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Effect of UVC Irradiation Using Pre- and Post-Drying on Quality of Dried Chili

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Highlights

- Drying chili with sunlight leads to a loss in quality and a risk to microorganism contamination.
- The integration of UVC with sunlight drying has potential for microbial safety and aflatoxin detoxification.
- The application of UVC before sunlight drying is recommended for the chili drying process.

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Abbreviations
AF=Aflatoxin
CFU=Colony-Forming Unit
Aw=Water Activity
MC=Moisture Content
PP=Polypropylene
ppb=part per billion
RYM=Rapid Yeast and Mold Count
UVC=Ultraviolet C

ABSTRACT

Background: Ultraviolet C (UVC) irradiation has been recognized as a non-thermal technology application in pre- and post-harvest agricultural work, since it is chemical-free and helps to reduce microorganisms and detoxify Aflatoxin (AF). Therefore, this study aimed to apply the UVC light before (pre-) and after (post-) sunlight drying in red chili and to investigate its qualities, yeast and mold growth, and AF level in dried red chili during storage at ambient temperature.

Methods: Red chilis were subjected to UVC irradiation at 5 min, 10 min, and 20 min pre- (UVC-Sun) or post-sunlight (Sun-UVC) drying. The physicochemical properties including Moisture Content (MC), Water Activity (Aw), surface color, pH, yeast and mold counts, and AF levels of dried chili, were investigated during storage. Data were analyzed using ANOVA, IBM software (SPSS version 23).

Results: MC and Aw tended to increase across all treatments during storage. UVC irradiation affected the surface color of chili, as UVC treatments tended to lower L* and a* values more than the control treatment (Sun). Sun and Sun-UVC treatments had significantly lower pH values compared to UVC-Sun treatments. Notably, UVC irradiation prior to sunlight drying was observed to be a superior method for reducing yeast and mold amounts and AF levels. In contrast, sunlight drying treatment resulted in higher yeast and mold amounts and AF levels. Therefore, using UVC irradiation prior to sunlight drying was more effective in these respects. This greater effectiveness may be attributed to the relatively smooth surface of chili, which enhances UVC light reflection and uniform exposure.

Conclusion: UVC irradiation and sunlight drying incorporation are recommended. Future studies should explore optimal exposure times and intensities to maximize safety and efficacy.

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Introduction

Capsicum annuum Linn. cultivar is a type of red hot chili. Superhot is a major Thai spice that could be a big seller in other countries. Due to cultivation and harvesting in a hot and humid climate, appropriate hygiene practices must be implemented for spices. In many countries that cultivate chili, like Thailand, the most common drying process is to utilize conventional methods, such as spreading chili on plastic sheet or directly on the ground and curing it in sunlight. Reducing Moisture Content (MC) to 10-15% (wet basis) requires approximately 7-20 days, depending on weather conditions. (Hossain, 2003; Oberoi *et al*., 2005). As a result, these methods may risk food safety by promoting bacteria, mold, yeast, and pest contamination from soil and environment. Moreover, high temperatures and humidity generate climatic conditions that promote crop infection by AF-producing fungus, resulting in AF production. Many human foods, agricultural commodities, fruits, and tree nuts in tropical and subtropical climates around the world may contain AF (Bandyopadhyay, Kumar and Leslie, 2007). Maize, peanut, cottonseed, tree nut, pistachio nut, spices, and other agricultural commodities have been identified as having the highest risk of AF contamination (Mokhtarian *et al*., 2020; Nwaehujor *et al*., 2022; Patel, Govindarajan and Dave, 1989). *Aspergillus* section *flavi* was found in dried chili samples packaged in major chili-producing countries, such as India, China, Thailand, and Pakistan. The samples were infected with more than 5 μg/kg of Aflatoxin B1 (AFB1) (Singh and Cotty, 2017). A recent study in Tunisia found mycotoxin levels in 5 out of 55 red chili powders above the European Union limit (Lasram, Hajri and Hamdi, 2022).

