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Impacts of Chinese spring festival on household $PM_{2.5}$ pollution and blood pressure of rural residents

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Abstract

Background: Household air pollution (HAP) from residential combustion considerably affects human health in rural China. Large-scale population migration and rural lifestyle changes during the Spring Festival are supposed to change the household air pollution and health risks; however, limited field study has determined its impacts on HAP and short-term health outcomes.

Methods: A field study was conducted in rural areas of Southern China before and during the Spring Festival to explore the associations between HAP and blood pressure considering different factors such as cooking fuel, heating fuel, and smoking. Stationary real-time $PM_{2.5}$ monitors were used to measure $PM_{2.5}$ concentrations of the kitchen, living room, and yard of 156 randomly selected households. Personal exposure to $PM_{2.5}$ was calculated based on the results of stationary samplers and corresponding time local residents spent in different microenvironments, and one adult resident was recruited of each family for the blood pressure measurement.

Results: Both personal exposure to $PM_{2.5}$ and blood pressures of local residents increased during Spring Festival compared to the days before the holiday. Based on generalized linear model coupled with dominance analysis approach, it was found that personal $PM_{2.5}$ exposure was positively associated with the factors of population size and the types of cooking and heating fuels with the relative contributions of approximately 82%, and systolic blood pressure (SBP, 100–120 mmHg as normal range for adults) was positively and significantly associated with personal $PM_{2.5}$ exposures with the relative contribution of 11%.

Conclusion: The findings in this study demonstrated that Spring Festival can give rise to increase of HAP and hypertension risks, also related to tremendous solid fuel use, suggesting further policy making on promoting cleaner energy in rural areas and more attention on large population migration during national holidays.

KEYWORDS
blood pressure, Chinese Spring Festival, household air pollution, solid fuel combustion

1 | INTRODUCTION

Air pollution was recognized as one of the top risks to human health all around the world.[1] Household air pollution (HAP) associated with solid fuel burning for cooking and space heating raised concern in recent years due to its severe health outcome on human, especially in developing countries.[2–4] In China, a majority of rural residents still partly, if not all, relied on solid fuels for cooking and/or space heating,[5,6] and the low efficiency of stoves used in rural homes usually resulted in severe HAP and personal exposure.[7–10] A recent study estimated that about 650,000 premature deaths were caused by HAP in rural China due to solid fuel use with a contribution about 67% and that was 3.8 million globally.[11,12]

For urban areas, traffic and industry sources were dominant contributors to air pollution.[13] While for rural areas which are far from industry sources and have limited motor vehicles, indoor solid fuel burning and/or smoking contributed most to HAP.[14,15] Apart from only focusing on the concentrations of HAP, "Home-Chem" is becoming an issue in recent studies.[16,17] In indoor, chemical and physical transformations of air pollutants could occur under certain conditions. For example, a latest study found light-induced heterogeneous reactions of NO_2 with grime on glass window could produce HONO.[16] In addition, air pollutants might be more toxic after chemical transformations. For example, nitro-PAHs and oxy-PAHs usually have higher toxicity compared to their parent PAHs.[18,19] Considering the fact that the "Home-Chem." might result in a higher complexity and/or toxicity of HAP, the health impact of HAP was nonnegligible.

Numerous evidences had demonstrated that HAP was relevant to cardiovascular diseases.[20–23] It was well recognized that $PM_{2.5}$ exposure was associated with alterations in altered autonomic nervous system balance, vascular tone blood pressure, increased systemic oxidative stress and inflammation, and then triggering blood pressure increase.[24–26] Previous studies had reported that $PM_{2.5}$ exposure was correlated with blood pressure increase and could trigger hypertension in China.[22,27,28] Although the negative outcome of hypertension of $PM_{2.5}$ exposure on human health was widely known, the field studies in rural homes burning solid fuels for cooking and heating were still limited,[21,22] especially in developing countries such as China where most rural residents are still suffering from severe HAP.

As a unique culture in China and other Asian countries such as Korean, people worked in cities always travel back to rural hometowns for the traditional Spring Festival.[29,30] The air pollution in Chinese cities might decrease accordingly during the Spring Festival due to the reduction of factory production, construction, and the vehicle flow,[31,32] while in rural areas it could be very different. Young people travelled from cities to rural homes and they need to live together with the elders as a bigger family and spent most time in indoor environments during the special traditional holidays. According to previous studies, household air pollution from residential combustion in rural areas of developing countries is the dominant factor to disease burdens of local residents.[4,12,33] The household air pollution is expected to be severer during the unique and traditional Festival in China. Therefore, for the endpoint of health outcome, the household air pollution during Chinese Spring Festival could be representative. In general, the national holiday is within 10 days. Health outcomes from short-term exposure to $PM_{2.5}$ could be more appropriate in the relatively short study period. Many studies have demonstrated the cardiovascular diseases are attributable to $PM_{2.5}$ exposure.[20,34] Blood pressure is considered as a good biomarker of the risks of cardiovascular diseases, and also found to be linked with short-term $PM_{2.5}$ exposure.[35] Therefore, blood pressure is a good parameter for the short-term field study via portable medical instrument.

Practical Implications

The quantitative impacts of Chinese Spring Festival on household air pollution and short-term health outcomes were determined in this field study. More solid fuel consumption during the Festival predominantly contributed to the elevation of household air $PM_{2.5}$ pollution and higher hypertension risks. Lower household air pollution and blood pressure of those residents rely on cleaner energy, suggesting urgent intervention programs on energy transition in rural areas of China.

Here, a field study was conducted in rural Hunan Province which located in the Southern China before and during the Chinese Spring Festival. The concentrations of $PM_{2.5}$ in different microenvironments (including kitchen, living room, and outdoor) were measured. The blood pressures (including systolic blood pressure and diastolic blood pressure) for the local residents were also measured simultaneously. The main objectives of this study were to investigate (1) the differences of household air pollution and blood pressures before and within the Chinese Spring Festival; (2) the effects of various factors (including energy types, age of the residents etc.) on household air pollution and blood pressure; (3) the association between household air pollution and blood pressure. This field campaign can provide new insights into the impacts of the Chinese Spring Festival on HAP and associated short-term health outcomes in rural areas.

