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Risk assessment model for different foodstuff drying methods via AHP-FCE method: A case study of "coal-burning" fluorosis area of Yunan and Guizhou Province, China

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ABSTRACT

Fluorosis is still a serious public health problem in China according to our field investigation. Current foodstuff drying methods were studied to evaluate the state of foodstuff contamination, including burning mixed coal (MC)/coal washing wastes (CWWs)/lump coal (LC)/fuelwood/fine coal + fixing materials (FCFM)/CWWs + fixing materials (CFM) in open stove (OS), honeycomb briquettes (HB) in improved stove (IS), sun-drying. The results demonstrate that elemental contents of F, As, Cd, Cr and Pb in roasted grain were 1.19–40.65 times higher than limting standard. The comprehensive risk of different drying methods based on AHP-FCE is ranked in the order of: CWWs(OS) > MC(OS) > HB(IS) > CFM(OS) > FCFM(OS) > LC(OS) > Fuelwood (OS) > sun-drying. It exhibits obviously higher risk due to burning CWWs/MC in OS than other methods. Burning CFM/FCFM/fuelwood in OS may be an economic and relatively safe foodstuff drying methods.

1. Introduction

Coal burning fluorosis is attributed to the intake of foodstuff (corn and chili) with high content of F and As, after roasted by mixed coal (fine coal + clay with high content of F) in open stove (OS) in Yunnan and Guizhou Province (Dai, Ren, & Ma, 2004; Luo, Li, & Niu, 2010; Luo et al., 2011, Xu et al., 2017; Sun, 2005). Over millions of people in eastern Yunnan and western Guizhou have been identified to have dental fluorosis and skeletal fluorosis (Ando et al., 2001, Luo et al., 2011, Ye, Yang, Peng, Wang, & Yang, 2004) and more than 80% of children aging from 8 to 12 years old are suffering from dental fluorosis (Liang, 1993; Li et al., 2005). Local authorities have advised people to use the improved stove (IS) (a kind of stove with smoke exhaust chimney) to prevent fluorosis (Ye et al., 2004; Luo et al., 2011; Li, Luo, Liu, & Xu, 2012). Recent literatures have documented that the occurrence of dental fluorosis has declined significantly in some coal burning fluorosis areas (Gao et al., 2015; Zhang et al., 2015; Liao et al., 2016).

Firstly, the current foodstuff drying methods are carefully performed in Puyi, Chahe, and Gusheng (Fig. 1, Fig. 2 and Fig. S1), such as burning mixed coal in open stove (MC + OS), lump coal in open stove (LC + OS), coal washing wastes in open stove (CWWs + OS), fuelwood in open stove, sun-drying (Table S1) and honeycomb briquettes (HB) in IS. The prevalence rate of dental fluorosis among rural children in Mangbu is still high and accounts for 75% (Table S2), where the daily diet is still mainly dependent on foodstuff roasted by CWWs/MC(OS) (Tables S1 and S2). But, the prevalence rate of dental fluorosis among rural children in Puyi and Gusheng is 19.05% and 14.29% (Table S2), respectively, where the decline of the dental fluorosis is ascribed to change of staple food from dried grain to rice (Table S2). The residents in Gusheng and Puyi sell some of the roasted grain and feed the rest of the roasted grain to poultry (pig, chicken, and so on) instead of eating by themselves. However, it is worth noting that grain must be baked in order to avoid mold as long as residents grow corn and chili, therefore, the pollution route and source of baking grain still exist.

Secondly, F and As contamination have attracted considerable attention in coal burning fluorosis area (Luo et al., 2011; Li et al.,2012; Finkelman,1999). Long-term environmental exposure to toxic elements has a detrimental effect on human health, such as fluorosis and arsenism (Dai et al., 2004; Ding et al., 2011; Steinmaus et al., 2016). High F-Cd coal is utilized to dry harvested crops in coal burning fluorosis area in Wushan County in the Three Gorges Region, SW China. F and Cd, emitting from coal combustion, are absorbed by foodstuff during

Abbreviations: MC, mixed coal; CWWs, coal washing wastes; LC, lump coal; HB, honeycomb briquettes; FCFM, fine coal + fixing materials; CFM, coal washing wastes + fixing materials; AHP–FCE, analytical hierarchy process–fuzzy comprehensive evaluation model; OS, open stove; IS, improved stove

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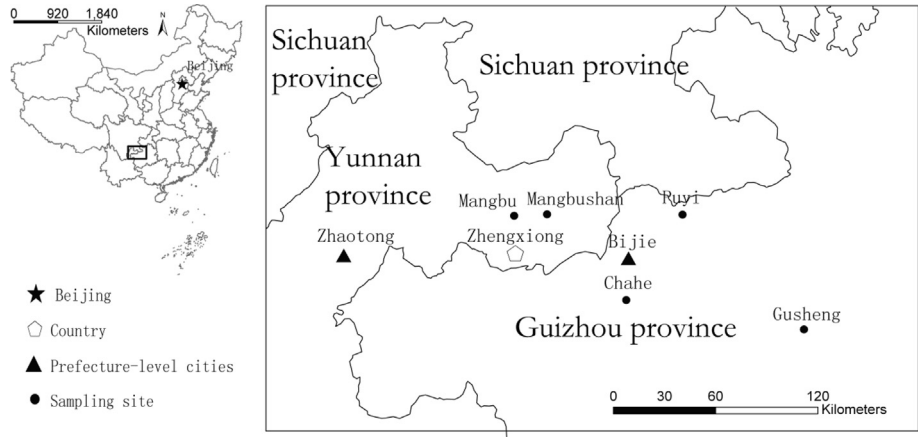

Fig. 1. Location map of the sampling site. Note: Province, Prefecture-level city, village are the government levels in China.

