postulated a possible relationship between the chemistry of the raw material and the composition of the emitted smoke [17–19]. A study by Hsueh et al. correlated the particulate emission in the smoke generated from burning Asian incense to the metallic elements in the raw incense [17]. They revealed the presence of the Na, Ca, Mg, Al, and K elemental species in both the aerosol and the ash of the Asian incense [17]. The presence of particulate matters that are smaller than 2.5 μm ($PM_{2.5}$) raises concerns as air pollutants and as a threat to human respiratory health [17]. A hazard assessment study on smoke produced from burning Bakhour in the UAE estimated the concentration of particulate matters (PM) to be 1.34–1.36 mg/m^3 with an emission rate of 5.9 mg/min, which is higher than the emission rate from cigarettes (0.7–0.9 mg/min) [11]. In another study, the relationship between smoke, ash formation and metallic content in incenses similar to Bakhour was evaluated [18]. The study concluded that the presence of higher metallic content in the raw incense materials results in higher burning rates associated with a reduction in the level of suspended particulate emissions by about 40% [18]. The authors of the study hypothesized that a temporary protective shield of melted inorganic salt may be formed, surrounding the burning section of the incense, insulating it from the cool air [18].

Although there is no specific research conducted to quantitatively correlate the levels of metals in raw Bakhour to their levels in smoke and how that might impact respiratory health, some studies were done on tobacco. Tobacco has been reported to contain 440–1150 mg Fe/kg of tobacco. However, only 0.1% of this iron enters the mainstream smoke [19]. The human respiratory tract is exposed to 40–100 mg PM from smoking one cigarette [19]. Research conducted on male rats exposed to cigarette smoke for 6 h per day for three days consecutively showed an increased accumulation of iron in the lower respiratory tract due to inhalation of PM [19]. Furthermore, the study showed that the particles in the cigarette smoke alter iron homeostasis, which may contribute to other diseases, due to elevations in catalytically active iron promoting oxidative stress that triggers a chain of biochemical events leading to inflammation [19]. Due to the PM lodged in the lungs, continued iron accumulation may occur [19]. This phenomenon could occur in Bakhour as well with iron or any other existing metals that are bioavailable, like cadmium and lead.

The objective of this study was therefore to obtain fundamental information on the chemical composition of various brands of raw Arabian Bakhour and then evaluate the potential impact of the identified species on human health and the environment. Advanced techniques for sampling and analysis were applied in order to obtain a detailed chemical profile of all organic and inorganic compounds present in raw Bakhour samples. The techniques used for analysis are gas chromatography–mass spectrometry (GC–MS), inductively-coupled plasma–optical emission spectroscopy (ICP–OES) and scanning electron microscopy coupled with energy dispersive X-ray spectroscopy (SEM/EDS).

2. Materials and methods

2.1. Bakhour samples

Three Bakhour samples were obtained and used in this study from a domestic producer in Sharjah, UAE. The samples were labeled as B1, B2 and B3. The choice of the Bakhour samples was based on their price and popularity in the market.

2.2. Ash content

The Bakhour samples were ashed in a furnace (Barnstead/Thermolyne Type 6000, USA). Four 1.0 g replicates of each Bakhour sample were weighed and placed in separate ceramic crucibles and ashed at 575 °C for 6 h before being cooled in a desiccator [20]. The mass of the remaining residue was used to determine the ash content for each Bakhour sample.

2.3. CHN elemental analysis

An elemental analyzer (EuroVector EA3000, Italy) equipped with a thermal conductivity detector (TCD) was used to determine the carbon, hydrogen and nitrogen (CHN) content of the three Bakhour samples. 2 mg of each Bakhour sample was