2 | METHODOLOGY

2.1 | Study site and household recruitment

The field study was conducted in three rural villages (Sanguan Qiao, Zhanxi, and Zhinan Zhou) of Taojiang county (28°13′-28°41′E, 111°36′-112°19′N), Hunan Province located in the Southern China during winter (January) in 2020. The local rural residents usually used biomass and/or clean fuels such as liquefied petroleum gas (LPG) for cooking. The typical cooking stove was traditional built-in place brick stoves equipped with an outdoor chimney. Because the ambient temperature usually ranged from −4°C to 5°C in winter, space heating in winter was very common in most homes especially in cold morning and evening although the need for space heating was not as strong as that in northern areas of China. Wood was commonly burnt in improvement wood stoves equipped with an outdoor chimney for heating in living rooms of most households and some rich households used charcoal burnt in fire pit or electricity for heating. The structure of most local households was usually with one kitchen, one living room and 2–3 bedrooms. The photos of typical cooking and heating stoves and fuels are provided in Figure S1.

2.2 | Household air pollution of $PM_{2.5}$

Local residents were recruited randomly in the three villages of the studied area. All the participants of this study received a detailed explanation of the measurements of household air pollution and blood pressures and questionnaire and signed the informed consents before the study. For household air pollution measurement, the optical real-time $PM_{2.5}$ monitors (Zefan Technol.) were used in this filed campaign, which were the same with our previous studies.[22,36] The $PM_{2.5}$ data were recorded with a 5-s interval for 24 h. Before the field campaign, all the $PM_{2.5}$ monitors were calibrated for at least 15 days against a particulate matter monitor (model 5030 synchronized hybrid ambient real-time particulate monitor; Thermo Scientific).

In the field, the $PM_{2.5}$ samplers were placed at the height of 1.5 m above the ground and 1.0 m away from stoves and walls. A total of 156 households were recruited in the present study. A questionnaire derived from a face-to-face interview recorded the fuel type for cooking and heating, the connection of kitchen and living room, the use of smoke ventilation, the population in the households and the daily window opening time (detailed seen Table 1.

2.3 | Blood pressure measurement

As mentioned above, 156 households were randomly selected for household $PM_{2.5}$ concentration measurements. One resident in each household was selected to measure the blood pressures depending on their willingness.[21,22] Only one adult chosen for blood pressure measurement was based on the following reasons: (1) for efficiency of statistical analysis, more households are better than more residents, because it could cover more participants with various influencing factors (eg, fuel type, stove type, population size etc.), (2) if multiple subjects are selected to measure blood pressure in one family, it will bring more trouble to each family and reduce the cooperation of villagers. Thus, 156 rural residents were enrolled for blood pressures measurement in total, of which 65 are males and 91 are females in the days before the Spring Festival (10 days before the Spring Festival). The detailed information such as age, BMI, education, smoking, and living pattern for the residents can be found in Table 1. The blood pressure (including systolic blood pressure (SBP, 100–120 mmHg as normal range for adults) and diastolic

TABLE 1 Descriptive statistics (including characteristic and samples size) of the participants and their corresponding households.

Factors/variables	Characteristic/ categories	Sample size (percentage, %)
BMI	<18	7 (4.5%)
	18–24	86 (55.1%)
	24–28	56 (35.9%)
	>28	7 (4.5%)
Age, yr	<20	1 (0.6%)
	20–30	9 (5.8%)
	30–40	3 (1.9%)
	40–50	15 (9.6%)
	50–60	52 (33.3%)
	60–70	33 (21.2%)
	70–80	27 (17.3%)
	80–90	14 (9.0%)
	>90	2 (1.2%)
Gender	Male	65 (41.7%)
	Female	91 (58.3%)
Education	None education	12 (7.7%)
	Elementary school	60 (38.4%)
	Junior high school	39 (25.0%)
	Senior high school	33 (21.2%)
	Bachelor	12 (7.7%)
Smoking activity	Active	40 (25.6%)
	Passive	52 (33.3%)
	No	64 (41.0%)
Cooking fuels	Lpg	96 (61.5%)
	Wood	55 (35.2%)
	Bamboo	3 (1.9%)
	Coal	2 (1.2%)
Heating fuels	Wood	103 (66.0%)
	Bamboo	13 (8.3%)
	Coal	7 (4.5%)
	Electricity	28 (17.9%)
	Charcoal	5 (3.2%)
Kitchen &living room connection	Yes	84 (53.8%)
	No	72 (46.2%)
Smoke ventilation	Yes	33 (21.2%)
	No	123 (78.8%)
Time in kitchen, h	<1	41 (26.3%)
	1–3	86 (55.1%)
	>3	29 (18.6%)
Time in outdoor, h	<1	37 (23.7%)
	1–3	42 (26.9%)
	>3	77 (49.4%)

(Continues)

TABLE 1 (Continued)

Factors/variables	Characteristic/ categories	Sample size (percentage, %)
Windows open, h	<1	20 (12.8%)
	1–3	12 (7.7%)
	>3	124 (79.5%)
Population	<2	6 (3.8%)
	2–3	86 (55.1%)
	4–5	26 (16.7%)
	6–7	28 (17.9%)
	>7	5 (3.2%)

blood pressure (DBP, 60–90 mmHg as normal range for adults)) were measured using an automated oscillometric monitor (HEM-759-E; Omron Healthcare Co., Ltd.). The measurements were taken after the meals for more than 1-h and 10 min rest. All the measurements were on right arms following the standard method[37] and 3 repeats were taken within 10 min and the average value was used for further analysis.

2.4 | Revisit during Chinese Spring Festival

Usually, during the traditional spring festival, many Chinese would travel back to their rural hometowns and ready for the festival. Considering larger family population were usually associated with larger fuel consumption for cooking and heating, difference in HAP and blood pressure were expected compared to the days before the Spring Festival. Thus, 42 participants were revisited at the first day of the Chinese Spring Festival to measure their blood pressure and the HAP at the same time, and the information of living pattern, family population etc. was updated during the revisit.