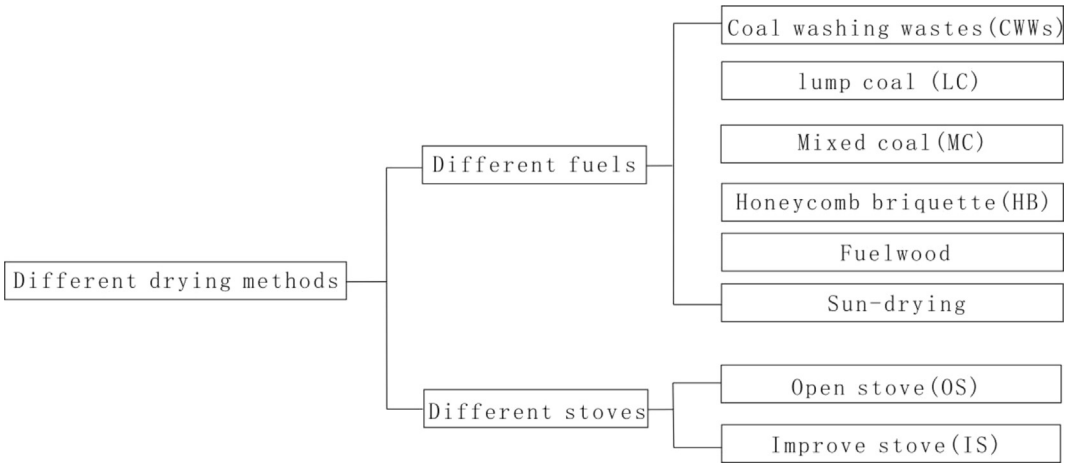

Fig. 2. Different drying methods to roast corn and chili in fluorosis area (investigated in April and September 2015).

drying procedure, which can result in bone and tooth damage (Liu et al., 2015). Medical experiments have preliminarily proved that Cr, Pb, and As are related to chronic fluorosis (Pethes, 1980; Rubin et al., 1994; Clarke, Beveridge, Slocombe, & Coulson, 2006). Moreover, excessive intake of heavy elements (Cr, Pb, and As) can cause cardiovascular and kidney disease (Duruibe, Ogwuegbu, & Egwurugwu, 2007; Fu et al., 2008). However, few research focused on toxic element (Cr, Cd, and Pb) contents in roasted grain and fuel in coal-burning fluorosis area.

In this study, combined current foodstuff drying method and pilot experiments conducted by our research group, such as burning fine coal + fixing materials (7:3) in open stove (FCFM + OS) and CWWs + fixing materials (7:3) in open stove (CFM + OS) (Li et al., 2012; Liu, Luo, Li, & Shahid, 2013), we attempt to solve the following problems: (1) Determining F, As, Cr, Cd, and Pb pollution levels in corn and chili roasted by different drying methods. We also estimated the atmospheric emissions of hazardous elements during drying procedure.

(2) We combine datasets to assess the comprehensive risk of F, As, Cd, Cr, and Pb based on different grain drying methods and then provide a theoretical basis for foodstuff drying. Multi-objective and multi-standard AHP- FCE method is applied to avoid any inconsistencies resulting from the comparative evaluation of multi-factors (Chan and Kumar, 2007; Wang et al., 2015; Wang, Li, Zhen, & Zhang, 2016).

2. Material and methods

2.1. Study area

Mangbu and Mangbushan Villages are located in Zhengxiong County, Zhaotong Prefecture, Yunnan Province, China. Gusheng Village, Puyi and Chahe Town are located in Bijie Prefecture, Guizhou Province, China (Fig. 1). Climate varies with altitude above sea level, producing a cool-wet climate with mean annual temperatures (MAT) of 13–18 °C, and mean annual precipitation (MAP) of 900–1300 mm. Local residents spend 10–15 days *per annum* drying corn and chili in order to avoid the effects of mildew (Liu et al., 2013). The traditional flue-curing barns (baking rooms) in our study area are 2–3 m high and are separate structures which do not connect with the other rooms, where fresh corn and chili are hung from the ceilings (Liu et al., 2013). Currently, most residents have realized that eating foodstuff roasted by MC(OS) method can cause fluorosis. Therefore, they sell part of the roasted grain and use the other part of the roasted grain to feed poultry, and living on bought rice.

Zhaotong is located in the southwest regions of China, which is a typical karst region. The major strata is Early Mesozoic strata and Early and Later Paleozoic strata, where are thousands of meters carbonate deposits (limestone and dolomite mainly) (Liu et al., 2013). According to our field investigation, the majority of households live on a diet of foodstuff roasted by CWWs(OS) due to fuel with cheap price.