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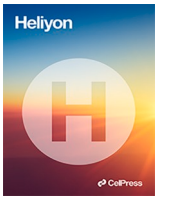

Research article

Effect of UV-C followed by storage on the fungal growth and aflatoxins content and storability characteristics of sesame (*Sesamum indicum*) seeds

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ABSTRACT

Background: UV-C has been suggested as an alternative technology in controlling food spoilage by primary and secondary pests. Its effects on the storability characteristics of sesame seeds during storage were evaluated.

Methods: The UV-C (0, 2.5, 5.0 and 10 kJ m^{-2}) was applied to explore its Effect on the fungal growth, aflatoxin content, water activity (a_w), colour and free fatty acid content (FFA) of sesame seeds.

Results: Applying the UV-C caused a significant reduction in the fungal growth, a_w, and the lightness (L* value) of sesame seeds in fresh and stored samples. However, significant increases ($p < 0.05$) in a^* and b^* values and the FFA of the sesame seeds were observed. Interestingly, the aflatoxins were not detected in the UVC-treated seeds even after storage for 12 months. The Partial Least Squares regression (PLS) analysis indicated that the application of 5.0 kJ m^{-2} followed by six months of storage reveals the greatest valid dose for UV-C treatments of sesame seeds.

Conclusion: UV-C treatment potentially shows effective quarantine security as an alternative method to chemical disinfection procedures to prolong the shelf life and improve the storability characteristics of sesame seeds.

1. Introduction

Sesame (*Sesamum indicum* L.), an ancient domesticated oilseed crop, has been around for thousands of years, and it contains a high level of oil, protein, and other nutrients, making it an important food and feed [1]. Sesame seeds contain 35–60% oil, 19–30% protein, 13.5% carbohydrate, and 5% ash [2] [3] [4]. Unfortunately, due to its high nutritive value, sesame seeds are commonly infested by several types of pests before and after harvest, resulting in severe qualitative and quantitative losses. During storage, sesame seeds are contaminated with mycotoxins, which are produced by many fungi. Hosseininia et al. [5] reported that fungi species of Aspergillus, such as *A. flavus* and *A. parasiticus* are mainly responsible for producing aflatoxins in seeds. According to the European Union maximum level of the total aflatoxin in seeds and grains should not exceed 4 μg/kg [6].

Recently, numerous preservative methods, such as freezing, cooling, pasteurization, canning, have been explored to improve food

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safety [7]. The UV-C (200–280 nm) is considered an alternative method to prevent food spoilage. The Food and Drug Administration permits UV-C application in food manufacturing [8]. Lately, UV-C's awareness of the application has increased due to its advantages in extending the shelf life of food. Lima et al. [9] reported that food's prolonged shelf life after the UV-C treatment might be associated with the enzymes' inhibition and the microbial load reduction. Since UV-C damages the DNA of the microorganisms, subsequently by inactivation and death [10].

Furthermore, UV-C treatment causes various physiological changes in agricultural products that decrease postharvest losses, improve nutritional value, and extend their shelf life [11]. Hassan et al. [10] reported that UV-C doses of 3.5, 7.0 and 10.4 kJ m^{-2} reduced the microbial load, eradicated Salmonella and *E. coli* and improved the total phenolic content and flavonoids, the antioxidant activity of the spices. Additionally, Faraji et al. [12] stated that the amount of the aflatoxins (B1, B2, G1 and G2) in rice grains significantly decreased with an increase in the UV-C dose. At the dose of 4.88 Jcm $^{-2}$, the amount of the aflatoxins reduced to more than 70% in the grains. Furthermore, UV-C treatments (0.8528, 1.2318 and 1.7238 mW/cm^2) could deactivate lipase enzymes and decrease the rate of free fatty acids formation in crude palm oil during storage for four weeks [13].

Similarly, UV-C radiation has many advantages, such as easy application, low cost, lack of toxic wastes, and not accumulating radioactivity in foods 14,15. However, as one of the ways of the UV-C radiation is the free radical formation, adverse effects may occur, containing oxidation of proteins and lipids, resulting in changes in colour and lipid oxidation which result in limiting the quality of food products and manufacturing application [15] [16] [17] [18]. However, the extensive uses of UV-C in the industry depend on factors like dose rate, the quantity of dose absorbed, the presence or absence of oxygen and temperature 19,20. So far, few studies have evaluated the impact of UV-C radiation on oilseeds. Therefore, this study aimed to assess the changes in storability characteristics, and physicochemical properties of UVC-treated sesame seeds. Accordingly, different UV-C doses were applied to investigate the variations in the fungal growth, aflatoxin content, a_w, colour parameters (*L*, a*, b** values, and *ΔE*) and FFA during the storage of sesame seed.