AFs are heat-stable compounds that can endure conventional cooking methods such as boiling, roasting, baking, and steaming. They develop in warm temperatures ranging from 25-35°C and require high humidity and moisture levels in meals, specifically greater than 14%. The deterioration of AFs occurs at elevated thermal temperatures between 237 °C to 306 °C. Hussain *et al*. (2011) observed that roasting peanuts at 150 °C for 120 min destroyed over 95% of AFB1. Moreover, naturally occurring AFs exhibited greater resistance to heat degradation than experimentally contaminated samples. Several strategies have been employed to inhibit synthesis or detoxify AFs, including chemical methods (such as hydrolytic, chlorinating, or oxidizing agents), biological methods (Dalie, Deschamps and Richard-Forget, 2010), and physical methods (such as UV light, heat, or ionizing radiation), and combination methods (for example, dehydroacetic acid plus ozonated water) (Esmaeilzadeh Nooghi *et al*, 2016). A powerful physical method is Ultraviolet C (UVC), which is a non-thermal, chemical-free technology for microbial decontamination, shelf-life extension, and chemical detoxification (Diao *et al*. 2015) that can augment chili commercial potential by preserving heat-sensitive bioactive, taste, and antioxidant chemicals after treatment. As previously stated, sunlight drying is a traditional method widely used to reduce the MC of chili, since it is simple and inexpensive. Nevertheless, this technique, which requires operation at a low ambient temperature, is time-consuming and poses a risk of contamination by pathogenic microbes. It was hypothesized that varied UVC can lead to varying changes in qualities and microorganisms of dried red chili. Thus, the purpose of this study was to apply the UVC light to red chili both before and after sunlight drying and to investigate its qualities, yeast and mold growth, and AF levels in dried red chili during storage at room temperature.

Materials and methods

Materials and chemicals

Fresh red chilie (*Capsicum annuum* Linn.) was purchased from a wholesale fresh market in Nakhonrachasima, Thailand. After transport to Laboratory, they were kept in a cool room at 10 °C. The chilies were free from insect infestation, disease symptoms, and any physical damage were selected for the study. Rapid Yeast and Mold Count (RYM; 3M Petrifilm, USA) plate, pH Buffer solution 4.0 and 7.0 (Mettler Toledo, Switzerland), sodium chloride (NaCl; KemAus, Australia), and ELISA test kit (Screen® EZ, Siam Inter Quality Co., Ltd., Thailand) were used in this study.

Chili preparation

Good chilies were divided into three groups. The first group served as the control, which was dried under sunlight until the MC fell below 10% and was not subjected to UVC irradiation (denoted Sun). The second group was dried under sunlight until the MC fell below 10%, and subsequently irradiated with UVC for 5, 10, and 20 min (denoted Sun-UVC). The last group was processed similarly to the second group, except that the chilies were irradiated with UVC prior to sunlight drying (denoted UVC-Sun). The fresh chilies (20 kg) were spread uniformly over a plastic wire mesh table (size 100 x 200 cm, height from ground 80 cm), which was covered with cheesecloth (Figure 1). The drying process was carried out under direct sunlight from 9.00 am to 3 pm (depending on the weather) in April 2024 (rainy season). Temperature in the range of 35 ^{o}C to 39 ^{o}C and relative humidity in the range of 65% to 73% were environmental conditions during drying. The MC of samples was randomly measured every day until it was below 10% (approximately 11-13 days). One hundred grams of dried chilies sample of each

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treatment were sampled and sealed in a polypropylene (PP) bag (8x12 inch) and stored at ambient temperature in the laboratory room, which ranged from 24 °C to 30 °C, with a relative humidity of 71% to 82%. All determinations were carried out at 30, 60, 90 and 120 days, three replicates of each treatment were performed.

Figure 1: Open sunlight drying of red chili in ambient temperature and relative humidity in April 2024

Experimental setup of UVC treatment

The irradiation was conducted utilizing a UVC chamber equipped with two UVC lamps (GL 20 T8, 253.7 NM; Philips) that provided a total radiation intensity of 10.5 W m^{-2}, which were positioned at the top, each with a power output of 20 W (254 nm). The UVC treatment was performed by carefully spreading dried chili (500 g) or fresh chili (1000 g) on the aluminum tray (size 32x60x5.5 cm). The lamp-to-sample distance was 8.5 cm, and sample thickness was approximately 1.5±0.5 cm. The UVC irradiation time was 5 (3.27 kJ m^{-2}), 10 (6.37 kJ m^{-2}), and 20 (12.60 kJ m^{-2}) min, designated as UVC_5, UVC_{10}, and UVC_{20}. During irradiation, the sample was turned five times until the time was up. The light intensity was measured using an optometer (Gigahertz-Optik X15, Germany). After each UVC treatment interval, the sample was kept in the PP bag and stored as mentioned in the chili preparation.

