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Indoor PM2.5 Concentration Emitted during and after Cooking with an Air Fryer under Different Ventilated Conditions

Nalin Chitapanarux[1] and Patumrat Sripan[2]*

[1]Montfort College, Chiang Mai, Thailand

[2]Research Institute for Health Sciences, Chiang Mai University, Chiang Mai, Thailand

Abstract

Cooking is one of the primary sources of indoor PM2.5 pollution. Nowadays, cooking with an air fryer has become increasingly popular in many households. This study investigated and compared the efficiency of range hoods and air purifiers in reducing PM2.5 emitted during air frying in residential settings. The experiments were performed in a test kitchen under controlled conditions. Three scenarios with different air ventilation methods were examined; Scenario 1: control setting without ventilation, Scenario 2: with a standard range hood system, and Scenario 3: with an air purifier system. Each scenario was repeated three times. Continuous measurements of PM2.5 were carried out at 5 minutes intervals for 70 minutes by an air quality monitor. The average concentrations of PM2.5 were plotted to describe the dynamic change over time during and after cooking and compared among the three different scenarios. The results indicate that cooking with an air fryer emits large amounts of PM2.5. Without air ventilation, the maximum PM2.5 concentration can reach up to 147 μg m^{-3}. However, with a range hood or an air purifier, the maximum average concentrations were only 18 and 37 μg m^{-3}, respectively. It can be concluded that both ventilation systems can reduce PM2.5 generated from air frying, but the range hood system has higher PM2.5 removal efficiency than the air purifier system.

Keywords: PM2.5; Air fryer; Range hood; Air purifier

Introduction

Exposure to elevated concentrations of particulate matter measuring 2.5 μm or less in diameter (PM2.5) has been highly associated with increased morbidity and mortality through cardiovascular and pulmonary diseases [1-6]. Since people spend most of their time in enclosed buildings, understanding indoor air pollution could be as important as learning about outdoor pollutants. Cooking-generated particles had the greatest effect on indoor particle concentration [7] and are a major source of PM2.5 as it is usually done several times daily. Although existing studies have primarily focused on fine particles generated from typical cooking on stovetops, research on the amount of PM2.5 emitted during air frying has yet to be conducted. Recently, air fryers have had a recent surge in popularity due to the population's growing health awareness and continuing demand for fried food. To produce healthier fried food, an air fryer works by circulating hot air around a food item to create the same crispiness as traditional fried food but with lower fat content. During the air frying process, PM2.5 is generated in the air fryer and later diffuses out of the machine. Therefore, the health of the occupants is at risk if these particles are not removed properly.

In modern dwellings, mechanical ventilation systems such as range hoods and air purifiers have been preferred to remove indoor air pollutants. A range hood exhausts cooking fumes using electric fans to suck hot gases, smoke particles, and PM2.5. On the other hand, an ionizer air purifier uses charged electrical surfaces or needles to generate electrically charged gas ions. These ions attach to airborne particles, which are then electrostatically attracted to a charged collector plate. Other studies have demonstrated the effects of range hood usage on reducing cooking fumes [8-12]. However, not much about the efficiency of air purifiers has been explored. Without knowing whether a range hood or an air purifier is more efficient in reducing indoor PM2.5, ensuring that kitchens have adequate ventilation during air frying can be hard to achieve.

The objective of this study is to systematically investigate and compare the efficiency of range hoods and air purifiers in reducing PM2.5 emitted during air frying in residential settings. To achieve this, PM2.5 concentrations produced through air frying were measured with an air quality monitor to provide guidance on choosing the appropriate ventilation method when cooking with an air fryer.

Methods

The experiments were performed in a test kitchen with dimensions of 3.70 × 1.75 × 2.70 m under controlled conditions. For relative comparison during the measurement process, three scenarios with different air ventilation methods were investigated:

Scenario 1: control setting without ventilation;

Scenario 2: with a standard range hood system operated and placed in the center of the kitchen, 0.5 m away from the air fryer;

Scenario 3: with an air purifier system operated and placed in the center of the kitchen, 0.5 m away from the air fryer;

In scenarios 2 and 3, the air ventilation systems were turned on to the highest setting at the start and turned off at the end of the operation. Each scenario was repeated three times to ensure the accuracy and the reliability of the data. To minimize the effects of air infiltration during the measurement process, the room was sealed.