2. Material and methods

2.1. Sample preparation and UV-C treatment

Sesame seeds (*Sesamum indicum*) were obtained from the was obtained from the Strategic Reserves Department at the Agricultural Bank of Sudan. The seeds were cleaned and freed from broken seeds and impurities before being stored in plastic bags at 4 °C. The UV-C treatments were performed according to Hassan et al. [10] with slight modifications. Sesame seeds (300 g) were packed and placed in a metal box 65 * 90 * 45 cm^3) equipped with a UV-C lamp (75 W). The Seeds were exposed to UV-C doses of 2.5, 5.0 and 10.0 kJ m^{-2}. During the treatments, the seeds packages were placed at a distance of 15 cm from the UV-C source. Three replicates of each treatment were performed. Untreated samples were defined as control. The control and UVC-treated seeds were backed into vacuum plastic bags and stored at room temperature 25 °C ± 2 °C for 0, 6 and 12 months, respectively.

2.2. Water activity of the sesame seeds

The Water activity (a_w) in untreated and UV-C treated sesame seeds was determined at 25 °C (±0.2 °C) using hygrometer with selectable sensors for determination of air humidity, material moisture, and water activity (humimeter RH2, Schaller, Vienna, Austria), equipped with a temperature-controlled system which allow to have a temperature stable sampling environment according to the AOAC [21].

2.3. Fungal growth and aflatoxin content of the sesame seeds

The fungal growth in control and UV-C-treated sesame seeds was determined according to AOAC [21] standard methods. One ml of the selected dilution of each sample was poured and platted on petri dishes containing sterile Potato Dextrose Agar (PDA) and then incubated at 25 ± 2 °C for 5 days. The colony formation were observed each day. The fungal growth was determined as a colony forming unit per gram (log cfu/g).

The aflatoxin content (AFG1, AFG2, AFB1 & AFB2) of the sesame seeds was determined with HPLC according to AOAC [21]. The mobile phase of the HPLC consisted of acetonitrile: water (80:20, v/v) and a flow rate of 1 ml/min. The column Carbon-18 (C18) temperature was maintained at 40 °C. All samples and standards were t analyzed using HPLC triple quadrupole system. The amount of the AFB1, AB2, AFG1 and AFG2 in the standard solution were 1.0, 0.60, 0.62 and 1.0 μg/ml. Therefore, the Method Quantification Limit (MQL) was adjusted to 0,06, 0.21, 0.03 and 0.07 μg/kg, for the AFG1, AFG2, AFB1 & AFB2, respectively, and the Method Detection Limit (MDL) were AFG2 = 0.03 μg/kg; AFG1 = 0.13 μg/kg; AFB2 = 0.015 μg/kg; AFB1 = 0.04 μg/kg.

2.4. Colour parameters of the sesame seeds

The colour parameters L*, a* and b* of control and treated seeds were determined using a colourimeter (Chroma Meter CR 400, brand Minolta, Japan). The equipment was calibrated using a standard white reflector plate. About 50.0 g of sesame seeds were filled into Petri dish. The changes in colour (*Δ E*) was estimated using the following equation

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2}$$

2.5. Determination of free fatty acid content of tsesame seeds

The FFA of control and treated seeds was determined according to the Zhao et al. [22] method. Briefly, 5 g of sesame seeds were extracted in ethanol (25 ml). The volume of the extract was completed to 25 ml with ethanol and then titrated with 0.1 N KOH using phenolphthalein (3%) as indicator. FFA content was calculated as mg KOH requisite to neutralize them on the dry matter at the 1-g grain.

2.6. Statistical analysis

All data were the mean of triplicate. Data were analyzed using two-way ANOVA, and the least significant difference (LSD) was calculated at $P < 0.05$. In addition, multivariate analysis HJ-Biplot PCA and Linear Partial Least Squares Regression test (PLS) validated were performed using the XLSTAT software 23,24.

3. Results and discussion

3.1. Effect of UV-C treatment followed by storage on the water activity, fungal growth and aflatoxin content of sesame seeds

Table 1 describes the changes in water activity (a_w) of control and UVC-treated sesame seeds during storage. As shown in the table, the a_w of the control sample was found to be 0.196. A significant ($P < 0.05$) reduction in water activity was observed on treated seeds to 0.184, 0.182 and 0.177 when the seeds were treated at 2.5, 5.0 and 10.0 kJm^{-2}, respectively. However, the seeds' a_w was significantly ($P < 0.05$) higher than that of unstored seeds, particularly for untreated seeds (Table 1). It was stated that water activity is an essential factor influencing a product's chemical reaction, microbial growth and shelf-life stability 25,26.