Assessment of MC and Water Activity (Aw)

MC was determined following the AOAC method (AOAC, 2000) using a hot air oven (Memmert UF110, Germany). Three grams of the ground sample were put in pre-weighed aluminum cans, and they were dried for 3 h at 105 °C. After drying, the cans were transferred to a desiccator with silica gel and allowed to cool for 30 min under dry conditions. The MC (% wet basis) was calculated based on the difference in the weight of the can (with sample) before and after drying. Aw meter (HD-3A, Aermanda, China) was used to measure Aw.

Surface color measurement

The surface colors of dried chili were evaluated using a colorimeter (MiniScan EZ 4500-L, HunterLab, USA). Color parameters were expressed in terms of CIE L* (lightness) and a* (redness and greenness) values. The mean was calculated from five random positions of each sample (Kalathil *et al*., 2023).

pH measurement

According to AOAC method (1982), 5 g of ground dried chili was mixed with 50 ml of distilled water and stirred for 5 min using a hot plate stirrer. The pH of the mixture was measured at 25 °C in a controlled air-conditioned environment using a calibrated pH meter (Model Eutech pH700, Singapore) standardized with buffer solutions of pH 4.0 and 7.0.

Yeast and mold evaluation

According to Teerasamit, Sangkai and Yuphet (2017), the 3M™ Petrifilm™ RYM plate was evaluated for yeast and mold. Ten grams of dried chili diluted with 90 ml of sterile 0.85% NaCl was weighed and was shaken 25 times to homogenize, then more dilutions were made as needed. The 3M Petrifilm RYM was incubated at room temperature for 48–60 h. The plates were counted immediately after the incubation period. Yeasts appeared as blue-green or off-white in color and developed small, distinct colonies. Mold colonies are usually blue but may also exhibit their inherent coloration. To calculate yeast and mold count, the total number of yeast and mold colonies per plate was multiplied by the corresponding dilution factor.

Determination of AF level

For qualitative analysis, an ELISA assay was performed using the Screen® EZ AF ELISA test kit (Siam Inter Quality Co., Ltd., Thailand) for AF detection. Briefly, 20 g of ground dried chili was weighed and mixed with 100 ml of 70% methanol solution. Then, the mixture was then shaken using a mechanical shaker, and the upper phase

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aqueous phase was filtered through Whatman No.4 filter paper. A portion of the filtered extract was diluted with washing buffer. The sample was ready for the ELISA test. The qualitative results were obtained by visually comparing color intensity of the sample with control standards at 0, 4, 10, 20 and 40 part per billion (ppb).

Statistical analysis

The experimental data performed in triplicate (n=3) were subjected to univariate analysis of variance (UNI-ANOVA) in a general linear model using IBM SPSS (Version 23) software. Before analyzing the difference of treatments, Levene’s Test of Equality of Error Variances was used. This test was used to assess the equality of variances for a variable calculated for groups. It tests the null hypothesis that the population variances are equal, indicated by a p-value, greater than the significance level of 0.05, which means the variance values of the tested groups are equal. After that, post hoc analysis was carried out using Duncan's Multiple Range Test of Honestly Significant difference at 0.05 level of significance.

Results and discussion

MC and Aw

The MC and Aw results are shown in Tables 1 and 2, respectively. MC, defined as the total available water in food products, was determined for all treatments. Table 1 presents the MC of dried chili stored under ambient conditions for 120 days. The initial MC across seven treatments ranged from 6.98% to 8.22%, with no statistically significant differences among treatments (p<0.05). A progressive increase in MC was observed during storage. After a 120-day storage period, seven treatments of dried chili exhibited an MC ranging from 11.85% to 12.65%, remaining within the permissible limit established by the Thai Agricultural Standard (TAS 3001-2010) for dried chili (less than 13.5%). Neither UVC irradiation prior to drying nor after drying had a substantial impact on the final MC. Aw, defined as the amount of unbound water present in a food matrix, was determined for all treatments (Table 2). The initial Aw values ranged from 0.32 to 0.42. A progressive increase in Aw was observed during storage. After 120 days of storage, Aw values ranged from 0.60 to 0.65. Aw can affect the shelf life of food in terms of resistance to microbial attack. Most microbes cannot proliferate on foods with Aw value of 0.60 or less. After 60 days of storage, Aw of all seven treatments surpassed 0.6. The products can become increasingly vulnerable to degradation due to microbial proliferation at this level. The duration of UVC irradiation (5, 10, and 20 min) did not affect MC or Aw. The result of MC and Aw increasing during storage might be due to two critical factors: the hygroscopic characteristics of dried chili and the moisture permeability of the PP packaging. Moisture from the atmosphere can penetrate the plastic bag, bond to the polymer through polar hydrogen bonds, and be absorbed by the dried chili inside the bag. Long storage time can increase MC and Aw of dried chili (Kent, 2018).

