

Effect of Ultraviolet Radiation on Microbial Contamination of Dried Saffron in Herat Province

Basir Ahmad Rahimi¹, Abdullah Masoumi^{✉2} and T. H. Shankarappa³

^{1, 2} Herat University, Food Technology Department, Agriculture Faculty, Herat, Afghanistan

³ College of Horticulture, UHS Campus, GKVK, Bengaluru-560 065, India

✉ E-mail: masomi256@gmail.com (corresponding author)

ABSTRACT

Saffron is an economically important crop in Herat Province, one of Afghanistan's major saffron-producing regions. Microbial contamination is a major concern for the safety, quality, and export of dried saffron. This cross-sectional laboratory study evaluated the effect of ultraviolet (UV) radiation on microbial contamination of dried saffron. A total of 100 dried saffron samples were collected from processors and farmers in Herat City and the districts of Ghuryan, Pashtoon Zarghun, and Guzara. The samples were subsequently subjected to laboratory analysis. Ghuryan samples showed the highest contamination, with *Escherichia coli* and fungi (yeasts and molds) detected in 30% and 66.67% of samples, respectively, whereas Pashtoon Zarghun showed the lowest contamination rates (5% and 40%, respectively). After 120 min of UV treatment, *E. coli* contamination decreased by 95.83%, while fungal contamination decreased by 55%. The lower effectiveness against fungi may be related to the greater cellular complexity and resistance of yeasts and molds. These findings indicate that UV radiation has potential as a practical, low-cost, and chemical-free method for reducing microbial contamination, particularly *E. coli*, in dried saffron. Therefore, 120-min UV treatment is recommended as a complementary post-harvest measure to reduce microbial contamination and improve the microbiological safety of dried saffron. Further studies are recommended to optimize exposure conditions and assess effects on saffron quality.

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INTRODUCTION

Saffron (*Crocus sativus* L.) is a perennial plant of the Iridaceae family, cultivated primarily for its dried red stigmas, which are widely recognized as a highly valuable spice. Its distinctive sensory characteristics, together with its diverse culinary and commercial applications, have made saffron an important agricultural commodity with substantial economic value in producing regions. Beyond its use as a spice, saffron has been traditionally valued for medicinal purposes. It contains bioactive constituents such as crocin, picrocrocin, and

safranal, which have been associated with a range of beneficial biological and pharmacological effects (Gohari et al., 2013; Aissa et al., 2023). Spices and herbs have been used mainly for their flavors, colors, and aromas in food preparation for centuries worldwide. Because spices were highly valued, they were used as currency in ancient times. Saffron is still used in some regions, where it is among the most expensive spices (Nikajima et al., 2005). Saffron is widely known as “red gold” because of its high economic value and status as one of the world's most expensive spices. Saffron comes from the dried stigmas, either alone or with portions of the styles, of *Crocus sativus* L. Saffron stigmas are divided into three parts called filaments, which are collected and dried to make saffron spice (Aslami, 2006). Saffron quality is mainly determined by three key compounds: crocins, which are responsible for its characteristic color; picrocrocin, which contributes to its bitter taste; and safranal, which imparts its characteristic aroma (Predieri et al., 2021).

Afghanistan is the world's fourth-largest saffron-producing country (Shahbandeh, 2020). Iran, Spain, Greece, Morocco, India, and Italy are other top saffron producers worldwide (Kafi et al., 2018). Herat Province is Afghanistan's major saffron-producing region and plays a significant role in the country's saffron industry. According to the Ministry of Agriculture, Irrigation and Livestock, saffron was cultivated on approximately 8,304 ha across 26 provinces of Afghanistan in 2023, with a total production of 23.249 metric tons. Herat Province accounted for 22.240 metric tons of the national production, highlighting its dominant contribution to saffron production in Afghanistan (Ministry of Agriculture, Irrigation and Livestock, 2024). Saffron is cultivated in several districts of Herat Province, including Injil, Karukh, Guzara, Pashtun Zarghun, Zende Jan, Ghoryan, and Obbeh (Food and Agriculture Organization of the United Nations, 2024).

Saffron, like many other agricultural products, is subjected to a broad range of microbial and environmental contamination during growing, harvesting, processing, and in markets by dust, wastewater, and even animal and human feces (Kafi et al., 2018). Heavy contamination of saffron with xerophilic molds and bacteria has also been reported during storage (Romagnoli et al., 2007). Depending on the end use, microbiological contamination of spices may pose a problem. Because saffron is usually cooked, thermal processing may reduce the risk; however, saffron is sometimes prepared in cold water, or Oleoresin (Cosano et al., 2009) may raise health concerns. The food processing industry has increased its use of ultraviolet light to inactivate microorganisms in recent years; however, its classical use was confined to biological safety cabinets (Gomez et al., 2011).