Fig. 1 illustrates the fungal growth of the control and UVC-treated seeds before and after storage. Before the treatment, the fungal growth in the seeds was found to be 4.56 log cfu/g. Treating of the sesame seeds with the UVC gradually reduced the fungal load significantly ($P < 0.05$), and the lowest value of the fungal growth 4.1 log cfu/g was observed at the dose of 10.0 kJm^{-2}. For both treated and untreated samples, a significant ($p < 0.05$) on the fungal load was observed during the storage, particularly those treated at 10.0 kJm^{-2} and stored for 6 months (4.07 log cfu/g) and 12 months (3.8 log cfu/g).

The obtained results agreed with those stated by Hassan et al. [10], who reported that UV-C doses of 3.5, 7.0 and 10.4 kJ m-2 reduce the fungal load in hot pepper, fennel and coriander. It has been stated that the UV-C's damage the fungal's DNA transcription and replication. Hence, this damage might diminish the spore multiplication 27,28. In addition, UVC encourages specific enzymes that motivate the production of phenolics that have defensive responses by strengthening the cell wall 29,30. Although fungi can repair DNA damage caused by UV-C radiation over the storage period [31], our results indicated that the UVC doses, particularly at 5.0 and 10.0 kJm-2, efficiently decreased fungal growth in sesame seeds even after 12 months of storage.

The aflatoxin content (B1, B2, G1, and G2) of the untreated and UVC-treated seeds before and after the storage is illustrated in Table 2. For the untreated samples, the AFB1, AFB2, AFG1 and AFG2 were in the range of 0.04–0.07, 0.015–0.03, 0.13–0.21 and 0.03–0.06 μg/kg, respectively. However, the aflatoxins were also unavailable in the treated seeds even after storage for 12 months. Despite the control and UVC-treated seeds being stored at the optimal environment for fungal growth, the aflatoxin level in the seeds was not raised and still below the permissible limits of aflatoxins in oil seeds 5–10 μg/kg. The findings of this study agree with those obtained by Faraji et al. [12], who stated that increasing the UVC dose significantly reduces the amount of the aflatoxin in rice grain. According to these findings, aflatoxin (B1, B2, G1, and G2) was sensitive to UV irradiation. Hence, this might be considered an efficient controlling postharvest processing method that could be applied to preserve agricultural products' safety and quality.

3.2. Effect of UV-C treatments followed by storage on the colour of sesame seeds

The colour changes (L*, a* and b*) of the control and UVC-treated sesame during storage were described in Table 3. As shown in the table, both UVC doses and storage time caused significant changes in the lightness (L*), redness (a*) and yellowness (b*) of sesame seeds.

The L* value of the seeds was found to be 64.6, and it was gradually reduced after the UV-C treatment. It was significantly ($P <$

Table 1
Effect of UV-C treatments followed by storage on the water activity of sesame seeds.

UV-C dose (kJ m−2)	Storage period		
	0 month	6 months	12 months
0.0	0.196 ± 0.005^{aB}	0.200 ± 0.001^{aB}	0.280 ± 0.002^{aA}
2.5	0.184 ± 0.003^{bC}	0.192 ± 0.002^{bB}	0.261 ± 0.002^{bA}
5.0	0.182 ± 0.002^{bB}	0.179 ± 0.000^{cB}	0.226 ± 0.001^{cA}
10.0	0.177 ± 0.003^{bB}	0.177 ± 0.000^{cB}	0.214 ± 0.003^{dA}

Values are means (±SD) of triplicate samples. Values with the same letter are not significantly different ($P > 0.05$) as assessed by LSD. Capital caps letters indicate significant differences among storage periods, whereas lower caps letters indicate significant differences among UVC doses.