2.5 | Data analysis

Personal $PM_{2.5}$ exposure was calculated based on the results of stationary samplers and corresponding time local residents spent in different environments (kitchen, living room and outdoor). This method was usually used in previous studies,[22,38] when no personal carried samplers were available. The estimation was adopted using the following equation:

$$\text{Exposure} = \sum_{i=1}^{i=n} Ci \times Ti/1440$$

Where, Ci is the $PM_{2.5}$ concentration in microenvironment i (kitchen, living room, and outdoor) and Ti was the corresponding time (minutes) the residents spent in microenvironment i. The $PM_{2.5}$ concentrations used in the calculation were the daily average concentrations measured by the real-time $PM_{2.5}$ monitors in kitchen, living room, and outdoor. It should be noted that the $PM_{2.5}$ concentrations in bedroom was not measured in this study, the time spent in bedroom was combined with the time spent in living room in the calculation.

The generalized linear model was used for the regression of $PM_{2.5}$ exposure and BP (Blood Pressure) from the various influencing factors. The formations of the regression models were listed below:

$$\begin{gathered} PM_{2.5}\text{exposure} \sim \text{population size} + \text{cooking fuel} + \text{heating fuel} \\ + \text{smoke ventilation} + \text{connection} + \text{window opening;} \end{gathered}$$

$$\text{BP} \sim PM_{2.5}\,\text{exposure} + \text{smoking} + \text{gender} + \text{BMI} + \text{age} + \text{education.}$$

Where, the population size ranged from 1 to 12; cooking fuel included LPG, wood, bamboo, and coal; heating fuel included wood, bamboo, coal, electricity, and charcoal; smoke ventilation represented the ventilation condition in the kitchen (yes or no); connection represented the connection of kitchen and living rooms (yes or no); window opening represented the window opening hour for each households; smoking included non-smoking, passive smoking, and active smoking; BMI was the ratio of body weight to height; age ranged from 19 to 95; education background included no education, elementary school, junior high school, senior high school, and bachelor.

The dominance analysis (Dominance Analysis package considering McFadden Index (r2.m)) was employed to reveal the average contributions of different influencing factors/independent variables to the variance of the dependent variables ($PM_{2.5}$ exposure and BP) following the GLM. The GLM and dominance analysis were all conducted in the R Studio (R v3.4.0, R Foundation for Statistical Computing). Kolmogorov-Smirnov Z statistical test was used for comparing two independent samples, One-way ANOVA was used for the various independent samples, Pearson test was employed for the linear correlation between two variables. SPSS 21.0 (IBM Corporation) was also used for the statistical analysis. The statistical significance (*P* value) was set at the level of 0.05.

3 | RESULTS

The daily average $PM_{2.5}$ concentrations in kitchen, living room and outdoor of the measured households were 149 ± 84 $\mu g/m^3$ (range: 29–467), 122 ± 62 $\mu g/m^3$ (35–481), and 93 ± 14 (45–120) $\mu g/m^3$, respectively. $PM_{2.5}$ in kitchens were found significantly higher than living room and outdoor, mainly due to the internal combustion emissions of solid fuels ($p < 0.05$). The national ambient $PM_{2.5}$ standard is 75 $\mu g/m^3$[39] in China, 90%, 89%, and 86% of $PM_{2.5}$ concentrations exceeded this standard for kitchen, living room, and outdoor air, respectively. The average $PM_{2.5}$ concentrations in kitchen, living room, and outdoor air were 2.0, 1.6, and 1.2 times of that standards, respectively. Apparently, the situation would be more severe when compared with the standard set by WHO, which is 25 $\mu g/m^3$.[40] Figure 1 shows the household $PM_{2.5}$ concentrations of all homes and homes before and during the Chinese Spring Festival. The $PM_{2.5}$

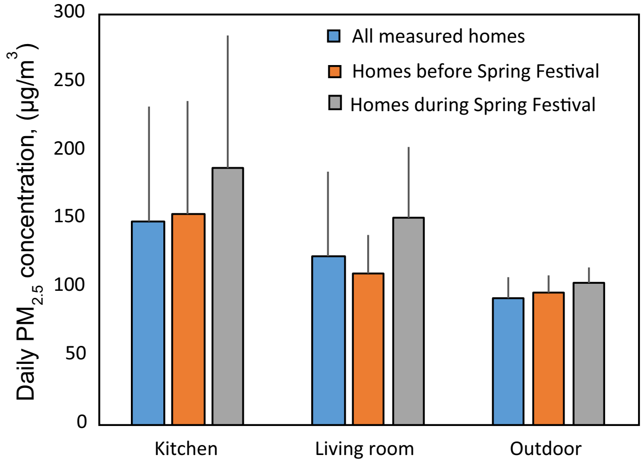

FIGURE 1 The average daily household $PM_{2.5}$ concentrations in all measured homes, homes before the Chinese Spring Festival, and homes during the Chinese Spring Festival, data shown were mean and standard deviation.

concentrations during the Chinese Spring Festival were 188 ± 97 $\mu g/m^3$, 150 ± 52 $\mu g/m^3$, and 103 ± 12 $\mu g/m^3$ for kitchen, living room and outdoor respectively, which were significantly higher than that before the Chinese Spring Festival ($p < 0.05$). Besides, based on the stationary concentrations and time the local residents spent in different microenvironments, the average daily personal $PM_{2.5}$ exposure was calculated to be 120 ± 49 $\mu g/m^3$ with a range from 45 $\mu g/m^3$ to 406 $\mu g/m^3$. The personal $PM_{2.5}$ exposures of local residents before and during the Chinese Spring Festival were 112 ± 48 $\mu g/m^3$ and 145 ± 42 $\mu g/m^3$, respectively and the difference was expectedly significant ($p < 0.05$) Figure 2A. It all suggested that the Chinese Spring Festival significantly increase the HAP and personal exposure in rural areas of China.

The SBP and DBP for females were 130 ± 18 mmHg (95% CI, 126 to 133 mmHg) and 77 ± 11 mmHg (95% CI, 75 to 80 mmHg), while 135 ± 20 mmHg (95% CI, 130 to 140 mmHg) and 82 ± 12 mmHg (95% CI, 79 to 85 mmHg) for males, respectively. The SBP was found positively correlated with $PM_{2.5}$ exposure ($p < 0.05$), while not for the DBP ($p > 0.05$). There was no significant difference found before and during the Chinese Spring Festival for the SBP and DBP ($p > 0.05$).

