Effects of the grade/price and thickness of cigarette on the PM2.5 concentration of smoke

Shengzhe Ji1 · Zhen Liu2 · Peng Liu1

Received: 16 August 2021 / Accepted: 9 May 2023 / Published online: 19 May 2023
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Abstract
In an attempt to promote sales of high-grade/price and slim cigarettes with lower tar and nicotine content, the State Tobacco Monopoly Administration (STMA) also known as the China National Tobacco Corporation (CNTC), whose monopoly controls all aspects of tobacco production, marketing, and distribution in China, have advertised them as safe cigarettes that cause less tobacco smoke pollution (TSP). However, cigarette smoke contains thousands of harmful components, and the effects of only tar and nicotine cannot be used to represent TSP. This study aimed to evaluate the impact of cigarette grade/price and size on TSP by measuring PM2.5 concentrations for three different grades/prices and two sizes of popular cigarettes in China. The results showed that cigarette grade/price did not significantly affect PM2.5 levels in regular (R) or slim (S) cigarettes in either sidestream or mainstream smoke. However, cigarette size had a significant effect on PM2.5 levels, with R cigarette PM2.5 being 116% higher than S cigarette PM2.5 in sidestream smoke. In mainstream smoke, this difference decreased to 31%, although R-cigarette PM2.5 levels remained higher. While S cigarette PM2.5 levels were lower than those of R cigarettes, this did not necessarily mean that S cigarettes were less harmful. The harmfulness of smoke is not only manifested in PM2.5 but also in other particulate matter such as PM10 and PM1.0. At the same time, it is also affected by smoking habits. Therefore, further experiments are required to evaluate the potential harmfulness of S cigarettes.

Keywords Cigarette grade/price · Cigarette size · PM2.5 · Second-hand smoke

Introduction
TSP, also referred to as “second-hand smoke” or “passive smoke,” is a global health issue in public areas. This type of pollution predominantly arises from cigarette combustion, also known as “sidestream smoke,” as well as the smoke exhaled by smokers, which is referred to as “mainstream smoke” (Sureda et al. 2013). Accumulating evidences suggest that TSP may be responsible for numerous respiratory problems, acute cardiovascular effects, and even lung cancer (Dunbar et al. 2013; Shikata and Takemura 2017; Vozoris and Lougheed 2008). Due to the toxicity of TSP, > 7 million people die every year worldwide (Öberg et al. 2011).

China has one of the highest levels of cigarette production and consumption in the world, with smoking playing a significant role in Chinese social customs, such as at weddings and funerals. The act of offering a cigarette to a friend is considered a social courtesy, often taking place in public spaces where the issue of TSP becomes a serious problem (Yang et al. 2015).

Over the past decade, there has been a decrease in the production and sales of cigarettes in China, which can be attributed to two main factors. The first factor is the increase in public awareness regarding the hazards of cigarette smoking. For instance, the percentage of people who were aware that cigarette smoking increases the risk of lung cancer increased from 36% in 1996 to 77.5% in 2010 (China CDC 2011). The other reason is that the Chinese government has implemented various policies to decrease cigarette smoking, including limiting cigarette advertisements and raising the price of cigarettes (Legislation Office of the State Council 2014; National Health and Family Planning Committee 2014).
The decline in cigarette sales had a significant impact on the profits of the State Tobacco Monopoly Administration (STMA) and the China National Tobacco Corporation (CNTC). Interestingly, the STMA and CNTC are actually the same organization, with the different names representing the separation between the government and tobacco industry. In order to maintain their profits, the STMA/CNTC utilized new marketing strategies (Fang et al. 2018). One of which was the “safe cigarette,” characterized by low tar and nicotine content. Certain scientists who were either associated with or funded by STMA/CNTC worked toward improving cigarette production technology and creating these new types of cigarettes.