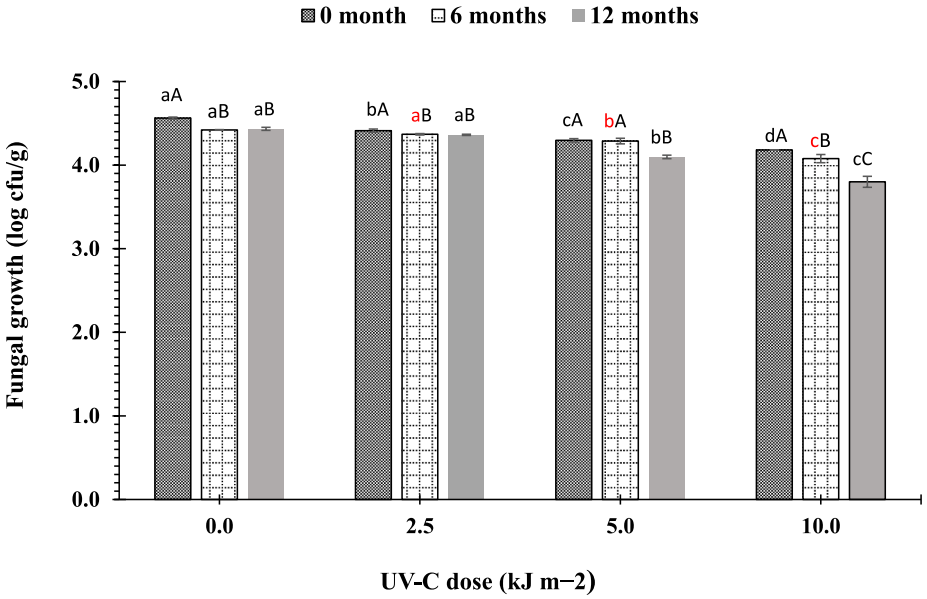

Fig. 1. Effect of UV-C treatments followed by storage on the fungal growth (log cfu/g) of sesame seeds. Values are means (±SD) of triplicate samples. Values with the same letter are not significantly different ($P > 0.05$) as assessed by LSD. Capital caps letters indicate significant differences among storage periods, whereas lower caps letters indicate significant differences among UVC doses.

Table 2
Effect of UV-C treatments followed by storage on the aflatoxin of sesame seeds.

UV-C dose (kJ m^{-2})	Storage period (months)	Aflatoxins (μg/kg)			
		AFG1	AFG2	AFB1	AFB2
0.0	0	< MQL	< MQL	< MQL	< MQL
	6	< MQL	< MQL	< MQL	< MQL
	12	< MQL	< MQL	< MQL	< MQL
2.5	0	ND	ND	ND	ND
	6	ND	ND	ND	ND
	12	ND	ND	ND	ND
5.0	0	ND	ND	ND	ND
	6	ND	ND	ND	ND
	12	ND	ND	ND	ND
10.0	0	ND	ND	ND	ND
	6	ND	ND	ND	ND
	12	ND	ND	ND	ND

The results were calculated in dry basis. MQL (Method Quantification Limit) in μg/kg, G2 = 0.06; G1 = 0.21; B2 = 0.03; B1 = 0.07. ND = Not detected. The results below MDL ((Method Detection Limit) in μg/kg, G2 = 0.03; G1 = 0.13; B2 = 0.015; B1 = 0.04) reported as ND.

Table 3
Effect of UV-C treatments followed by storage on the colour of sesame seeds.

UVC doses (kJ m−2)	*L**			*a**			*b**		
	Storage period (months)			Storage period (months)			Storage period (months)		
	0	6	12	0	6	12	0	6	12
0.0	64.6 ± 1.78^{aA}	61.6 ± 0.56^{aB}	61.5 ± 1.00^{aB}	0.5 ± 0.38^{aC}	1.5 ± 0.25^{aB}	4.5 ± 0.38^{aA}	23.0 ± 0.95^{aB}	22.7 ± 0.60^{aB}	28.0 ± 0.44^{aA}
2.5	62.2 ± 0.68^{bA}	60.9 ± 0.62^{bAB}	60.1 ± 1.59^{bcB}	0.5 ± 0.24^{aC}	1.7 ± 0.03^{aB}	5.1 ± 0.63^{aA}	24.0 ± 0.26^{aB}	23.3 ± 0.05^{aB}	28.5 ± 0.63^{aA}
5.0	61.8 ± 0.16^{bcA}	59.98 ± 1.20^{cB}	58.6 ± 0.91^{cdC}	0.8 ± 0.16^{aC}	1.8 ± 0.10^{aB}	5.5 ± 0.28^{aA}	24.2 ± 0.75^{aB}	23.4 ± 0.14^{aB}	28.7 ± 1.39^{aA}
10.0	60.6 ± 0.43^{cA}	57.7 ± 0.55^{dB}	57.1 ± 0.91^{dB}	0.8 ± 0.06^{aC}	1.9 ± 0.14^{aB}	5.6 ± 0.36^{aA}	24.5 ± 0.03^{aB}	23.2 ± 0.00^{aB}	29.3 ± 0.49^{aA}

Values are means (±SD) of triplicate samples. Values with the same letter are not significantly different ($P > 0.05$) as assessed by LSD. Capital caps letters indicate significant differences among storage periods, whereas lower caps letters indicate significant differences among UVC doses.

0.05) decreased when the seeds were exposed to the doses of 2.5, 5.0 and 10.0 kJ-2 to 62.2 m 61.8 and 60.6, respectively. During the storage of the seeds for 6 and 12 months, the L* value of the control and UVC-treated seeds was found significantly ($P < 0.05$) decreased for each UV-C dose (Table 3).