The SBP and DBP of revisited residents before the Chinese Spring Festival were 131 ± 18 mmHg (95% CI, 128 to 134 mmHg) and 79 ± 12 mmHg (95% CI, 77 to 81 mmHg) and during the Chinese Spring Festival were 135 ± 22 mmHg (95% CI, 128 to 142 mmHg) and 79 ± 11 mmHg (95% CI, 76 to 83 mmHg). Though the SBP during the Chinese Spring Festival was slightly higher than that before the Chinese Spring Festival, there was no significant difference found for the SBP and DBP before and during the Chinese Spring Festival (both $p > 0.05$) Figure 2B,C.

4 | DISCUSSION

4.1 | Impacts of various factors on personal $PM_{2.5}$ exposure

Figure 3 shows the personal $PM_{2.5}$ exposure levels under the different levels of various influencing factors, which depicts that the exposure levels significantly differed among different levels of population size and cooking fuel and heating fuel types (all these $p < 0.05$). Previous studies also found that fuel type contributed significantly to personal exposure.[9,41] With the increase of population size of the rural households, the $PM_{2.5}$ exposure concentration significantly increased ($p < 0.05$). It is easy to understand this result since when more people stay at home, more solid fuels would be consumed and emit more air pollutants.[42]

Numbers of previous studies have already found the impacts of fuel types (including heating fuel and cooking fuel) on personal airborne pollutant exposure levels in rural areas of China.[9,43,44] Rural residents using LPG for cooking had the lowest $PM_{2.5}$ exposure (115 ± 39 $\mu g/m^3$), followed by residents using wood (120 ± 40 $\mu g/m^3$), bamboo (124 ± 38 $\mu g/m^3$) and coals (371 ± 50 $\mu g/m^3$), suggesting that the clean fuel such as LPG would emit less pollutants compared with solid fuels,[45,46] and result in better household air quality and lower inhalation exposure.[2,9,45,47] In comparison of heating fuels, residents using wood and charcoal suffered highest exposure concentrations (131 ± 55 $\mu g/m^3$ and 130 ± 38 $\mu g/m^3$, respectively) and those using electricity had the lowest exposure level (103 ± 24 $\mu g/m^3$) ($p < 0.05$). The results here suggested that using clean fuels, such

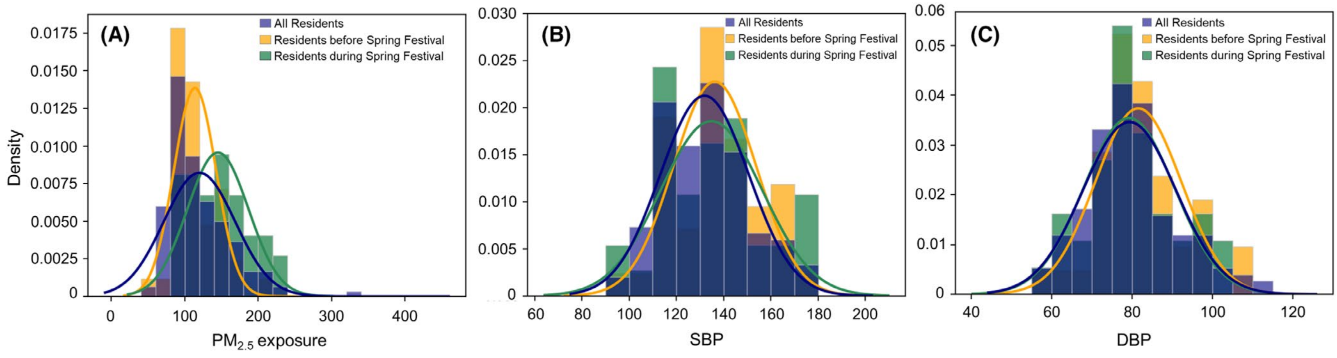

FIGURE 2 The histograms of $PM_{2.5}$ exposure concentrations (A), SBP (B), and DBP (C) of all residents, residents before the Chinese Spring Festival, and residents during the Chinese Spring Festival.