In an effort to promote the idea of “safe” cigarettes, various new technologies have been employed, such as the use of filters made from novel materials, high-permeability cigarette papers, and methods to enhance combustion, all of which were reported to reduce the presence of harmful substances (Case et al. 2003; Ning et al. 2019; Wu et al. 2017). The implementation of these new technologies resulted in an increase in manufacturing costs, which were ultimately transferred to the consumer. Unfortunately, this hike in price could be misinterpreted by consumers as a direct correlation between cost and safety. In other words, a higher-priced cigarette could be perceived as being safer than a cheaper one, leading to a false sense of security among smokers. In an effort to boost profits for STMA/CNTC, the promotion of “slim” (S) cigarettes (rod circumference: 14–24 mm), which contain less tobacco than the standard “regular” (R) cigarettes (rod circumference: 24–25 mm), has been touted as a “safe cigarette” (Braun et al. 2020). In 2014, 2.9 million cartons of S cigarettes were sold, but by 2018, this number had skyrocketed to 347 million cartons (according to data from the STMA from 2014-2018). In addition to creating new products, cigarette manufacturers have also publicized the concept of “safe cigarettes” by showcasing the work of tobacco researchers. One notable example is the “tobacco academician,” who promoted the use of low-tar tobacco products and was subsequently elected to the Chinese Academy of Engineering, the highest scientific honor in China (Hvistendahl 2012). The tobacco industry’s efforts to promote and conduct research on “safe cigarettes” have contributed to a widespread misconception among the public that the tobacco smoke produced by these products is either harmless or less harmful to one’s health.

While low tar and nicotine contents are important factors, they cannot fully represent TSP found in cigarette smoke. To accurately evaluate emission and exposure to TSP, it is necessary to consider atmospheric particulate matter (PM) of diameter < 2.5 μm, also known as PM2.5. According to Czogala et al. (2013), PM2.5 concentrations serve as a suitable and reliable airborne marker for this purpose. The aim of this study was to assess the impact of grade/price, cigarette size, and grade/price×size on PM2.5 concentrations following cigarette smoking. Six types of cigarettes were chosen for this purpose.

**Materials and methods**

STMA/CNTC divides cigarettes into five grades according to price in China (Danna 2016). To clarify the relationship between cigarette price and PM2.5, we selected three grades/prices: 1 (≥ ¥100), 3 (¥30 ≤ and <¥70), and 5 (< ¥16.5). According to their size, there are two types of cigarettes: R and S (Table 1).

**PM2.5 measurement**

Second-hand smoke PM2.5 concentrations was measured by a Dustrak aerosol monitor 8532 (TSI, St. Paul, MN, USA) in a closed chamber (1 m × 1 m × 1 m). The closed chamber was placed in a dust-free laboratory with a temperature of 20–24 °C and a relative humidity of 45–60% RH. After each measurement, the gas cylinder exhaust device reduces the PM2.5 of the closed chamber to the same level as the clean laboratory where the PM2.5 was kept at 10–15 μg/m³. The monitor was calibrated before each experimental session following calibration specifications for PM2.5 mass concentration measurement instruments proposed by the National Metrology Technical Specifications of the People’s Republic of China. The PM2.5 sensors were calibrated via comparisons with large standard instruments (PM2.5: Thermo 1405-F, BC: Aethalometer™, AE31) at an environmental monitoring station of the Shanghai Environmental Monitoring Center. This comparison was conducted for a consecutive 49-h period, using 5-min averages. The PM2.5 sensor has a relatively good linear relationship with the standard instrument (y = 0.32 x + 3.6, R² = 0.96), and the slope of the regression line was the calibration factor. Sidestream smoke was collected in the chamber through cigarette combustion. Mainstream smoke was collected with a piston-operated

| Table 1 | The material selected in the present study |
|---|---|
| **Size** | **Grade** | **Tar** | **Nicotine** |
| Regular | 1 | 10 mg | 0.9 mg |
| | 3 | 10 mg | 0.9 mg |
| | 5 | 10 mg | 0.9 mg |
| Slim | 1 | 8 mg | 0.8 mg |
| | 3 | 8 mg | 0.8 mg |
| | 5 | 8 mg | 0.8 mg |
smoking machine under the following conditions: puff volume of 40 mL, puff duration of 2 s, and interval between puffs of 10 s, and smoking was continued until an entire cigarette was smoked. According to this method, we could simulate the smoking of tobacco by a human (Czogala et al. 2013). Before data collection, we operated exhaust equipment to ventilate the PM2.5 of the chamber down to the dust-free laboratory air level (10–15 μg/m³).

Statistical analysis

The study utilized the two-way ANOVA statistical method to evaluate the presence of significant differences between size (R or S) and grade/price (1, 3, or 5) as independent variables and PM2.5 level as the dependent variable using SAS v8.0 (SAS, Cary, NC, USA). If the size × grade/price interaction effect is significant, we would then examine the simple effects of the independent variable (size) at each level of the other independent variable (grade/price) to determine the specific nature of the interaction. This involves comparing the estimated marginal means for the independent variable of interest (size) at each level of the other independent variable (grade/price) to determine if there are significant differences between groups.

