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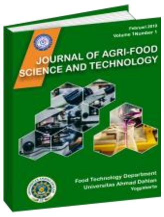

Effect Of UV-Assisted Titanium Dioxide (TiO_2) Photocatalysis on Viable Airborne Bacteria and Fungi in The Seasoning Powder Industry

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ABSTRACT

Titanium dioxide (TiO_2) has been known to have anti-microbial activity against fungi, bacteria, and viruses. The application of TiO_2 in the membrane attached to the air conditioner was expected to minimize airborne microorganisms. This study contribution to investigate the efficacy of UV-assisted TiO2 photocatalysis in controlling airborne microorganisms in the seasoning powder industry. TiO2 was coated to the non-woven membrane and attached with a UV lamp inside the air conditioner. When the AC was on, the Ti^{3+} was released into the air. Enumeration of airborne microorganisms was conducted by opening the agar plates for 15 min at several food processing facilities, followed by incubating agar plates for 72 hours at 30 °C. The result shows dry processing facility had the highest number of initial airborne bacteria while the wet production facility had the highest number of initial airborne fungi. Interestingly, the number of airborne microorganisms fluctuated in the packaging facility related to the number of people going inside and outside. On the contrary, the number of airborne microorganisms was deficient in empty rooms, which indicated that the number of airborne microorganisms might be related to people and products. Overall, airborne microorganisms were reduced after 60 min of irradiation. Therefore, it is recommended to irradiate the facilities for 60 min before production start. SEM images and EDAX analysis results show TiO2 was detected after 160 h. However, it was recommended to change the TiO2 membrane after one month. This research was expected to contribute to controlling airborne microorganisms during food production in food processing facilities.

1. INTRODUCTION

Particulate matter in the air is essentially controlled in food processing facilities that must comply with specific guidelines (Nowshad et al., 2021). Airborne microorganisms are usually attached to the particulate matter (Zhai et al., 2018) that might be related to food contamination during food production (Asif et al., 2019). Several factors, namely temperatures, and humidity, are specified qualities required in food processing facilities. These qualities are essential for the safety of employees and for controlling the possibility of food contamination (Møretrø & Langsrud, 2017).

Food contamination by microorganisms is a drawback in the food industry. Contamination can occur during processing, packaging, and storage. Air is one of the potential sources of contamination (Poormohammadi et al., 2021). Wigmann et al. (2018) reported the fungi *Penicillium glabrum* was found in frozen nuggets was the predominant fungi found in the air environment of the facility. Fungi contamination is also found in the air, raw materials, and surface of dry fermented sausages' production facilities (Parussolo et al., 2019).

Technology has been developed to capture and deactivate microorganisms in the air. The ventilation system plays an essential role in controlling airborne microorganisms (Madureira et al., 2015). Moreover, Kim et al. (2017) showed that using photocatalysis equipment consisting of titanium oxide and an ultraviolet lamp had the highest effectivity against the virus. Several methods to disinfect the air have been done. Masotti et al. (2019) showed that ozone could reduce microbial contamination in food and water treatment industries. However, Ahmadi et al. (2021) reported the superior ability of photocatalysis to inactivate a wide range of harmful bacteria and its widespread application in the food industry, pharmaceuticals, water treatment, and healthcare facilities.

The application of photocatalysis has been used for water treatment and fruit cleaning to substitute chlorine (Yoo et al., 2015). Moreover, nanoTi-O_2 was incorporated in LDPE to improve strawberries' quality and antioxidant capacity at room temperature (Li et al., 2017). Meanwhile, powdered seasonings have low water activity (aw) value, and the number of contaminations was limited (Nyhan et al., 2021). However, it might become a problem during storage that microorganisms can grow and decrease food quality under high humidity. Moreover, Nyhan et al (2021) reported several bacteria, namely *Salmonella spp.*, *Clostridium perfringens*, *Escherichia coli*, *Staphylococcus aureus*, and *Enterobacter spp*, found in dried herbs and spices during storage at retail. Moreover, Abdul-Rashid et al. (2022) reported cross contamination might occur during food handling and might transferred from workers.