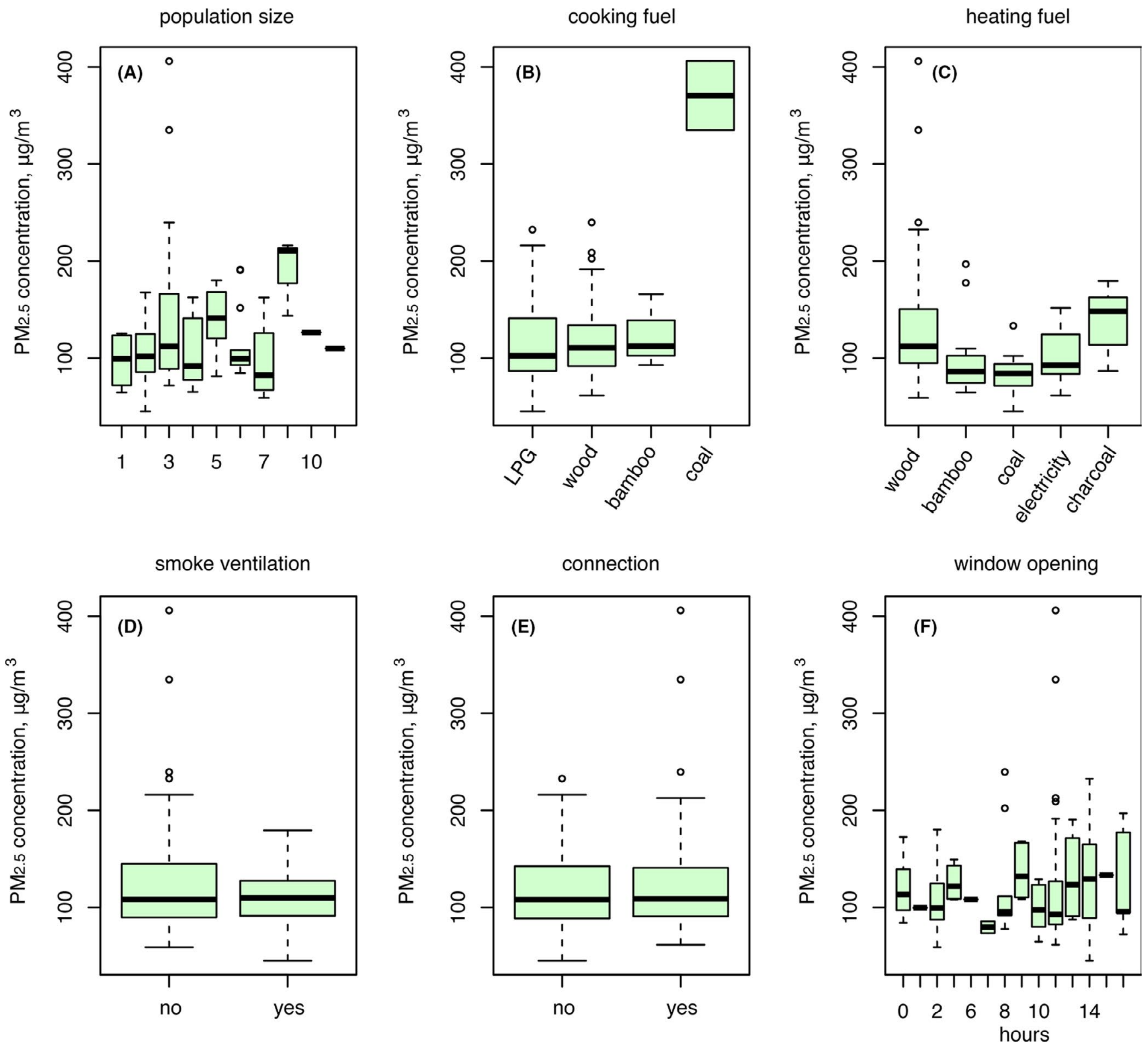

FIGURE 3 The personal exposure to $PM_{2.5}$ (μg/m^3) under the effects of various influencing factors. The influencing factors include population size, cooking fuel (LPG, wood, bamboo, and coal), heating fuel (wood, bamboo, coal, electricity, and charcoal), smoke ventilation (no & yes), connection of kitchen and living room (no & yes), and window opening time (hours).

as LPG and electricity, for heating and cooking activities can reduce the $PM_{2.5}$ exposures for the rural residents.[9,48] For the other influencing factors including smoke ventilation, connection of kitchen and living room, and window opening time, there is no significant difference found among different levels/categories (all these $p > 0.05$).

Furthermore, the GLM was employed to explore the partial effects of various influencing factors on personal $PM_{2.5}$ exposures and their relative contributions Figure 4 and Table S1. Population size, cooking fuel, and heating fuel were significantly associated with the $PM_{2.5}$ exposures ($p < 0.05$) after the adjustment of the other influencing factors. It was also found that the influencing factors of smoke ventilation, connection of kitchen and living room, and opening window hour had no significant partial effect on personal exposure ($p > 0.05$). Previous study also found the ventilation condition and independent kitchen or not did not have significant influence on personal exposure to PMs.[49] In comparison, population size had the largest contribution (55%), followed by cooking and heating fuels (27%) and window opening time (18%), and the influencing factors of smoke ventilation and connection of kitchen and living room shared the smallest contributions with less than 1%. Since there were not many motor vehicles in the rural areas of the study areas, and many industrial productions in the near cities were also stopped during the Spring Festival, the ambient air pollution and household air pollution in this area were mainly derived from solid fuel combustion emissions.[15] It is reasonable to conclude that the combustion of solid fuels is the key factor on the personal $PM_{2.5}$ exposure for

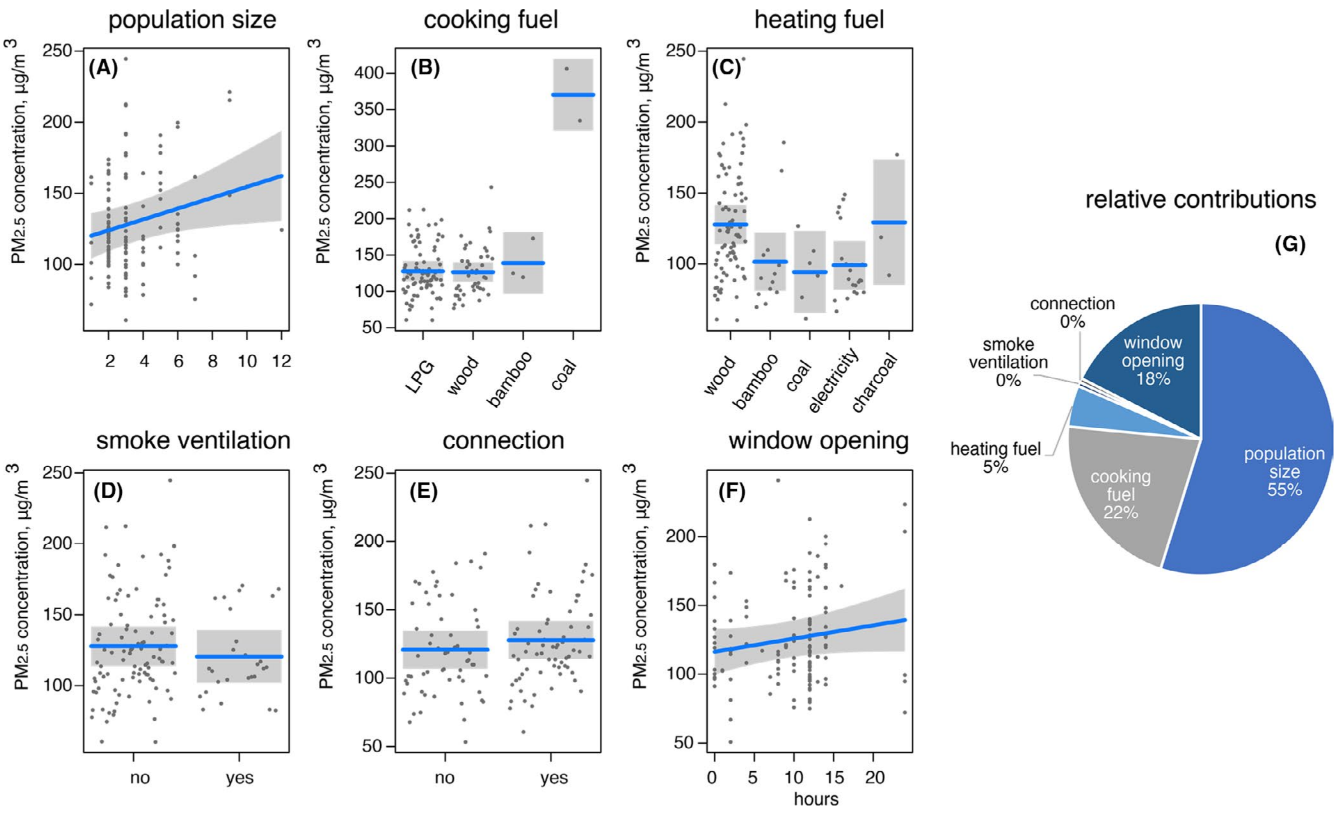

FIGURE 4 The partial effects of different influencing factors on personal exposure to $PM_{2.5}$ (A–F) and their relative contributions to the total variances (G) based on the generalized linear model coupled with the dominance analysis. The influencing factor included population size, cooking and heating fuels, smoke ventilation, connection of kitchen and living room, and window opening time. The partial effects were estimated from the "linear" scale.