Results

The two-factor ANOVA was performed to analyze the effect of the factors: “size” and “grade/price” on PM2.5 levels. The results showed that the main effect of “size” was significant (F = 528.594, p < 0.001), indicating that there was a significant difference in PM2.5 levels between R and S. The mean PM2.5 concentrations for R cigarette were obviously higher than that for S cigarette by 116% (Table 2). However, the study found that there was no significant impact of the grade/price of cigarettes on the PM2.5 concentrations of sidestream smoke in either group (Fig. 1). This was supported by the data analysis, which indicated that the main effect of grade/price was not significant (F = 0.206; p = 0.817). Additionally, the interaction effect between “size” and “grade/price” was also not significant (F = 0.364; p = 0.702), indicating that the effect of size on PM2.5 levels did not depend on the grade (Table 3).

Just like for sidestream smoke, cigarette size had an effect on the PM2.5 concentrations in mainstream smoke (Fig. 2). The analysis shows that size has a significant effect on the response variable, with an F-value of 87.243 and a p-value of 0.000. However, grade/price did not have a significant effect on the response variable, as indicated by an F-value of 2.054 and a p-value of 0.171. Additionally, the interaction between size and grade/price was significant with an F-value of 9.065 and a p-value of 0.04, suggesting that the

| Table 2 The effect of cigarette size and grade/price on PM2.5 concentration (μg/m³) |
| Second-smoke | Size | Grade |
| Side stream | Regular | 1828 ± 164 | 1793 ± 90 | 1830 ± 96 |
| | Slim | 809 ± 46 | 861 ± 33 | 854 ± 36 |
| Main stream | Regular | 23,000 ± 1540 | 21,400 ± 567 | 20,306 ± 892 |
| | Slim | 15,533 ± 924 | 14,746 ± 560 | 18,960 ± 1141 |

| Table 3 Multivariate analysis of variance of sidestream smoke PM2.5 |
| df | F | p |
| Size | 1 | 528.594 | 0.000** |
| Grade/price | 2 | 0.206 | 0.817 |
| Size*grade/price | 2 | 0.365 | 0.702 |

df: degree of freedom, F: F-statistic, p: p-value. **: p ≤ 0.01
The effect of size on the response variable varies across different levels of grade/price (Table 4). The lack of parallelism in the marginal mean value fold line across cigarette sizes in Fig. 3A suggested a significant interaction effect between grade/prize and cigarette size. Specifically, the simple effect of cigarette size varied across different grades, with a particularly notable difference in cigarette grade 5, where the interaction was significant, as shown in Fig. 3B. The PM2.5 concentrations of S1 and S3 were similar and lowest among all treatments. Interestingly, the PM2.5 concentrations of S5 were significantly higher than that of S1 and S3 and close to that of R5.

Discussion

According to the annual report, STMA/CNTC has experienced consistent growth in recent years, with a total revenue of ¥1155.6 billion ($168 billion) in 2018. (Administration SMT 2018). The success of this achievement was largely due to the support of millions of smokers, who commonly engage in smoking in public places in China. However, this habit has resulted in the spread of TSP, which has negative impacts on the health of non-smokers. The government and families bear the burden of the health risks associated with TSP exposure. According to a report, the total cost of healthcare due to TSP exposure in rural China accounted for 0.3% of the national healthcare expenditure in 2011 (Yao et al. 2015). Fortunately, cigarette carton sales decreased gradually from 260.98 billion in 2014 to 233.58 billion in 2018, according to the National Bureau of Statistics (National Bureau of Statistics of China 2014–2018).

The notable difference between the decline in cigarette sales and the increase in profit can be attributed to STMA/CNTC’s new sales strategy. In order to comply with government and societal regulations for tobacco control, STMA/CNTC reduced the production of low-grade/low-price cigarettes while slightly increasing the production of high-grade/high-price cigarettes. Several research institutions affiliated with or funded by STMA/CNTC have conducted studies indicating that high-grade/price cigarettes may be a safer option than low-grade/price cigarettes. The filters used in Chinese cigarettes are typically made from either cellulose acetate (CA) or polypropylene (PP). According to Wu et al. (2017), CA filters have a higher filtration efficiency than PP filters, with a difference of 6%. Lower-quality and less expensive cigarettes, as noted by Yu (2009), tend to use PP filters. High-quality tobacco leaves used in premium cigarettes exhibit superior combustion performance,