Little information was available on the effect of UV-assisted TiO_2 in maintaining airborne microorganisms in the food industry. Therefore, this study aimed to investigate the effectiveness of UV-assisted TiO_2 photocatalysis in maintaining the level of airborne microorganisms to comply with the standard of the Ministry of Health. Moreover, the shelf life of the UV kit filter containing TiO_2 was evaluated to understand the release of TiO_2 during membrane use. The application of UV-assisted TiO_2 photocatalysis was expected to be contributed to providing a better understanding of managing the number of microbes in food processing facilities to comply with health regulations.

2. MATERIALS AND METHODS

2.1. Materials

UV-assisted TiO_2 photocatalysis was obtained from UV Kurin (Jakarta, Indonesia). UV-assisted TiO_2 kit consisted of the UV lamp, a non-woven membrane that contained TiO_2. UV-assisted TiO_2 kit was attached to the air conditioner. Plate count agar was used for bacterial culture and potato dextrose agar was used for yeast and fungi. All media were purchased from Merck (Merck KGAa, Darmstadt, Germany).

2.2. Research Methods

2.2.1. Measurement of airborne microorganisms

The effect of TiO_2 photocatalysis on airborne microorganisms in seasoning powder processing facilities was evaluated by culture-settling plate techniques following the method proposed by Zacharski et al. (2018). UV-assisted TiO_2 kit was attached inside the air conditioner so that when AC was turned on, the UV lamp would also be turned on and TiO_2 would release anti-microbial activity into the air. The following areas were evaluated: wet processing facility, dry processing facility, packaging facility, and empty room as control. Nutrient agar (NA) was used to determine the number of airborne bacteria, while potato dextrose agar (PDA) was used to determine the number of airborne fungi. Petri dishes containing NA or PDA were opened for 15, 30, 45, and 60 min at the processing facilities. The Petri dishes were then closed and incubated for 48 h at 30 °C. The results were reported as CFU m^{-3}.

2.2.2. SEM analysis

The surface morphology of the UV kit filter after use was 40, 80, 120, and 160 h analyzed using a Scanning electron microscope (SU3500, Hitachi, Tokyo, Japan). The SEM analysis was held at SEM Laboratory, Centre of Advance Sciences, Bandung Institute of Technology, Bandung Indonesia

2.2.3. Statistical analysis

Two separate replications were conducted to obtain data. Analysis of variance followed by Duncan's Multiple Range Test at the significant level of 0.05 was used to analyze the data. Microsoft Excel was used to calculate and analyze the data.

3. RESULT AND DISCUSSION

During experiments, temperature, humidity, ozone level, UV A, and UV C level were measured to ensure UV radiation and ozone level were below regulations issued by the Ministry of Health in 2018. The results show UV A and C radiation and ozone levels were undetected. Room temperature was 23.5 to 25.1 °C, while humidity varied from 52% to 70 %.

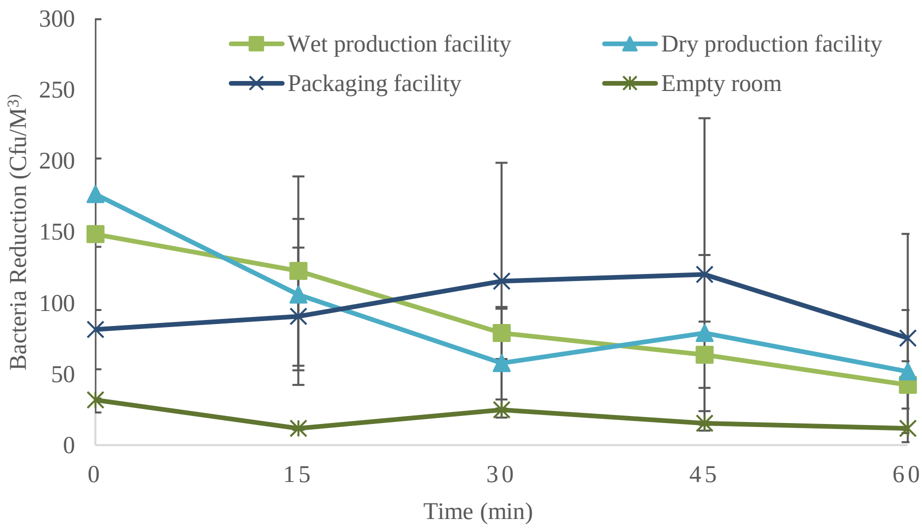

Figure 1. Effect of UV Kit Filter with TiO_2 Catalyst on Bacteria Reductions in Food Processing Facilities. The bar represents the standard deviation.