Increasing the UV-C doses caused an increase in the values a* and b* of the sesame seeds (Table 2). However, compared to control seeds, there was no significant ($P < 0.05$) effect of the UV-C doses on a* values of the sesame seeds observed. Control seeds showed less values of a* (0.5) and b* (23.0) than those treated with UV-C at the dose of 5.0 to 10.0 kJm^{-2} for each storage time. However, significant ($P < 0.05$) changes in the a* values were observed in the stored seed treated with UV-C. The stored seeds displayed higher a* values than those without storage for each UV-C dose. Moreover, the highest a* and b* values, 5.6 and 29.3, were observed in the sesame seeds exposed to 10.0 kJm^{-2} and stored for up to 12 months.

Fig. 2 shows the total difference in colour (ΔE) of the control and treated sesame seeds before and after storage. It was clearly observed that the ΔE in the seeds significantly ($P < 0.05$) increased as the doses were increased. The ΔE was found to be 2.6, 3.06 and 4.28 when the seeds were treated with UV-C doses of 2.5, 5.0 and 10.0 kJm^{-2}. Similar findings were also observed in each storage time. Likewise, the ΔE was significantly ($P < 0.05$) increased during the storage of UVC-treated sesame seeds. For each UVC dose, the ΔE value significantly increased as the storage time was increased.

Obtained results revealed that the UV-C treatments at 2.5, 5.0 and 10.0 kJm^{-2} caused observed colour changes in the seeds. It has been stated that the variations in colour due to the UV-C treatments in goat and chicken meat are also reported by Refs. 15,29. The change in colour after UV-C treatment of the seeds might be a result of lipid oxidation and protein denaturation of seeds leading to exposure of hydrophobic groups and increased free water changing meat surface reflectance 14,29. Furthermore, this change in the colour might be due to the effect of UV-C on the main groups of pigment that contribute to the seeds' colour [32].

3.3. Effect of UV-C treatments followed by storage on the free fatty acid of sesame seeds

The effect of UV-C alone and/or storage time on the free fatty acid (FFA) content of sesame seeds was described in Fig. 3. The FFA content in the seeds was significantly affected by the UV-C treatment, and it was increased as the doses were increased. Before treatment, the FFA was found to be 2.6 mg/g. Treatment of the seeds at 2.5, 5.0, and 10 kJm^{-2} significantly increased their FFA content to 2.8, 2.9 and 2.9 mg/g, respectively. Similarly, storing the control and UVC-treated seeds to 6 and 12 months increased the content of the FFA. However, a more significant increase of the FFA (11.5 & 15.4%) was found in the control seeds that were stored for 6 and 12 months.

Nevertheless, the level of increase of FFA content ranged between 3.6 and 7.7% in the treated seeds. Said et al. [12] reported that the reduction of lipase activity which is a response to the formation of the FFA, might reduce FFA development in treated seeds during storage. Since the FFA is considered an index of rancidity and is associated with the development of off-flavour and off-odours in oil during storage [33]. Therefore, UVC energy could be an optimum preserve technique to destroy the enzymes and, in this way, inhibit the development of the FFA in stored seeds and stabilize their shelf life.

3.4. Multivariable analysis

In this study, the Principal Component Analysis (PCA) was performed to describe the interrelationships between UV-C doses,

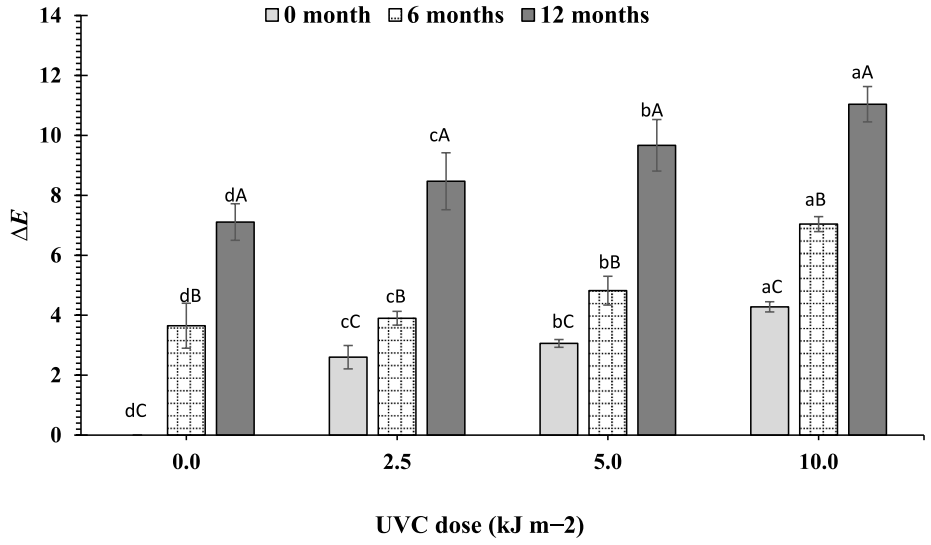

Fig. 2. Effect of UV-C treatments followed by storage on the changing colour (ΔE) of sesame seeds. Values are means (±SD) of triplicate samples. Values with the same letter are not significantly different ($P > 0.05$) as assessed by LSD. Capital caps letters indicate significant differences among storage periods, whereas lower caps letters indicate significant differences among UVC doses.