Microbial contamination of dried saffron may be influenced by harvesting, drying, handling, transportation, packaging, and storage conditions. Inadequate hygienic practices during these stages can facilitate the introduction and persistence of microorganisms in the final product. Although drying reduces water availability and limits microbial growth, some microorganisms can survive under the low-moisture conditions of dried spices (Schaarschmidt et al., 2016). Studies on saffron have also shown that different drying methods can influence its microbial population, with microbial diversity varying according to

drying conditions (Fancello et al., 2018). Therefore, the microbiological quality of saffron should be considered throughout the production and post-harvest chain rather than only at the point of consumption.

The control of microbial contamination in spices is particularly important because decontamination treatments should reduce microorganisms while preserving product quality. Conventional thermal treatments may affect important quality attributes of saffron, including its aroma, color, and flavor, through changes in compounds such as safranal, crocins, and picrocrocin (Gregory et al., 2005; Sánchez et al., 2011). Therefore, non-thermal technologies such as UV radiation have attracted attention as alternative methods for microbial reduction in spices. UV can reduce microbial contamination without substantial heating or chemical preservatives, although its effectiveness depends on factors such as dose, exposure time, microbial type, and product characteristics (Hassan et al., 2020; Molina et al., 2020; Arcos-Limiñana et al., 2025).

Ultraviolet (UV) radiation is a promising non-thermal technology for reducing microbial contamination in spices and other food products. UV inactivates microorganisms mainly by damaging their DNA, thereby inhibiting replication and transcription (Cutler & Zimmerman, 2011). Recent reviews report its potential to decontaminate spices while preserving quality attributes (Arcos et al., 2024). However, the effectiveness of UV treatment depends on factors such as exposure time, UV dose, microbial load, and product characteristics. This study aimed to evaluate the efficacy of ultraviolet (UV) radiation in reducing microbial contamination, including *E. coli* and fungi, in dried saffron collected from different districts of Herat Province. The study addressed the following research questions:

1. What is the prevalence of *E. coli* and fungal contamination in dried saffron collected from different districts of Herat Province?
2. How effective is UV radiation in reducing these microbial contaminants?
3. Does the efficacy of UV treatment differ between *E. coli* and fungal contaminants?

METHODS AND MATERIALS

Research design

A cross-sectional laboratory-based study design was used to examine dried saffron samples collected from multiple districts of Herat Province at a single time point, with the aim of assessing microbial contamination and the effect of ultraviolet (UV) radiation. This design was selected because it permits concurrent assessment of microbial contamination across samples and locations, providing a representative overview of contamination in dried saffron. It also allows controlled laboratory testing of UV radiation efficacy against different microorganisms, including *Escherichia coli* and fungi, under standardized conditions. This approach is efficient, economical, and well-suited for studies that identify contamination patterns and evaluate interventions without longitudinal monitoring.

Saffron sample collection

A total of 100 dried saffron samples were collected throughout Herat province from saffron processors and farmers during October 2018. Herat City (n = 31), Ghurian District (n = 30), Pashtun Zarghun District (n = 20), and Guzara District (n = 19). Saffron samples were collected and analyzed for indicator microorganisms, viz., bacteria (*Escherichia coli*) and fungi (Yeast and molds), at the Herat University Food Technology Laboratory.

UV light radiation

Saffron samples (0.25g) were added to a 50mm standard Petri dish to obtain a thin layer of sample and exposed to UV light radiation in a biological safety cabinet by placing the Petri dish directly below the UV beam for 120 min.

Enumeration of *Escherichia coli* and fungi

The microbial enumeration of treated and untreated saffron samples was done using serial dilution and the plate count method. One gram of each sample was homogenized in 9 ml peptone water (0.1%) using a vortex mixer apparatus for 1 to 2 min and plated on respective media plates.

For detection of *E. coli*, one mL of an aliquot taken from 1:10, 1:100, and 1:1000 dilutions were plated in duplicate on *E. coli* / Coliform count plates; solidified plates were incubated for 24 hours at 37°C, and the blue colonies with gas bubbles were counted as *E. coli*, as instructed by Petrifilm Company (Bird et al., 2020).