the rural residents, considering that solid fuel consumption is always correlated with population size.

4.2 | Impacts of various factors on blood pressures

For the continuous variables (including $PM_{2.5}$ exposure, BMI, and age), $PM_{2.5}$ exposure was found significantly and positively correlated with SBP ($p < 0.05$) Figure 5A but was not significantly correlated with DBP Figure S2A), which is consistent with previous studies.[22,50] A previous study also found only SBP of pregnant women increased after exposure to incense burning,[51] and another study found only SBP of cooking women decreased significantly after an improved cookstove intervention,[52] all suggesting SBP was a better bio-indicator for the air pollutant exposure. Besides, both SBP and DBP were significantly and positively correlated with age ($p < 0.05$) and BMI has better correlation relationship with SBP ($p < 0.05$) other than DBP ($p > 0.05$) Figure 5D,E and Figure S2D,E).

For the categorical variables, different levels of smoking, gender, and education have non-significant difference on both SBP and DBP (all $p > 0.05$) Figure 5B,C,F and Figure S2B,C,F). Though the active smokers was found to have the highest SBP (136 ± 20 mmHg) and DBP (82 ± 11 mmHg), followed by the passive smokers (SBP: 131 ± 19 mmHg,DBP: 78 ± 11 mmHg) and non-smoker (SBP: 130 ± 18 mmHg,DBP: 79 ± 12 mmHg), the levels were not significantly different ($p > 0.05$) due to the large variation of the SBP and DBP for the individual residents under various influencing factors and the severe HAP from the solid fuel combustion in rural areas.

Therefore, the partial effects of various influencing factors and their relative contributions to the total variance of blood pressures were explored based on the GLM coupled with dominance analysis Figure 6, Figure S3, Table S2, and Table S3. It was found that the age of the rural residents was positively and significantly associated with SBP and DBP (all $p < 0.05$) and the BMI was only positively and significantly associated with SBP ($p < 0.05$). Consistent with the correlation analysis results, DBP was not significantly associated with $PM_{2.5}$ exposure concentration ($p > 0.05$), suggesting DBP is not sensitive to the short-term exposure of $PM_{2.5}$, which was also found in many previous studies.[22,26,48] In contrast, SBP was significantly and positively associated with $PM_{2.5}$ exposure concentrations ($p < 0.05$). With per-10 μg/m^3 increase of $PM_{2.5}$ exposure concentration, the SBP will increase by 0.67 mmHg (95% confident intervals (CI): 0.11-1.22 mmHg). The positive association between $PM_{2.5}$ exposure and SBP in this study was also accordance with epidemiological studies in rural China. For example, a field study conducted for the rural residents living in cave dwellings in Northern China found that with per-10 μg/m^3 increase of $PM_{2.5}$ exposure concentration,