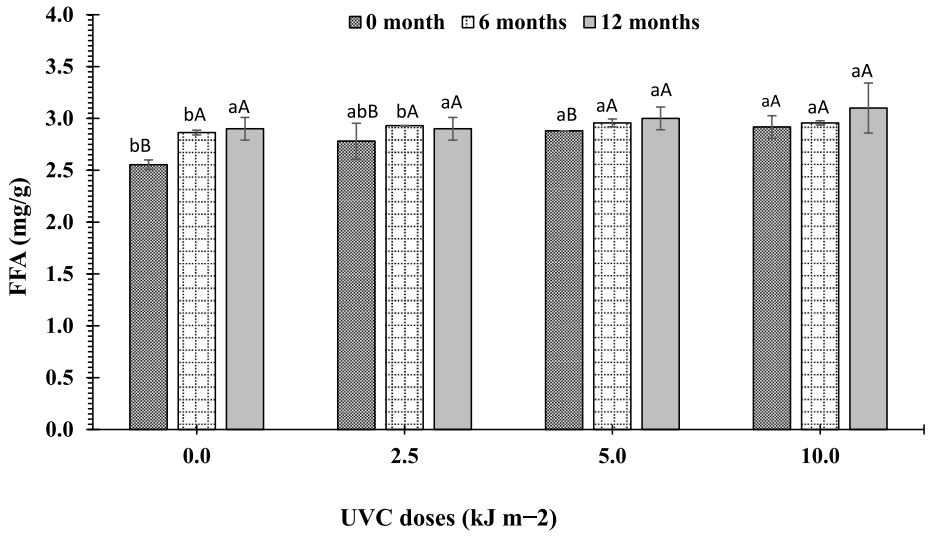

Fig. 3. Effect of UV-C treatments followed by storage on the free fatty acid (mg/g) of sesame seeds. Values are means (±SD) of triplicate samples. Values with the same letter are not significantly different ($P > 0.05$) as assessed by LSD. Capital caps letters indicate significant differences among storage periods, whereas lower caps letters indicate significant differences among UVC doses.

storability characteristics and quality parameters of a sesame seed. As illustrated in Fig. 4, the total variability of the plotted component was found to be 93.76% resulting from the contribution of 68.42% and 25.34% for F1 and F2, respectively. Additionally, there was a strong positive correlation between UV-C-treated seeds and the measured parameters. As stated by Yan and Fregeau-Reid [34], the variable eccentricity and observation that act $< 90°$ angle is positively correlated, whereas that of angels $> 90°$ is associated with negative correlation. However, those with a 90° angle do not explain any correlation in the biplot. Accordingly, three groups occurred in the biplot to describe the interaction between the impact of the UV-C doses alone or followed by storage on the storability and quality characteristics of the sesame seeds. The untreated seeds showed greater values of the fungal load and L* value of the sesame seeds. These observations revealed that UV-C treatments of sesame seeds could improve their storability and nutritional characteristics.

Fig. 5 describes the validation of the UV-C doses and their interactive impacts on the sesame seeds. The model was conducting the Partial Least Squares regression analysis (PLS) according to Ref. [24]. Four groups were observed in the model describing the effect of the UVC in the studied parameters. According to these groups, the PLS model showed a positive validation score for most of the studied parameters. However, the PLS indicated that the use of UV-C at 5.0 kJm-2 followed by 6 months' storage reveals the most valid treatment for functional food applications, which might consider for food industry applications.

4. Conclusion

This study was undertaken to validate the doses of UV-C energy of sesame seeds to optimize the dose, improving sesame seed's storability and quality properties. As a result, the UV-C treatments eliminate fungi and prevent aflatoxin production even after 12 months. In addition, it caused a decrease in FFA formation, particularly in stored seeds. However, it causes a change in the sesame seed's colour. In addition, it decreases the L* value and increases the a* and b* values. According to the PLS, the application of 5.0 kJm^{-2} showed the most positive validation score for most of the studied parameters. However, further research on food radiation concerning its impact on individual fungal growth, mycotoxin profiling, and the storability properties of the sesame is needed. Furthermore, to improve its efficiency to the extent of the practical application of the non-chemical alternative effective preservative method in food production and grain technology.