Fungi, yeast, and mold enumeration was carried out using the 3M™ Petrifilm™ yeast and mold count plate. One mL of the sample, prepared to have a 10⁻¹ dilution, was plated onto the Petrifilm yeast and mold count plate in duplicate. Petrifilm plates were incubated at 27°C for 3 days, and yeast and mold enumeration was done according to the instructions issued by the Petrifilm Yeasts and Molds Count Plates (Schumacher et al., 2023).

FINDINGS

The results of microbial analysis of saffron samples collected from markets throughout Herat city are presented in Table 1. The results showed that, out of 31 collected samples from supermarkets in Herat city, nine samples were contaminated with bacteria (Mean ± SD = 1.31±0.47), and after the treatment with UV light radiation for 120 minutes, bacterial contamination was eliminated completely. The enumeration of fungi in saffron samples indicates that, 19 samples had fungal (yeast and mold) contamination (Mean ± SD= 1.46±0.37). Upon UV treatment the contamination of yeast and mold was eliminated in 12 out of 19 samples. The UV light radiation treatment for 120 minutes could only decrease the population in 7 samples (Mean ± SD = 1.302±0.30). This level of contamination (3log₁₀CFU/g) was within the acceptable limits prescribed by ICMSF and therefore considered as satisfactory.

Table 1. Presents the microbial analysis results for saffron samples collected from markets throughout Herat city

^aStandard deviation for contaminated samples.

	<i>E. coli</i> before UV treatment	<i>E. coli</i> after UV treatment	Yeasts and Molds before UV treatment	Yeasts and Molds after UV treatment
No. of samples tested (n=31)	31	31	31	31
No. of Samples contaminated	9	0.00	19	7
Average	1.31	NA ^b	1.46	1.30
SD ^a	±0.47	NA	±0.37	±0.30
ICMSF MCL ^c (log ₁₀ CFU/g)	3.00	3.00	4.00	4.00
% of samples above MCL	0.00	0.00	0.00	0.00

^bNot applicable^c International Commission for Microbiological Standards of Food (ICMSF), Maximum Contaminant Level (MCL).

The results presented in Table 2 showed that nine samples from Guryan district were contaminated with *E. coli* (Mean ± SD = 2.27±0.86). Among these samples, three exceeded the ICMSF limits (> 3log₁₀ CFU/g). Following UV treatment, *E. coli* was eliminated from eight of the nine contaminated samples, demonstrating the effectiveness of UV irradiation in reducing *E. coli* contamination. In contrast, yeast and mold populations were less than 4log₁₀ CFU/g in 20 samples (Mean ± SD = 1.95±0.88), within ICMSF limits. UV treatment of 20 contaminated samples inhibited fungal contamination in 12 samples; the remaining eight samples showed reduced fungal populations.

Table 2. UV radiation on microbial contamination of dried saffron in Ghuryan District

	<i>E. coli</i> before UV treatment	<i>E. coli</i> after UV treatment	Yeasts and Molds before UV treatment	Yeasts and Molds after UV treatment
No. of Sample tested (n=31)	30	30	30	30
No. of samples contaminated	9	1	20	8
Average	2.27	1.5	1.95	1.37
SD ^a	±0.86	NA ^b	±0.88	±0.42
ICMSF MCL ^c (log ₁₀ CFU/g)	3.00	3.00	4.00	4.00
% of samples above MCL	3.00	0.00	0.00	0.00

^aStandard deviation for contaminated samples.^bNot applicable^c International Commission for Microbiological Standards of Food (ICMSF), Maximum Contaminant Level (MCL).

Only one sample (5%) was contaminated with *E. coli* (Mean = 1.2) in saffron collected from Pashtoon Zarqoon district (Table 3). This level of contamination is considered acceptable according to the ICMSF recommendation, and *E. coli* contamination was eliminated after UV treatment in this sample, showing the efficacy of UV light radiation on bacterial cells. As per

the data from Table 3, yeast and mold contamination were observed in eight samples; of these, five samples showed fungal contamination, but within the limits after UV treatment (Table 3).