Table 1: Moisture Content **(**MC; %) of the red chili dried by sunlight incorporated with and without UVC irradiation

Treatments	Storage time (day)				
	0	30	60	90	120
Sun (control)	7.31±0.97 ^{ns}	9.80±0.41 ^{ns}	10.65±0.64 ^{ns}	11.15±0.68 ^{ns}	12.12±0.13 ^{ab}
Sun-UVC$_5$	7.90±0.22 ^{ns}	9.23±0.31 ^{ns}	10.24±0.04 ^{ns}	10.94±0.33 ^{ns}	11.85±0.07 ^{a}
Sun-UVC$_{10}$	7.94±0.17 ^{ns}	8.90±0.30 ^{ns}	10.19±0.12 ^{ns}	10.97±0.31 ^{ns}	12.39±0.46 ^{bc}
Sun-UVC$_{20}$	8.22±0.80 ^{ns}	9.18±0.33 ^{ns}	10.55±0.03 ^{ns}	10.85±0.68 ^{ns}	12.65±0.19 ^{c}
UVC$_5$-Sun	7.06±0.35 ^{ns}	8.94±0.44 ^{ns}	10.36±1.02 ^{ns}	11.07±0.41 ^{ns}	12.12±0.31 ^{ab}
UVC$_{10}$-Sun	6.98±0.08 ^{ns}	9.24±0.13 ^{ns}	10.23±0.21 ^{ns}	10.78±0.34 ^{ns}	12.00±0.07 ^{ab}
UVC$_{20}$-Sun	7.10±0.43 ^{ns}	9.25±0.13 ^{nsB}	9.87±0.32 ^{ns}	10.47±0.35 ^{ns}	12.08±0.13 ^{ab}

Values are the mean ± Standard Deviation (SD). Different letters in the same column are statistically significantly different at p<0.05, ns indicates no statistically significant difference.
UVC=Ultraviolet C

Table 2: Water Activity (Aw) of red chili dried by sunlight incorporated with and without UVC irradiation

Treatments	Storage time (day)				
	0	30	60	90	120
Sun (control)	0.40±0.01 ^{cd}	0.52±0.01 ^{cd}	0.54±0.01 ^{ab}	0.59±0.02 ^{ab}	0.62±0.02 ^{abc}
Sun-UVC$_5$	0.41±0.00 ^{de}	0.53±0.00 ^{d}	0.55±0.01 ^{bc}	0.61±0.01 ^{cd}	0.64±0.00 ^{cd}
Sun-UVC$_{10}$	0.42±0.00 ^{e}	0.52±0.01 ^{c}	0.56±0.00 ^{c}	0.62±0.00 ^{d}	0.65±0.01 ^{d}
Sun-UVC$_{20}$	0.42±0.01 ^{e}	0.52±0.00 ^{c}	0.56±0.00 ^{c}	0.63±0.00 ^{d}	0.65±0.01 ^{d}
UVC$_5$-Sun	0.32±0.02 ^{a}	0.48±0.00 ^{a}	0.53±0.01 ^{a}	0.58±0.02 ^{a}	0.60±0.01 ^{a}
UVC$_{10}$-Sun	0.36±0.01 ^{b}	0.51±0.00 ^{b}	0.56±0.01 ^{c}	0.59±0.00 ^{abc}	0.62±0.00 ^{ab}
UVC$_{20}$-Sun	0.39±0.00 ^{c}	0.51±0.00 ^{b}	0.56±0.00 ^{c}	0.60±0.00 ^{bc}	0.62±0.01 ^{bc}

Values are the mean ± Standard Deviation (SD). Different letters in the same column are statistically significantly different at p<0.05, ns indicates no statistically significant difference.
UVC=Ultraviolet C