Declarations

Author contribution statement

Amro B. Hassan: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Funding statement

This research received no external funding.

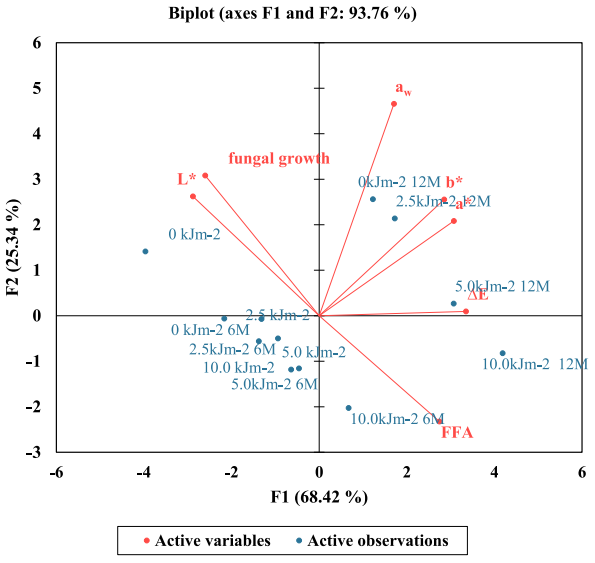

Fig. 4. Principal Component Analysis (PCA) of the fungal growth, FFA, colour values (L*, a* & b*), changes in colour ΔE and water activity (a_w) of sesame seeds.

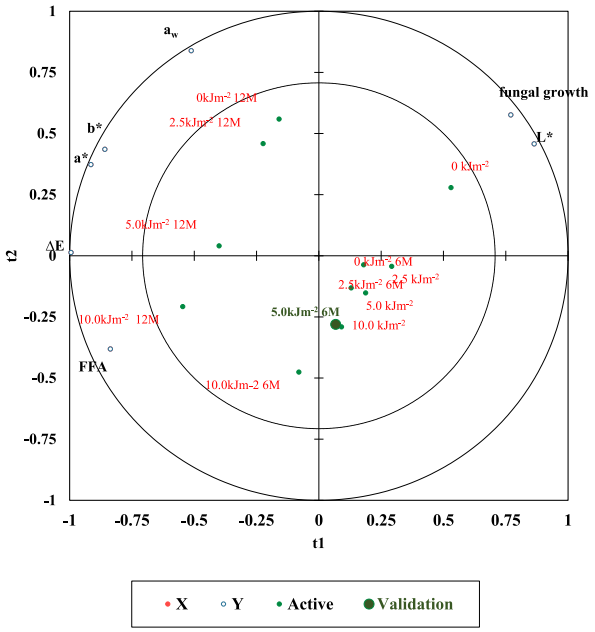

Fig. 5. Partial Least Squares regression analysis (PLS) of the fungal growth, FFA, colour values (L*, a* & b*), changes in colour *ΔE* and water activity (a_w) of sesame seeds.

Data availability statement

Data included in article referenced in article.

Additional information

No additional information is available for this paper.

References

[1] U. Najeeb, M.Y. Mirza, G. Jilani, A.K. Mubashir, W.J. Zhou, Sesame, in: S. Gupta (Ed.), Technological Innovations in Major World Oil Crops, vol. 1, Springer, New York, NY, 2012, https://doi.org/10.1007/978-1-4614-0356-2_5P.

[2] R. Nimmakayala, S. Perumal, U.K. Mulpuri, Reddy, Sesamum, in: C. Kole (Ed.), Wild Corp Relatives: Genomic and Breeding Resources, Vol Oilseeds, Springer, Berlin, 2011, pp. 261–273.

[3] M. Elleuch, S. Besbes, O. Roiseux, C. Blecker, H. Attia, Quality characteristics of sesame seeds and by-products, Food Chem. 103 (2007) 641–650.

[4] A.A. Aly, M.M. Refaey, A.M. Hameed, A. Sayqal, S.A. Abdella, A.S. Mohamed, H.A. Ismail, Effect of sesame seeds powder with different ratio on microstructural and some properties of low fat Labneh, Arab. J. Chem. 13 (2020) 7572–7582, https://doi.org/10.1016/j.arabjc.2020.08.032.

[5] A.R. Hosseininia, M. Vahabzadeh, M. Rashedinia, B. Riahi-Zanjani, G. Karimi, A survey of aflatoxins in sesame seeds imported into Khorasan Province, Iran, Mycol. Res. 30 (2013) 43–46, https://doi.org/10.1007/s12550-013-0186-7.

[6] CAC. Committee on food additives and contaminants, joint FAO/WHO food standards programme, codex alimentarius commission, Report of the 37th session of the Codex Committee on Food Additives and Contaminants (2005) 18–20.