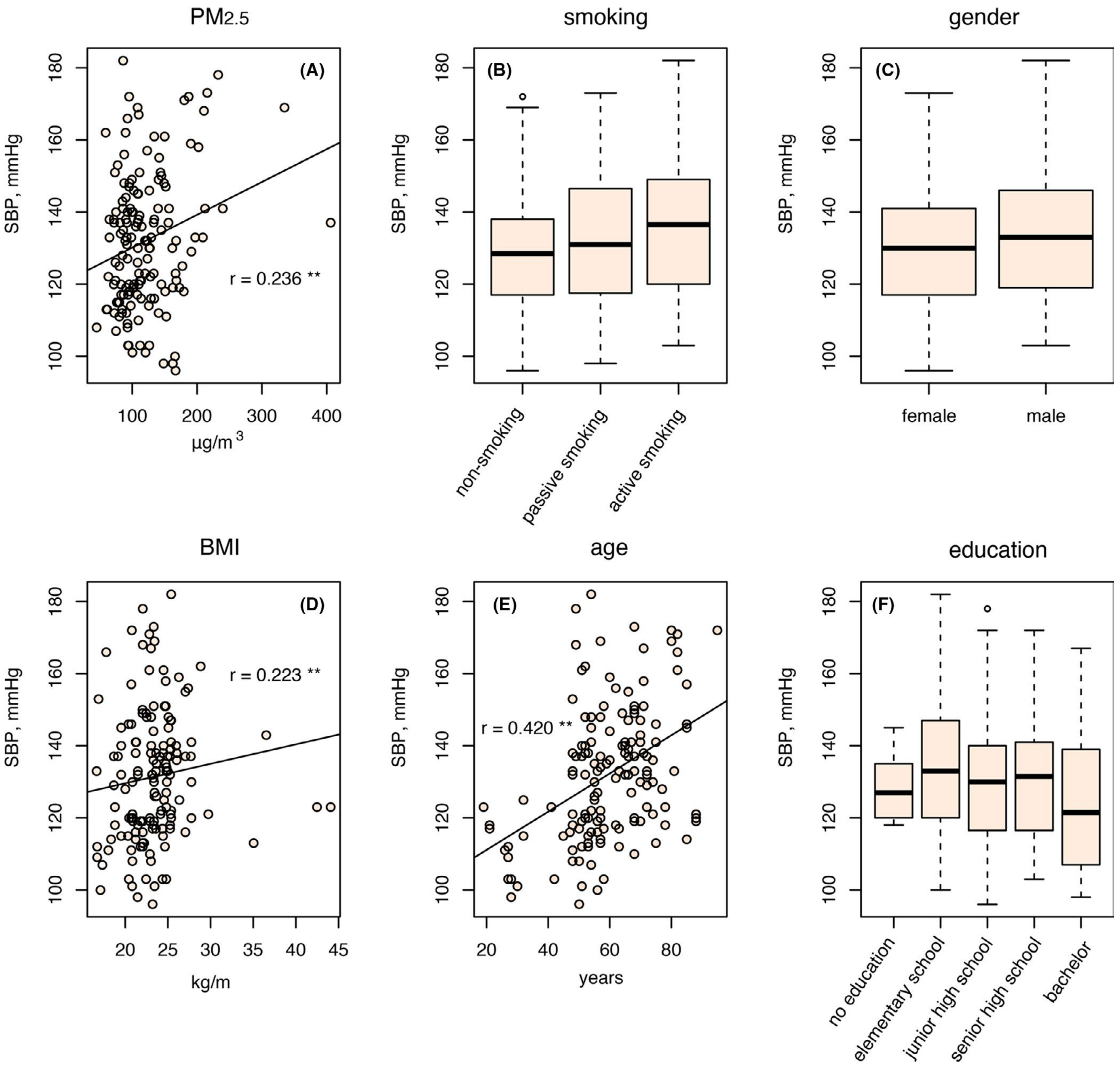

FIGURE 5 The systolic blood pressure (SBP, mmHg) under the effects of various influencing factors (A–F). The influencing factors include $PM_{2.5}$ exposure (μg/m^3) (A), smoking (non-smoking, passive smoking, and active smoking) (B), gender (female & male) (C), BMI (kg/m) (D), age (E), and education (no education, elementary school, junior high school, senior high school, bachelor) (F). The correlation coefficient (*r*) is also provided for the correlation between SBP and $PM_{2.5}$ concentration, SBP and BMI, and SBP and age. * represents the statistically significant level ($p < 0.05$). ** represents the statistical extreme significant level ($p < 0.01$).

the SBP would correspondingly increase by 0.36 mmHg (95% CI: 0.05-0.77 mmHg).[22]

For the comparison of the relative contributions of different influencing factors, BMI was the dominant factor for the variances of SBP and DBP with contribution of 36% and 55%, respectively, and age had the second large contributions of 39% and 17% respectively. Higher relative contribution was found for $PM_{2.5}$ exposure concentration to SBP (11%) than to DBP (4%). Besides, gender (4%), education (6%), and smoking (4%) were the minor influencing factors on the variance of SBP, suggesting that HAP from solid fuel combustion should not be neglected when evaluating the hypertension risk of rural residents.

4.3 | Impacts of Chinese Spring Festival on household air pollution and blood pressure

The daily average $PM_{2.5}$ concentrations in kitchen, living room, and outdoor increased 21.9%, 36.4%, and 6.4% during the Chinese Spring Festival compared to that before the Chinese Spring Festival,