The effect of TiO_2-photocatalysis on bacterial reduction in food processing facilities, namely dry production facility, wet production facility, packaging facility, and empty room as control was shown in Figure 1. Seasoning powder food processing facilities offer a varying number of airborne microorganisms. The number of bacteria ranges from 51.8 to 176.6 CFU m^{-3}. This result complied with regulations issued by the Health Ministry of Indonesia number 1045 in 2002 that the number of microorganisms in the air should be under 700 CFU m^{-3}. An empty room has the lowest bacterial number, while a wet production facility has the highest number of bacteria. The number of microorganisms in wet and dry facilities decreased after 60 min of irradiation. However, the number of bacteria in the packaging room fluctuated during the irradiation. It was assumed that the activities of workers during entering and leaving the room lead to fluctuations in bacterial numbers as also reported by Heo et al. (2017). Moreover, Asif et al. (2019) also reported that higher bacterial load is related to longer operational hours of human activities in the facility.

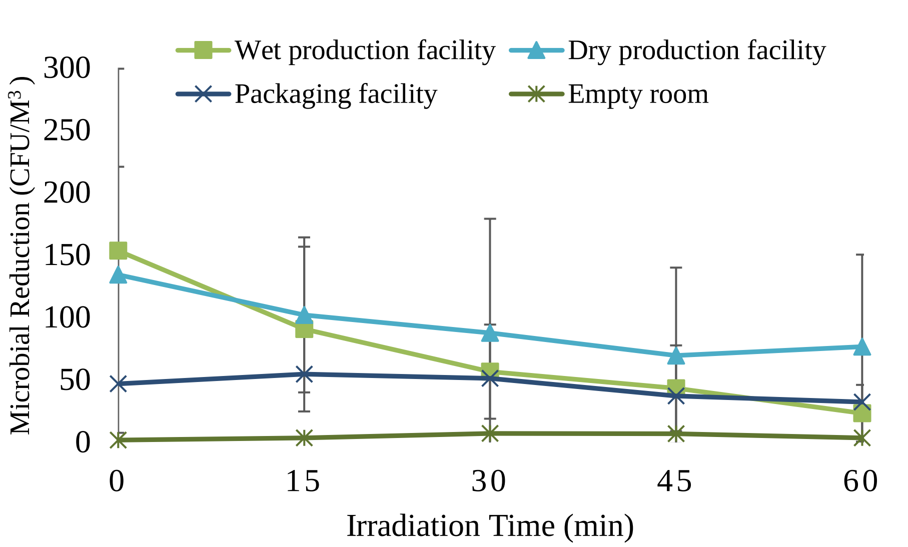

Figure 2. Effect of UV and TiO2 Irradiation on Fungi Reduction in Food Processing Facilities. The bar represents the standard deviation.