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Surface color measurement

The surface color of dried chili, comprising L* and a*, was assessed. Color parameters are critical quality attributes for dried chili since visual appearance can affect consumer perception and purchasing decisions. Moreover, surface color can provide vital information about the product fundamental features, such as its acceptability for ingestion or specific culinary applications. The surface color values of dried chili were measured with a colorimeter and expressed in Hunter Scale values, specifically lightness (L*) and redness (a*) (Table 3). The control treatment (Sun) had an initial L* value of 26.80. All UVC-irradiated treatments showed significantly lower L* values than the Sun (p<0.05), ranging from 21.82 to 25.94 for Sun-UVC treatments and 21.46 to 23.65 for UVC-Sun treatments. During storage, all treatments showed a drop in L* value, indicating progressive darkening. By day 120, L* values did not differ significantly among treatments and ranged from 21.08 to 23.02. Before storage, a* values of all seven treatments varied from 18.78 to 27.00. At the end of storage (day 120), a* values varied from 16.51 to 21.52. However, storage time significantly affected a* values over 120 days (p<0.05). While UVC reduced initial L* and a* values, by day 120 differences disappeared. This suggests that storage time had a stronger effect than UVC. The a* value describes the intensity of red hue; a greater a* value suggests a darker red. The decrease in L* values and a* values of chili after drying and storage was probably due to the discoloration of carotenoids and other pigments. Tavakolipour and Mokhtarian (2016) found that the discoloration of dried chili varied with drying temperature. During the ripening state, chili produces a variety of distinct carotenoid pigments, which contribute to its rich and deep red color. As a result, dried chili and its derivatives can darken due to browning reactions caused by both non-enzymatic (Maillard) and enzymatic oxidation processes (Ergüneş and Tarhan, 2006; Kwanhathai, Duenchay and Rungnaphar, 2012). Browning pigment production is caused by high quantities of reducing sugar and amino acids in red chili (Vega-Galves *et al.*, 2008), which affects the quality of dried chili. Furthermore, sunlight drying exposes chili surfaces to oxygen through strong vaporization, which promotes pigment loss (Topuz and Ozdemir, 2004).

Table 3: L* and a* values of red chili dried by sunlight incorporated with and without UVC irradiation

Treatments	Storage time (day)				
	0	30	60	90	120
L* value					
Sun (control)	26.80±3.87 ^{b}	22.02±1.25 ^{ab}	24.12±2.10 ^{a}	21.95±2.02 ^{a}	22.35±0.90 ^{ns}
Sun-UVC$_5$	21.82±1.23 ^{a}	21.35±1.39 ^{a}	23.28±1.91 ^{a}	23.77±1.23 ^{ab}	21.96±1.21 ^{ns}
Sun-UVC$_{10}$	25.94±2.51 ^{b}	24.11±1.33 ^{bc}	24.10±1.42 ^{a}	24.11±1.16 ^{b}	22.09±1.45 ^{ns}
Sun-UVC$_{20}$	24.04±1.20 ^{ab}	23.71±1.99 ^{bc}	28.04±2.32 ^{b}	26.73±1.12 ^{c}	21.90±0.62 ^{ns}
UVC$_5$-Sun	21.46±1.39 ^{a}	25.24±0.98 ^{cd}	23.28±1.73 ^{a}	23.60±1.14 ^{ab}	23.02±2.42 ^{ns}
UVC$_{10}$-Sun	21.62±3.00 ^{a}	24.94±2.81 ^{cd}	24.68±1.49 ^{a}	22.43±1.27 ^{ab}	21.64±3.23 ^{ns}
UVC$_{20}$-Sun	23.65±2.06 ^{ab}	26.92±0.98 ^{d}	23.96±1.27 ^{a}	23.32±1.02 ^{ab}	21.08±2.50 ^{ns}
a* value					
Sun (control)	23.96±2.47 ^{c}	23.33±1.96 ^{ns}	26.58±2.29 ^{ns}	24.03±3.76 ^{bc}	19.30±2.00 ^{ab}
Sun-UVC$_5$	18.78±2.67 ^{a}	23.83±4.14 ^{ns}	23.51±0.73 ^{ns}	22.02±1.65 ^{ab}	16.51±2.89 ^{a}
Sun-UVC$_{10}$	23.02±3.61 ^{bc}	22.86±3.10 ^{ns}	22.76±3.54 ^{ns}	19.88±1.01 ^{a}	17.79±1.58 ^{a}
Sun-UVC$_{20}$	20.52±0.88 ^{ab}	23.30±2.92 ^{ns}	26.50±3.63 ^{ns}	24.99±2.86 ^{bc}	21.52±1.24 ^{b}
UVC$_5$-Sun	19.95±1.32 ^{ab}	23.62±1.58 ^{ns}	24.49±1.94 ^{ns}	20.71±1.27 ^{a}	17.75±3.05 ^{a}
UVC$_{10}$-Sun	27.00±1.74 ^{b}	23.72±1.73 ^{ns}	25.22±1.96 ^{ns}	25.35±1.73 ^{c}	17.23±2.97 ^{a}
UVC$_{20}$-Sun	23.88±2.14 ^{c}	23.77±2.02 ^{ns}	25.38±2.67 ^{ns}	23.76±1.65 ^{bc}	21.24±2.76 ^{b}