Table 3. UV radiation on microbial contamination of dried saffron in Pashtoon Zarghun District

	Occurrence of <i>E. coli</i> before UV treatment	Occurrence of <i>E. coli</i> after UV treatment	Occurrence of Yeasts and Molds before UV treatment	Occurrence of Yeasts and Molds after UV treatment
No. of samples tested (n=20)	20	20	20	20
No. of samples contaminated	1	0.00	8	5
Avg	1.2	NA ^b	2.2	1.26
SD ^a	NA	NA	±1.00	±0.54
ICMSF MCL ^c (log ₁₀ CFU/g)	3.00	3.00	4.00	4.00
% of samples above MCL	0.00	0.00	0.00	0.00

^a Standard deviation for contaminated samples.

^b Not applicable

^c International Commission for Microbiological Specifications for Foods (ICMSF), Maximum Contaminant Level (MCL).

Five samples from Guzara District contained *E. coli* (Table 4), but none reached the ICMSF limit of 3 log₁₀ CFU/g, and UV exposure for 120 minutes eliminated the bacterial contamination. Yeast and molds were also found in 13 (68%) samples (Mean ± SD = 1.79 ± 0.50). UV light radiation eliminated fungi in six samples; the remaining seven samples had lower populations of yeast and molds (Mean ± SD = 1.25±0.30).

Table 4. UV radiation on microbial contamination of dried saffron in Guzara District

	Occurrence of <i>E. coli</i> before UV treatment	Occurrence of <i>E.</i> <i>coli</i> after UV treatment	Occurrence of Yeasts and Molds before UV treatment	Occurrence of Yeasts and Molds after UV treatment
No. of samples tested (n=19)	19	19	19	19
No. of Samples contaminated	5	0.00	13	7
Avg	1.42	NA ^b	1.79	1.25
SD ^a	±0.58	NA	±0.50	±0.30
ICMSF MCL ^c (log ₁₀ CFU/g)	3.00	3.00	4.00	4.00
% of samples above MCL	0.00	0.00	0.00	0.00

^a Standard deviation for contaminated samples.

^b Not applicable

^c International Commission for Microbiological Specifications for Foods (ICMSF), Maximum Contaminant Level (MCL).

DISCUSSION

The International Commission on Microbiological Specifications for Foods (ICMSF) allows a maximum contamination level of 10^4 CFU of fungi (yeasts and molds) and 10^3 CFU of *E. coli* per g of spices such as saffron (ICMSF, 2005). In the present study, microbial contamination was detected in dried saffron samples collected from different districts of Herat Province, with considerable variation among sampling locations. *E. coli* was detected in 9 of 31 samples from Herat city and 9 of 30 samples from Ghuryan district, while Pashtoon Zarghun and Guzara showed lower bacterial contamination, with all detected levels remaining within the acceptable limits. Fungal contamination was observed in a larger proportion of samples than bacterial contamination, with Ghuryan showing the highest level of fungal contamination. Three samples exceeded the ICMSF maximum level for *E. coli* contamination ($3 \log_{10}$ CFU/g). Following UV treatment for 120 minutes, bacterial contamination was eliminated in nearly all samples, whereas fungal contamination was reduced to a lesser extent, with approximately 55–60% of contaminated samples achieving complete inhibition.

The differences in microbial contamination among districts may reflect variations in agricultural, harvesting, handling, drying, transportation, and storage practices. The relatively higher contamination observed in Ghuryan may be associated with less hygienic harvesting or post-harvest handling conditions, inadequate protection of saffron from environmental contamination, or differences in storage conditions. However, these factors were not directly measured in the present study and therefore should be considered possible explanations rather than confirmed causes. The greater occurrence of fungal contamination compared with *E. coli* may also be related to the ability of yeasts and molds to survive under the relatively low-moisture conditions characteristic of dried spices. Thus, the observed microbial profile suggests that both bacterial and fungal contamination should be considered when evaluating the microbiological quality of dried saffron.

The detection of *E. coli* in saffron is particularly relevant because its presence can indicate inadequate hygienic conditions or contamination from environmental and fecal sources. The fact that three samples exceeded the ICMSF limit indicates that a proportion of the analyzed saffron did not meet the microbiological criterion applied in this study. In contrast, the lower bacterial contamination observed in Pashtoon Zarghun and Guzara suggests comparatively better microbiological quality of the sampled products from these locations. Nevertheless, differences among districts should be interpreted cautiously because the study was based on a limited number of samples and did not investigate the specific sources of contamination.

The findings regarding fungal contamination are also important because fungi may survive during storage of dried spices and may adversely affect product quality. The higher prevalence of fungi compared with *E. coli* in the present study may indicate that the environmental and storage conditions of dried saffron are more favorable for fungal survival than for the persistence of vegetative bacterial cells. In addition, differences in resistance among microbial groups may contribute to the observed results. Recent reviews indicate that microorganisms differ substantially in their susceptibility to UV irradiation and that molds

and yeasts may show greater resistance than many vegetative bacterial cells under some treatment conditions.