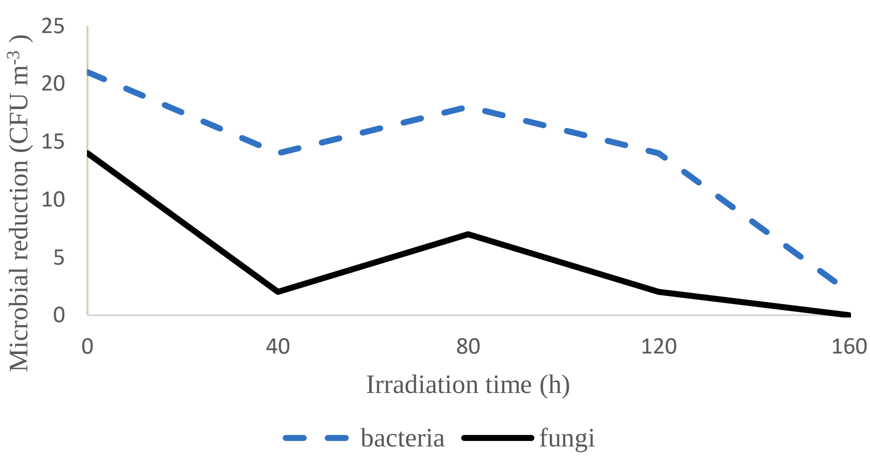

Figure 3. Effect of UV- assisted TiO2 photocatalysis on microbial reduction

Figure 2 shows the effect of TiO_2-photocatalysis on bacterial reduction in food processing facilities, namely dry production facility, wet production facility, packaging facility, and empty room as control. The number of fungi ranged from 3 to 76 CFU m^{-3} after 60 min of irradiation. The dry facility has the highest number of fungi, while the empty room has the lowest number of fungi. Fungal contamination was commonly found in the dry spice and seasoning powder due to the low aw. The fungi widely found were *Aspergillus* and *Rhizophus* (Ahmadi et al., 2021). It was observed that photocatalysis incorporated with UV could reduce airborne fungi *Aspergillus niger*, as reported by Pigeot-Remy et al. (2013).

Figure 3 shows the microbial reduction during 160 h. The number of microbial reductions fluctuated during 80 h. However, the trend shows decreasing in microbial number after 160 h. The same result was also observed by Valdez-Castillo et al. (2019).

SEM image of TiO2 membrane after 0, 40, 80. 120, and 160 h are shown in Figure 4(A), 4(B), 4(C), 4(D), and 4(D). The rougher surface was observed on the TiO_2 filter kit at 160 h. EDAX analysis also showed TiO_2 was not detected in the membrane. It might be because, under UV light, TiO_2 was degraded into negative-charged free and positive-charged free electrons (Ramesh et al., 2016).

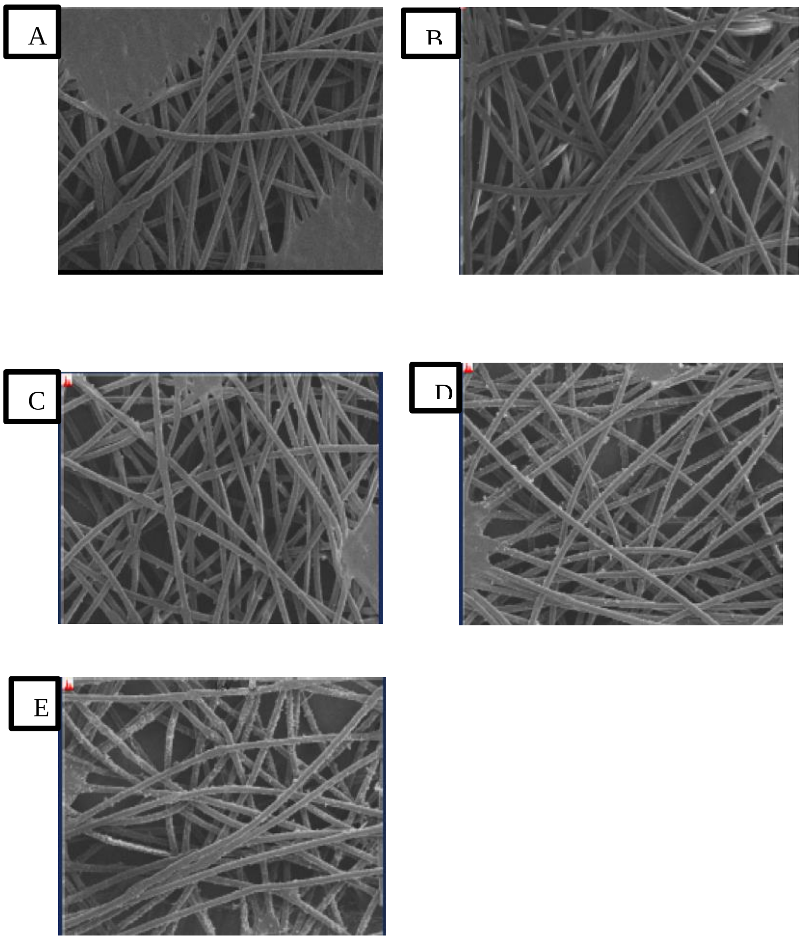

Figure 4. Images of TiO_2 membrane obtained from SEM images at (A) 0 h; (B) 40 h; (C) 80 h; (D) 120 h, and (E) 160 h