Values are the mean ± Standard Deviation (SD). Different letters in the same column are statistically significantly different at p<0.05, ns indicates no statistically significant difference.
UVC=Ultraviolet C

pH measurement

pH values of chili dried under sunlight, with or without UVC irradiation, are presented in Table 4. The pH value was within the range of 5.18 to 5.26, regardless of the treatments. pH values of all treatments decreased as the storage time increased. On the 120th day of storage, all treatments had lower pH values than before storage (day 0), ranging from 4.75 to 4.97. According to Kennao *et al*. (2020), the increased organic acid concentration caused a significant reduction in pH value of chili. During storage, inherent heated air exposed the dried chili to oxidation, therefore reducing their ascorbic acid content. In addition, it may be caused by contamination from microorganisms, particularly lactic acid bacteria, which produce organic acids during metabolism. In general, sunlight drying is an open system and chili is more susceptible to microbial contamination compared with enclosed systems, such as solar tunnel dryers (Mangaraj *et al*., 2001). In this study, Sun and Sun-UVC treatments had considerably lower pH values than UVC-Sun treatments (p<0.05), and pH values were not affected by UVC irradiation at intensities of 5, 10, or 20 min.

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Table 4: pH values of red chili dried by sunlight incorporated with and without UVC irradiation

Treatments	Storage time (day)				
	0	30	60	90	120
Sun (control)	5.26±0.01 d	5.07±0.02 b	4.97±0.01 bc	4.85±0.03 a	4.79±0.01 b
Sun-UVC_5	5.20±0.01 b	5.06±0.02 a	4.93±0.01 a	4.88±0.02 a	4.77±0.02 b
Sun-UVC_{10}	5.24±0.01 c	5.04±0.01 a	4.95±0.01 ab	4.86±0.03 a	4.75±0.02 a
Sun-UVC_{20}	5.18±0.02 a	5.05±0.01 a	4.97±0.02 c	4.87±0.02 a	4.78±0.01 b
UVC_5-Sun	5.23±0.01 c	5.18±0.01 c	5.06±0.02 d	5.04±0.01 b	4.94±0.01 c
UVC_{10}-Sun	5.20±0.01 ab	5.12±0.01 b	5.08±0.01 e	5.02±0.02 b	4.95±0.01 c
UVC_{20}-Sun	5.23±0.01 c	5.15±0.02 bc	5.13±0.01 f	5.06±0.02 b	4.97±0.02 d

Values are the mean ± Standard Deviation (SD). Different letters in the same column are statistically significantly different at $p<0.05$, ns indicates no statistically significant difference. UVC=Ultraviolet C

Yeast and mold evaluation

Table 5 shows yeast and mold of dried chili. Chili was sunlight dried previously, the reduction in UVC dose (3.27 kJ m^{-2}) (Sun-UVC_5) reduced yeast and mold from 3.1 log Colony-Forming Unit (CFU)/g (control) to 2.2 log CFU/g. The same amount of yeast and mold (2.2 log CFU/g) was achieved by doubling the UVC dose of 6.37 kJ m^{-2} (Sun-UVC_{10}). Increasing the UVC dose to 12.60 kJ m^{-2} (Sun-UVC_{20}) caused a slight increase to 2.5 log CFU/g. For applying UVC prior to sunlight drying treatments, a low UVC dose of 3.27 kJ m^{-2} (UVC_5-Sun) reduced yeast and mold to 2.1 log CFU/g. By increasing UVC dose to 6.37 kJ m^{-2} (UVC_{10}-Sun), yeast and mold levels obtained the same level. The highest UVC dose at 12.60 kJ m^{-2} (UVC_{20}-Sun) resulted in a slight increase to 2.3 log CFU/g. Yeast and mold levels were the highest in the UVC_{20} treatment group, both with UVC applied prior to drying and UVC applied after drying. This could be due to the two treatments (Sun-UVC_{20} and UVC_{20}-Sun) applied for the final sample. Microorganisms may proliferate when stored for prolonged periods at 10 °C. Hassan *et al.* (2020) reported that UVC treatment of hot pepper at 3.5, 7.0 and 10 kJ m^{-2} could reduce the total viable count of bacteria and fungal growth. There was a dependent decrease in microbial load with an increase in exposure power.