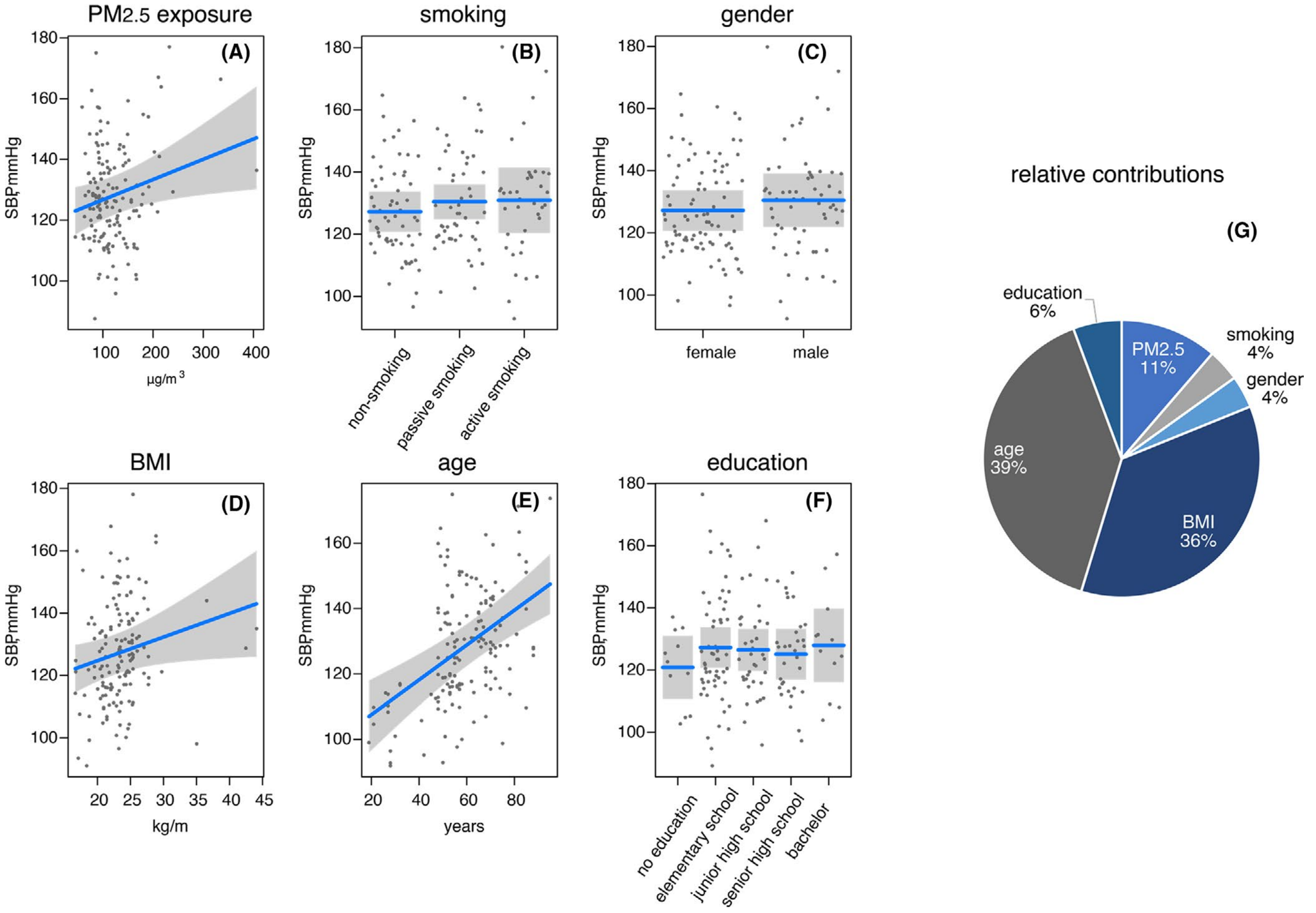

FIGURE 6 The partial effects of different influencing factors on the systolic blood pressure (SBP, mmHg) (A-F) and their relative contributions to the total variances (G) based on the generalized linear model coupled with the dominance analysis. The influencing factor included $PM_{2.5}$ exposure concentration (μg/m^3), smoking (non-smoking, passive smoking, and active smoking), gender, BMI, age, and education (no education, elementary school, junior high school, senior high school, and bachelor). The partial effects were estimated from the "linear" scale.

and the difference was significant (all $p < 0.05$). In this study, the average number of people stayed home during the Chinese Spring Festival was 5.9, significantly higher than that before the Chinese Spring Festival (3.4). Thus, more solid fuels were expected to be consumed during the Chinese Spring Festival due to more people stayed home. Considering solid fuels were commonly used in the sampling homes, more pollutants would be emitted from solid fuel combustion associated with larger fuel consumption. The personal $PM_{2.5}$ exposures increased 27.5% during the Chinese Spring Festival compared to the days before the Chinese Spring Festival. Though the Chinese Spring Festival mitigated the ambient air pollution in cities,[32] the national Festival increased the HAP in rural areas, because people spent more time in indoor environments and consumed more solid fuels for cooking and heating during the Spring Festival. The time residents spent in indoor (kitchen, bedroom, and living room) was 20 and 21 h before and during the Chinese Spring Festival. And, as mentioned above, the kitchen and living room $PM_{2.5}$ concentrations also increased 34 μg/m^3 and 40 μg/m^3, respectively. These two reasons resulted in the increase of $PM_{2.5}$ exposures. Till now, no available study based on field measurement on the health impact associated with HAP caused by the Chinese Spring Festival except for this study. The $PM_{2.5}$ exposure increase during the Chinese Spring Festival indicated the importance of HAP in China, especially in rural areas solid fuels were commonly used for heating and cooking.

Though the blood pressure was found to be positively associated with $PM_{2.5}$ exposure concentration and the $PM_{2.5}$ exposure concentration increased during the Chinese Spring Festival, no significant difference was found for both SBP and DBP during the Chinese Spring Festival ($p > 0.05$) due to the large variation among different households and the short-term study. However, this results from the GLM (the significant association between blood pressure and personal $PM_{2.5}$ exposures) still suggested that the Chinese Spring Festival is expected to increase the HAP and hypertension risks. In addition, the rural residents who had the higher level of SBP suffered from a significant increase of SBP during the Chinese Spring Festival, indicating that the people with higher blood pressure were more sensitive to the increase of HAP from the Spring Festival Figure 2B.

4.4 | Implication and limitation

During the unique and traditional Festival in China, large number of people return to their hometowns which were mostly in rural China. It is expected to induce severe household air pollution in rural areas. Numbers of publications focused on the impact of Spring Festival on ambient air pollution in cities, which reported a reduction of air pollutant emissions and better air quality.[32,53] However, few studies focused on HAP, especially in rural areas during the annual festival days. Based on the field study in rural areas, it was demonstrated that the Spring Festival led to larger population size in households and more $PM_{2.5}$ emissions from solid fuel use, eventually increased the hypertension risk of the rural residents. In addition, more attention should be paid to those people with higher blood pressure who are more sensitive to the increase of personal $PM_{2.5}$ exposure during the Spring Festival. These results provide new insights to the effects of Spring Festival on human beings living in rural areas of China which are quite different for the people living in urban areas.

There are several limitations should be addressed in this study. Although 156 households were recruited in the present study, the sample size in some subgroups might be relatively small limited to high cost in the field study, which may affect the statistical analysis power due to various influencing factors. In addition, when comparing the difference of HAP and BP between before and within the Spring Festival, the confounding effects of population change could not be excluded, because none of the households has the same population size during the two periods.

It was accepted higher $PM_{2.5}$ exposure would affect human health, although the long-term effect of $PM_{2.5}$ exposure increase is hard to investigate, some short-term effect such as asthma, acute lower respiratory infection etc. may be caused by the increase of $PM_{2.5}$ exposure in a relative short time such as Chinese Spring Festival.[54,55] Given this, more studies are welcomed to investigate the acute health impact associated with air pollution caused by Chinese Spring Festival in rural area of China in the near future.

4.5 | Conclusion

The quantitative impacts of Chinese Spring Festival on household air pollution and short-term health outcomes were determined in this field study. The $PM_{2.5}$ concentrations in kitchen, living room, and outdoor air within Spring Festival were significantly higher than days before the annual festival days, mainly caused by more internal emissions in these households. In addition, the personal exposure to $PM_{2.5}$ exposures of local residents during the Spring Festival were 145 ± 42 $\mu g/m^3$, significantly higher than that before the annual festival days (112 ± 48 $\mu g/m^3$). It was demonstrated that population size and type of cooking and heating fuel contributed more than 80% to the variance of $PM_{2.5}$ exposure, indicating the Spring Festival might result in higher personal exposure to $PM_{2.5}$. The Spring Festival gave a slight rise to SBP, although the difference was not significant. SBP was positively associated with $PM_{2.5}$ exposures which contributing 11% to the total variance of SBP. However, lower household air pollution and blood pressure of those residents rely on cleaner energy suggesting urgent intervention programs on energy transition in rural areas of China.

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AUTHOR CONTRIBUTION

Wei Du, Gehui Wang, and Yuanchen Chen conceptualized the study, involved in project administration, provided resources, and involved in funding acquisition. Wei Du and Yuanchen Chen analyzed the study and wrote the manuscript. Wei Du, Jinze Wang, Shanshan Zhang, and Nan Fu investigated the study. Fengqin Yang, Qi Meng, Zhenglu Wang, Kang Mao, Shijie Liu, Can Wu, and Guofeng Shen reviewed and edited the manuscript.

PEER REVIEW

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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