French fries were chosen as the model dish because this recipe is

***Corresponding author:** Patumrat Sripan, Research Institute for Health Sciences, Chiang Mai University, Chiang Mai, Thailand, E-mail: patumrat.sripan@cmu.ac.th

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popular worldwide and is known to be extensively cooked with an air fryer. Before the start of the operation, 400 g of frozen French fries were placed inside an air fryer (HD9621/91, PHILLIPS, Amsterdam, The Netherlands) with dimensions of 36.5 × 26.6 × 29.2 cm (5.3 kg). Subsequently, the air fryer was then turned on at 180°C to start the cooking process. After 15 min, the cooking session ended, the air fryer was then turned off, and the French fries were removed from the device and transported out of the room. After this, the operation continued for another 55 min. Indoor PM2.5 concentration inside the room were continuously measured and monitored throughout the operation using an air quality monitor (M10, Temtop, London, United Kingdom) equipped with a laser PM sensor. The monitor has a PM2.5 measuring range of 0-999 μg m^{-3} and a PM2.5 resolution of 1 μg m^{-3}. Figure 1 show continuous measurements of PM2.5 carried out at 5 min intervals for 70 min (Figure 1).

Characteristics of the Range Hood

In scenario 2, one standard range hood (2950X60, MEX, Italy) with dimensions of 59.8 × 50.0 × 14.0 cm (7.2 kg), was installed and operated in the test kitchen. A range hood exhausts cooking fumes by using electric fans to suck hot gases, smoke particles, and PM2.5 inside. According to the manufacturer, the range hood has a suction power of 380 m^3 cm^{-1}. During the operations, we operated the device at the highest airflow speed.

Characteristics of the Air Purifier

In scenario 3, one portable air purifying device (AC-M4-AA, Mi, Beijing, China) with dimensions of 24 × 24 × 52 cm (4.5 kg) was installed and operated in the test kitchen. This ionizer air purifier uses charged electrical surfaces to generate electrically charged gas ions. These ions then attach to airborne particles, which are then electrostatically attracted to a charged collector plate. The device has a cleaning capacity of 310 m^3 of air per hour, and the functional area is 21-37 m^2. During the operations, we operated the device at the highest airflow speed.

Statistical Analysis

A descriptive statistic was used to describe the primary outcomes. The average concentrations of the PM2.5 with the standard deviation (SD) at each time point for different scenarios were computed and plotted to explore the dynamic change over 70 min during and after cooking with the air fryer.

Results and discussion

In this study, we followed the 2005 global updated air quality guideline limits for PM2.5 recommended by the World Health Organization (WHO), which is the 24-hour mean threshold of 25 μg m^{-3} [13]. Currently, there are only guidelines for outdoor PM2.5. However, the steering group assisting WHO in designing the indoor air quality guidelines concluded that there is no convincing evidence of a difference in the hazardous nature of particulate matter from indoor sources compared to those from outdoors. Therefore, the updated outdoor air quality guidelines also apply to indoor spaces (Figure 2) (Table 1).

Due to the lack of research on the amount of PM2.5 emitted during air frying, reports on PM2.5 generated from different stovetop cooking methods were reviewed and compared instead. Figure 2 shows the average PM2.5 concentration measured in three scenarios over time. In scenario 1, which was the control setting without air ventilation, PM2.5 was generated right after the start of air frying. The amount of PM2.5 increased rapidly during cooking and even after the end of the air frying period. As demonstrated in Table 1, the greatest concentration of 147 μg m^{-3} was observed at 25 min. Kim et al. [14] found that the fine particles spread quickly after only 6 min of grilling fish and that the maximum concentration of fine particles was the largest, from 16 min immediately after the end of cooking to 2 min after the end of cooking. These observations are in agreement with the measured concentrations in scenario 1.