The scanning electron microscopy-energy dispersive X-ray spectroscopy (SEM-EDS) is shown in Figure 5. The element of titanium and oxygen in undoped TiO2 was revealed based on SEM-EDS analysis. The smooth surface of the membrane was observed at 0 h, while the rough surface was observed after 160 h. The result shows TiO_2 presence fluctuated and was detected at 0, 40, and 120 h. It might be due to the sampling method.

Table 1 shows the atom composition analyzed by EDX. Carbon atoms decreased over time while oxygen increased. Titanium atom was observed until 120 h. However, at 160 h, it was not detected.

Table 1. ZAF method standardless quantitative analysis

Hour	element	keV	Mass %	Error %	Atom %	K
0	C K	0.28	94.83	0.09	96.11	98.30
	O K	0.52	5.09	0.64	3.87	1.62
	Ti K	4.06	0.09	2.05	0.02	0.08
	Total		100		100	
40	C K	0.28	93.10	93.10	94.90	97.52
	O K	0.52	6.55	0.65	5.01	2.16
	Ti K	4.06	0.35	2.09	0.09	0.32
	Total		100		100	
80	C K	0.28	92.36	0.09	94.16	97.42
	O K	0.52	7.64	0.64	5.84	2.58
	Ti K	-	-	-	-	-
	Total		100		100	
120	C K	0.28	89.57	0.10	92.21	95.95
	O K	0.52	9.89	0.65	7.65	3.53
	Ti K	4.06	0.54	2.16	0.14	0.52
	Total		100		100	
160	C K	0.28	88.01	0.09	90.72	95.52
	O K	0.52	11.99	0.55	9.28	4.48
	Ti K	-	-	-	-	-
	Total		100		100	

Incorporating UV-assisted TIO_2 into the air conditioner might improve the air conditioner's effectiveness in cleaning the air (Liu et al., 2017). Moreover, the application of UV-assisted TIO_2 photocatalysis was able to maintain the number of airborne microorganisms below standard. This might be due to the anti-microbial activity of TiO_2 along with maintaining low RH in the facility (Bono et al., 2021; Bui et al., 2021). The UV-assisted TIO_2 filter was put inside the air conditioner that would release TiO_2 when AC was turned on and while AC turned on, the RH remained under 70%. The result showed that airborne microorganisms could comply with the standard after 160 h.

The number of airborne bacteria was different among different room facilities. The result shows processing facility with many people inside had a fluctuating number of airborne bacteria. Interestingly, the number of airborne microorganisms was almost the same between the empty room and the wet facility. During seasoning powder production, some volatile compounds were released into the air. Salussoglia et al. (2022) state that volatile compounds obtained from herbs could have anti-microbial activity. However, contamination might come from fungi that Valdez-Castillo et al. (2019) reported UV-assisted TiO_2 photocatalysis could reduce contamination of bacteria and fungi.

UV-assisted TiO_2 photocatalysis has been used broadly as it is a chemically stable, non-hazardous, and non-toxic semiconductor, as reported by Prakash et al. (2022). Therefore, UV-assisted TiO_2 photocatalysis is recommended in food processing facilities to control the number of airborne microorganisms.