AF level

The level of AF was evaluated qualitatively by visually comparing the color intensity of the sample with AF standards at 0, 4, 10, 20, and 40 ppb. For chili dried first, UVC doses of 3.27 kJ m^{-2} (Sun-UVC_5) and 6.37 kJ m^{-2} (Sun-UVC_{10}) had the highest concentration of AF, remaining equal to the control (Sun) at 20 ppb. The highest UVC dose of 12.60 kJ m^{-2} (Sun-UVC_{20}) resulted in the lowest AF levels at 10 ppb. When UVC was applied before sunlight drying, UVC doses of 3.27 kJ m^{-2} (UVC_5-Sun), 6.37 kJ m^{-2} (UVC_{10}-Sun), and 12.60 kJ m^{-2} (UVC_{20}-Sun) achieved the exact same half reduction (10 ppb) as the highest UVC dose of Sun-UVC. The effectiveness of UVC irradiation is affected by microbial type, duration of exposure, light intensity (Koutchma, 2009; Singh, 2021), and surface characteristics of materials (Koutchma, 2009). Surface optical properties, including reflection, absorption, transmission, and scattering, can affect UV-C penetration. Porous or rough chili surfaces may scatter UVC light, perhaps diminishing its strength in a certain direction (Tchonkouang *et al*., 2023). At low doses, exposure may not be sufficient to cause significant harm on microorganisms and facilitate the degradation of AF; therefore, it allows some microorganisms to repair the damage and survive (Chen *et al*., 2020; Mercier *et al*., 2001). This investigation revealed that sunlight drying alone was inadequate to inhibit microbial proliferation or AF detoxification. In contrast, the integration of UVC irradiation with sunlight drying significantly reduced both yeast and mold populations as well as AF levels.

Table 5: Amount of yeast and mold and AF levels of dried red chili before storage (day 0)

Treatments	Yeast and Mold (log CFU/g)	AF (ppb)
Sun (control)	3.1±0.00 a	20±0.00 b
Sun-UVC_5	2.2±1.50 a	20±0.00 b
Sun-UVC_{10}	2.2±1.00 a	20±0.00 b
Sun-UVC_{20}	2.5±1.50 a	10±0.00 a
UVC_5-Sun	2.1±0.00 a	10±0.00 a
UVC_{10}-Sun	2.1±1.00 a	10±0.00 a
UVC_{20}-Sun	2.3±0.60 a	10±0.00 a

Values are the Mean ± Standard Deviation (SD). Different letters in the same column are statistically significantly different at $p<0.05$.
AF=Aflatoxin; CFU=Colony-Forming Unit; ppb=part per billion; UVC=Ultraviolet C

Conclusion

This study highlights the effect of UVC irradiation applied before or after sunlight drying on the quality, yeast and mold, and AF levels in dried chili. UVC treatment more effectively reduced surface color in terms of L* and a* and lowered yeast and mold, and AF levels, especially when combined with sunlight drying. A 2.1-2.5 log CFU/g reduction in the population of yeast and mold was observed following UVC irradiation at 3.27, 6.37, and 12.60 kJ m^{-2} compared to non-irradiated chili (3.1 log CFU/g). In addition, the highest UVC irradiation (12.60 kJ m^{-2}) and all doses of UVC irradiation used before sunlight drying are more effective to reduce AF levels from 20 ppb (control) to 10 ppb. Therefore, these results suggest that UVC irradiation combined with traditional drying can enhance

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microbial safety and reduce toxins in dried chilis. However, further research is required to assess how UVC doses affect the phytochemical properties of chilis such as capsaicin, which is the important chemical content of chili.

Author contributions

P.P and N.P designed, conducted the experimental work, analyzed the data, and wrote the manuscript; P.J., and J.S., conducted the experimental work; W.M., and N.S. designed and constructed UVC box. All authors read and approved the final manuscript.

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Conflicts of interest

The authors declare that there is no conflict of interest.

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Ethical consideration

Not applicable.

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