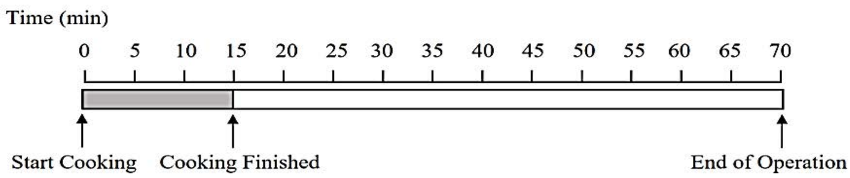

Figure 1: Measurement schedule of cooking conditions.

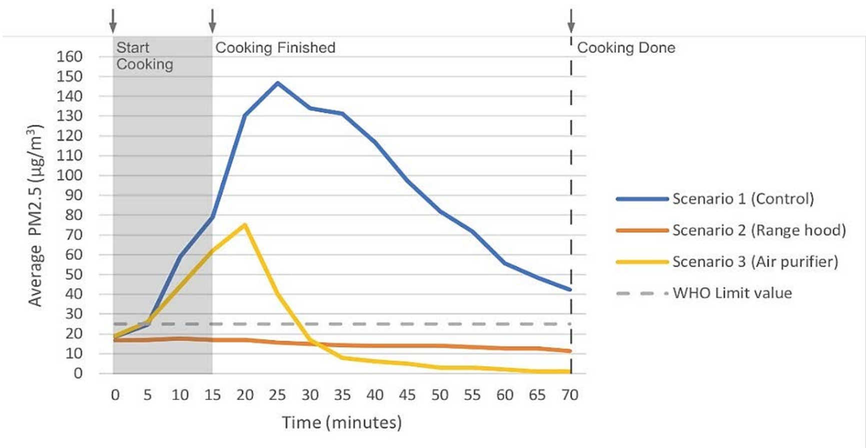

Figure 2: Average PM2.5 concentration emitted by air frying over time in 3 scenarios.

Table 1: Peak and final PM2.5 concentration in 3 scenarios.

	Scenario 1 (Control setting)	Scenario 2 (With Range Hood System)	Scenario 3 (With Air Purifier System)
Maximum Average Concentration of the 3 tests (μg m^{-3}) (SD)	147 (76)	18 (6)	37 (4)
Final Average Concentration (μg m^{-3}) (SD)	42 (16)	11 (7)	3 (0.6)
Difference between Maximum Concentration and WHO limit value (25 μg m^{-3})	122	7	12

After the peak, PM2.5 decreased continuously at a slower rate for the rest of the operation. Table 1 shows that at the end of the operation, the concentration measured was 42 μg m^{-3}, which was still over the daily threshold. The results are similar to a previous study by Liu et al. [15], which reported that the elevated PM2.5 levels in various indoor spaces after pan frying bacon lasted over 120 min during baseline ventilation conditions.

The difference between the highest PM2.5 concentration and the recommended limit was 122 μg m^{-3}, as shown in Table 1. Throughout the operation, the PM2.5 concentrations measured in scenario 1 were always substantially higher than in the other two scenarios and exceeded the recommended PM2.5 limit. This suggests that air frying without a proper air ventilation system is unsafe. Our findings are in line with earlier research [16]. The measured PM2.5 concentrations in the kitchens of non-smoking, high occupancy dwellings in Nottingham, the UK, indicated that cooking with a gas stove or electric oven led to elevated kitchen PM2.5 concentration. This is also consistent with another study [17] that measured mean PM2.5 emission rates from cooking four complete meals. The results confirmed that cooking for a prolonged period in a house without adequate ventilation could lead to indoor PM2.5 concentrations that exceed those found outside and could negatively affect the health of occupants.