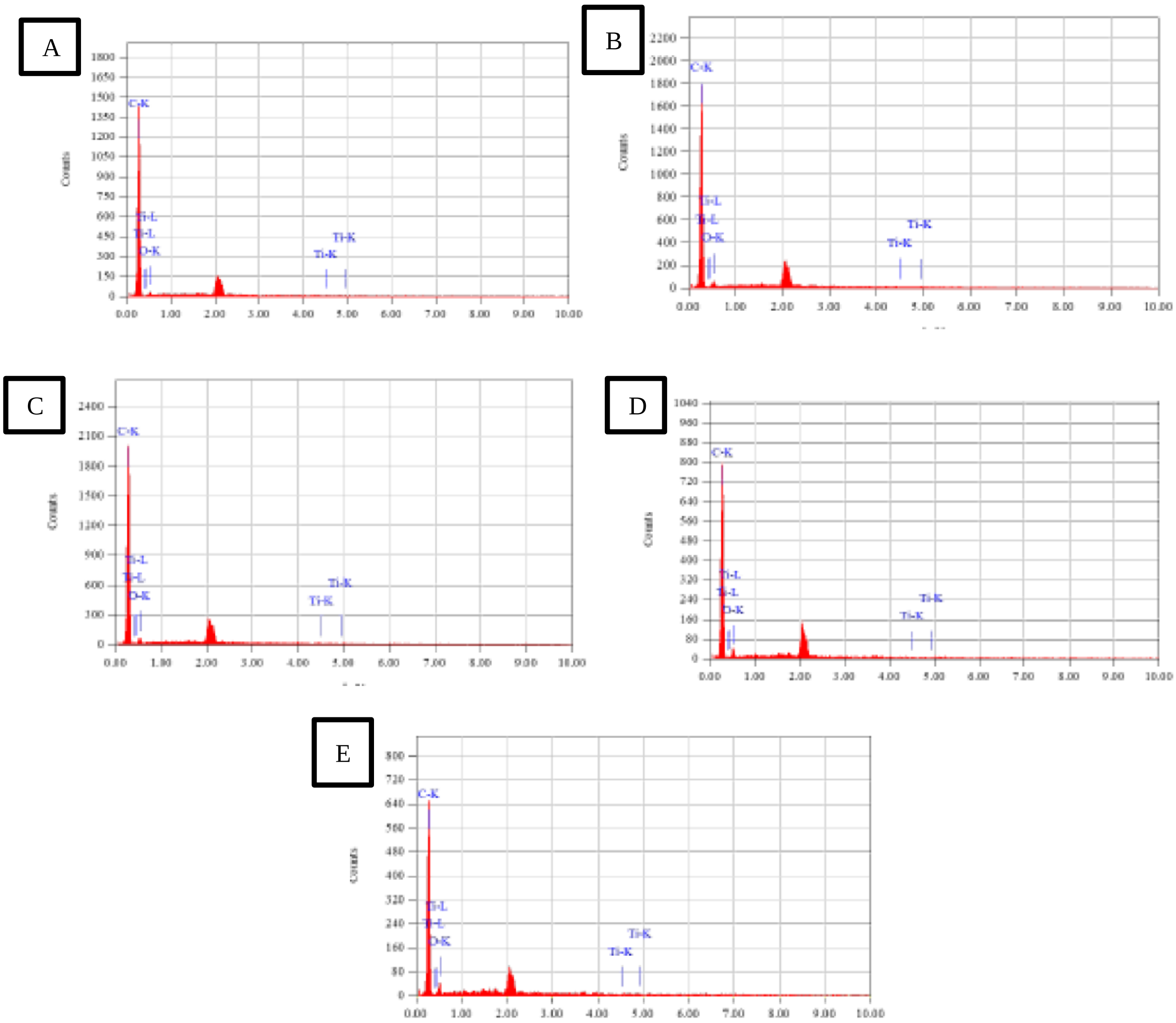

Figure 5. EDAX of TiO2 membranes at (A) 0 h; (B) 40 h; (C) 80 h; (D) 120 h and (E) 160 h

4. Conclusion

Monitoring microbial air quality of food production facilities in seasoning powder industries shows different numbers of airborne microorganisms. Although the number of airborne microorganisms fluctuated, UV-assisted TiO_2 photocatalysis could control airborne microorganisms to comply with the standard after irradiation for 60 min. Therefore, turning on the AC for 60 min before production starts is recommended. This research provides an understanding of the effects of UV-assisted TiO_2 photocatalysis to control airborne microorganisms in food processing facilities. Moreover, this research also includes information on the shelf life of the TiO_2 membrane and the maintenance needed to ensure the effectiveness of the anti-microbial of UV-assisted TiO_2 photocatalysis.

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