The effectiveness of UV treatment was substantially greater against *E. coli* than against fungi in the present study. Treatment for 120 minutes eliminated bacterial contamination in nearly all samples, whereas complete fungal inhibition occurred in only approximately 55–60% of contaminated samples. This difference indicates that the same UV exposure condition does not necessarily provide an equivalent level of inactivation for different microbial groups. The higher susceptibility of *E. coli* may be related to differences in cellular structure and resistance mechanisms, whereas the greater persistence of fungal cells or spores may reduce the effectiveness of surface UV treatment. UV acts primarily through photochemical damage to microbial DNA, but the actual degree of inactivation depends on microbial characteristics as well as treatment conditions and exposure uniformity.

The present findings are generally consistent with previous studies reporting the effectiveness of UV radiation for reducing microbial contamination in herbs, spices, and seeds (Cosano et al., 2009; Nur et al., 2018; Chembioagro, 2022; Khan et al., 2022). Arcos-Limiñana et al. (2025) reported that UV treatment can effectively reduce microbial contamination in spices and culinary seeds while maintaining important quality characteristics. Their review also emphasized that UV effectiveness is influenced by factors such as microbial type, treatment dose, exposure conditions, and the physical characteristics of the product. Similarly, a recent review by Pravallika et al. (2025) concluded that UV is a promising non-thermal technology for microbial decontamination of spices and herbs, while emphasizing the importance of processing parameters, spice morphology, and microbial load in determining treatment efficacy. These findings support the high bacterial inactivation observed in the present study.

However, the moderate effectiveness of UV against fungi in the present study also highlights an important difference from studies reporting stronger fungal reductions. Previous research has shown considerable variability in fungal response to UV treatment, with some studies reporting limited inactivation and others observing substantial reductions under different treatment conditions. Such differences may be explained by variation in UV dose, exposure time, wavelength, distance from the UV source, initial microbial load, microbial species, and the physical arrangement of the treated material. In dried saffron, the irregular arrangement and overlapping of stigmas may create shaded areas in which microorganisms receive less UV exposure. Therefore, the 120-minute treatment used in the present study should not be interpreted as universally sufficient for complete fungal inactivation under all conditions.

The findings provide direct answers to the research questions. Regarding the first research question, *E. coli* contamination was detected in dried saffron from several districts of Herat Province, with the highest bacterial contamination observed in Herat city and Ghuryan. Three samples exceeded the ICMSF maximum acceptable level, while Pashtoon Zarghun and Guzara showed lower bacterial contamination within the acceptable limits.

Fungal contamination was more prevalent than bacterial contamination and was highest in Ghuryan. Regarding the second research question, UV radiation applied for 120 minutes was highly effective in reducing bacterial contamination and also reduced fungal contamination, although its effectiveness against fungi was lower. Regarding the third research question, the efficacy of UV treatment differed between *E. coli* and fungi, with substantially greater inhibition of bacterial contamination than fungal contamination. These findings demonstrate that UV has potential as a non-thermal and chemical-free method for reducing microbial contamination in dried saffron, although optimization of treatment conditions may be required for more effective fungal control.

CONCLUSION

This study found that ultraviolet (UV) radiation is an effective non-thermal method for reducing microbial contamination in dried saffron produced in Herat province. Although contamination prevalence varied across districts, Ghuryan saffron showed the highest levels, and most samples remained within the microbial limits recommended by ICMSF. UV treatment for 120 minutes successfully eliminated *E. coli* in almost all contaminated samples and significantly reduced yeast and mold populations to acceptable levels. These findings indicate that UV radiation can serve as a practical post-processing decontamination step for saffron producers, improving microbiological safety and potentially extending shelf life. Further research is recommended to optimize UV exposure time and intensity, evaluate its effects on saffron's chemical, sensory, and physicochemical properties, and assess its feasibility for large-scale industrial application. Pilot-scale studies are also recommended to establish standardized UV treatment conditions for commercial saffron processing.

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CONFLICT OF INTEREST STATEMENT

The authors declare that there are no conflicts of interest regarding the publication of this paper. All authors have read and approved the final manuscript and agree that no financial or non-financial interests could be perceived as potential conflicts.

DATA AVAILABILITY STATEMENT

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

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