At the start of the operation in scenario 2, the range hood system was operated. Table 1 shows that the initial average PM2.5 concentration was approximately the same as in scenario 1. However, unlike scenarios 1 and 3, the PM2.5 level in scenario 2 never increased both during and after air frying finished but decreased gradually with a constant rate over time, suggesting that range hoods are efficient at keeping PM2.5 level low and stable for an extended period. This also indicates that it is safe to turn off the range hood right after the cooking is done. In addition, no peak in the concentration was observed, and only small fluctuations were detected. These observations agree with an earlier study [15], which reported that interventions that include range hood, combined with baseline ventilation, reduced peak PM2.5 concentration generated during pan frying bacon. Range hoods' impact on peak levels was expected because they are designed to capture and exhaust emissions at the source. Similarly, a previous study focused on pan frying hamburgers [18] found that applying a range hood equipped with a fresh carbon filter resulted in a reduction of 28% in the peak PM2.5 concentration.

The maximum value was observed at 10 min (18 μg m^{-3}), which was 7 μg m^{-3} lower than the WHO recommended threshold, and the final concentration was 11 μg m^{-3}, see Table 1. For the entire duration of the operation conducted in scenario 2, PM2.5 concentration had always been maintained within the daily limit, indicating that range hoods are effective at reducing air frying-related pollutants to safer levels at a steady pace. This is supported by the findings in previous research [15] that range hoods caused faster decay of PM2.5 concentration to less than 50 min and that the addition of a range hood reduced the duration of exposure to elevated PM2.5 levels to less than 40 min compared to 120 min of the situation without it. Moreover, they reported that the application of the range hood resulted in a 90.15% reduction in integrated PM2.5 concentration compared to the baseline ventilation condition [15]. This indicates that range hoods were able to capture emissions and remove cooking-emitted PM2.5 in residential settings. Our findings also agree with Catherine O'Leary et al. [16] that the range hood system is currently the best known and quickest mitigation strategy to reduce PM2.5 emitted from cooking.

For scenario 3, the air purifier system was operated, and the average PM2.5 concentration measured at the start of air frying was nearly equal to scenarios 1 and 2. A sharp rise in the amount of PM2.5 can be observed after 5 min of air frying and continued for 15 minutes, suggesting that air purifiers take more time to ventilate indoor PM2.5 compared to range hoods. After the highest concentration of 37 μg m^{-3} exceeded the recommended threshold by 12 μg m^{-3}, the PM2.5 concentration reduced substantially at first, and then started decreasing steadily at a slower pace after 25 min and ended at 3 μg m^{-3} at the end of the operation as demonstrated in Table 1. This suggests that it is safe to turn off the air purifier after 30 min of operation. For most of the operation, the PM2.5 concentrations remained below the WHO PM2.5 quality standard but slightly surpassed the threshold for 10 min, resulting in a peak in concentration levels. It is noticeable that the total amount of PM2.5 measured in scenario 3 was the lowest among the three scenarios. Still, the maximum value was larger in scenario 3 (37 μg m^{-3}) than in scenario 2 (18 μg m^{-3}). The obtained results indicate that air purifiers are less effective at reducing PM2.5 emitted from air frying than range hoods.

To the best of our knowledge, this study is the first to systematically investigate and compare the efficiency of range hoods and air purifiers in reducing PM2.5 emitted during air frying in residential settings. The PM2.5 concentration data were also obtained from a long-term measurement period of 70 min. However, there were some limitations in the research process. First, given that the study focused only on air frying French fries, further investigation of PM2.5 generated from air frying other types of food with different fat content is recommended. Second, the number of operations repeated was three times per scenario, which was relatively small. Lastly, the operation was conducted in a sealed room to reduce air infiltration as much as possible. This situation may not apply to residential settings with different ventilation conditions.

Conclusions

The results from this study indicate that cooking with an air fryer emits large amounts of PM2.5 that substantially exceeded the daily mean threshold issued by WHO (25 μg m^{-3}). Both ventilation methods are proven effective in reducing PM2.5 concentration generated during air frying in residential settings. However, the range hood system showed better performance than the air purifier system with a lower maximum average PM2.5 concentration which remained under the limit value over time. Thus, the application of range hoods when air frying is highly recommended. It should also be noted that air purifiers can partially compensate for a less effective PM2.5 reduction method in the absence of a range hood.

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