Table 4 Multivariate analysis of variance of mainstream smoke PM2.5

|                | df | F      | p    |
|----------------|----|--------|------|
| Size           | 1  | 87.243 | 0.000**|
| Grade/price    | 2  | 2.054  | 0.171 |
| Size*grade/price | 2 | 9.065  | 0.04* |

Df degree of freedom, F F-statistic, p p-value, **, p ≤ 0.01; *, p ≤ 0.05

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resulting in reduced tar and nicotine content and, subsequently, reduced toxicity. (Yu 2009). Furthermore, research has suggested that the use of high-burning cigarette paper and safer additives can further decrease the harmful effects of smoking. However, these advancements in technology come at a cost, driving up manufacturing expenses and ultimately, the price of the product (Liu et al. 2015; Case et al. 2003). This has given smokers the wrong lead, making them think that high-priced cigarettes are less harmful. Our findings indicate that the grade/price of a cigarette did not have any impact on the PM2.5 concentrations in sidestream or mainstream smoke. The conflicting results between our study and previous studies may be attributed to differing research objectives. While previous studies have focused on analyzing specific components of smoke, such as tar, nicotine, and tobacco-specific nitrosamines, our study specifically investigated PM2.5 concentrations. Tobacco smoke contains over 7000 constituents, making it difficult to measure toxicity by analyzing only a few substances with high toxicity (Hall et al. 2013). In contrast, PM2.5 contains almost all of the constituents found in tobacco smoke that is small enough to penetrate deep into the lungs and can cause respiratory and cardiovascular health problems. Therefore, monitoring PM2.5 levels can provide a useful indicator of second-hand smoke pollution and help inform public health policies and interventions aimed at reducing exposure to this harmful pollutant (Ott et al., 2022).

S cigarette is a relatively new type of cigarette and attracts smokers rapidly upon their introduction. Their carton sales increased from 2.9 million to 347 million within 5 years. One of the important reasons for this massive increase in sales was that STMA/CNTC and their research institute transmitted a simple message: S cigarette can decrease harm to health (Yan et al. 2018). In the Chinese cigarette market, the tar and nicotine content of S cigarette annotated on cartons is 6–8 and 0.6–0.8 mg, respectively, which is lower than that for R cigarette (Table 1). Ge and colleagues compared the components in mainstream smoke between S and R cigarettes and found that S cigarettes released less nicotine, tar, and carbon monoxide than R cigarettes (Ge et al. 2017). In the present study, although PM2.5 concentrations were significantly lower in S cigarette in sidestream smoke and mainstream smoke, it was not enough to suggest that S cigarette was safer than R cigarette. In addition to PM2.5, second-hand smoke can also affect other pollution particles such as PM10 and PM1.0. In recent research, the PM pollution (including PM10, PM2.5, and PM1.0) of slim-size tobacco products was substantial and sometimes higher than king-size tobacco products. Second-hand smoke of Couture Gold contained about 36% and Couture Purple about 28% more PM than the king-size cigarette (Braun et al. 2020). Similar research has also recently been made by Kant (2016), who conducted research demonstrating that super slim-size cigarettes emit more PM than king-size cigarettes. Additionally, PM1.0, which consists of small particles, is responsible for the majority of second-hand associated PM and may cause more harm due to its size. Moreover, it should be noted that experiment results merely represented one cigarette difference between the two types. But for one smoker, the objective of tobacco smoking is the satisfaction elicited by nicotine. If smokers changed from R cigarette to S cigarette, to maintain the desired intake of nicotine, they could change the way they smoked (e.g., deeply inhale each draw of the cigarette, increase the number of cigarettes smoked) (Stratton et al. 2001). Thus, their exposure to tobacco may be higher or at least equal to that of R cigarettes.

To our knowledge, this was the first study to investigate the effects of grades/prices and the size of cigarettes on the PM2.5 concentrations. We found no significant difference between lower and higher grades/prices of cigarettes. S cigarette produced lower concentrations of PM2.5 compared with that of R cigarette. However, this result does not demonstrate that S cigarette is safer than R cigarette because the harmfulness of smoking is determined not only by PM2.5 but also by other air pollution markers and inhalation habits by smokers. This was theoretical research undertaken using a closed chamber, and indoor studies are needed to verify our data.

Author contribution ShengZhe Ji collected the data, Zhen Liu drafted the manuscript, and Peng Liu designed the experiment.

Data availability The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethical approval and consent to participate Not required.

Consent for publication Not required.

Competing interests The authors declare no competing interests.

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