[7] S.K. Amit, M.M. Uddin, R. Rahman, et al., A review on mechanisms and commercial aspects of food preservation and processing, Agric. Food Secur. 6 (2017) 51, https://doi.org/10.1186/s40066-017-0130-8.

[8] United States Food and Drug Administration (USFDA), Ultraviolet radiation for the processing and treatment of food. Code of federal regulations (21 CFR 179 section 179.39), Fed. Regist. 65 (2000) 230.

[9] F. Lima, K. Vieira, M. Santos, P. Mendes de So, Effects of radiation technologies on food nutritional quality, in: A.V. Diaz (Ed.), Descriptive Food Science, Intech open, London, 2018.

[10] A.B. Hassan, S.A. Al Maiman, K.A.S. Elkhatim, N.A. Elbadr, S. Alsulaim, M.A. Osman, I.A.M. Ahmed, Effect of UV-C radiation treatment on microbial load and antioxidant capacity in hot pepper, fennel and coriander, LWT (Lebensm.-Wiss. & Technol.) 134 (2020), 109946.

[11] G. Shama, P. Alderson, UV hormesis in fruits: a concept ripe for commercialisation, Trends Food Sci. Technol. 16 (2005) 128–136.

[12] H. Faraji, F.T. Yazdi, N. Razmi, The influence of ultraviolet radiation on aflatoxin producing Aspergillus species' isolated from Iranian rice, Toxicol Rep 9 (2022) 1528–1536.

[13] S.D. Said, T. Maimun, T.M. Asnawi, A. Muslim, Inhibition of free fatty acids generation in crude palm oil during storage by using UV-C light treatment, IOP Conf. Ser. Mater. Sci. Eng. C. 854 (2020), 012015.

[14] H. Chun, K. Jooyoun, K. Chung, M. Won, K.S. Song, Inactivation kinetics of Listeria monocytogenes, Salmonella enteric serovar Typhimurium, and Campylobacter jejuni in ready-to-eat sliced ham using UV-C irradiation, Meat Sci. 83 (2009) 599–603.

[15] T. Koutchma, L. Forney, C. Moraru, Principles and applications of UV technology, in: T. Koutchma, L. Forney, C. Moraru (Eds.), Ultra- Violet Light in Food Technology, FL: CRC Press, Boca Raton, 2009, pp. 1–32.

[16] C.A. Lázaro, C.A. Conte-Junior, M.L.G. Monteiro, A.C.V.S. Canto, B.R.C. Costa-Lima, et al., Effects of ultraviolet light on biogenic amines and other quality indicators of chicken meat during refrigerated storage, Poultry Sci. 93 (2014) 2304–2313, https://doi.org/10.3382/ps.2013-03642.

[17] B. Molina, M.I. Sáez, T.F. Martínez, J.L. Guil-Guerrero, M.D. Suárez, Effect of ultraviolet light treatment on microbial contamination, some textural and organoleptic parameters of cultured sea bass fillets (Dicentrarchus labrax), Innovat. Food Sci. Emerg. Technol. 26 (2014) 205–213, https://doi.org/10.1016/j.ifset.2014.07.002.

[18] M.L.G. Monteiro, E.T. Marsico, A.C.V.C.S. Canto, B.R.C. Costa- Lima, M.P. Costa, et al., Impact of UV-C light on the fatty acid profile and oxidative stability of Nile tilapia (Oreochromis niloticus) fillets, J. Food Sci. 82 (2017) 1028–1036.

[19] F.O. Bottino, B.L. Rodrigues, J.D.N. Ribeiro, C.A. Lazaro, C.A. Conte- Junior, Influence of UV-C radiation on shelf life of vacuum package tambacu (Colossoma macropomum x Piaractus mesopotamicus) fillets, J. Food Process. Preserv. 41 (2017) 1–11.

[20] L. Rizzotti, N. Levav, F. Fracchetti, G.E. Felis, S. Torriani S, Effect of UV-C treatment on the microbial population of white and red wines, as revealed by conventional plating and PMA-qPCR methods, Food Control 47 (2015) 407–412.

[21] AOAC Official Methods of Analysis of Association of Official Analytical Chemists, sixteenth ed., Association of Official Analytical Chemists, 2005.

[22] S. Zhao, S. Xiong, C. Qiu, Y. Xu, Effect of microwaves on rice quality, J. Stored Prod. Res. 43 (2007) 496–502.

[23] N.P. Vidal, C.F. Manful, T.H. Pham, P. Stewart, D. Keough, R.H. Thomas, The use of XLSTAT in conducting principal component analysis (PCA) when evaluating the relationships between sensory and quality attributes in grilled foods, MethodsX 7 (2020), 100835.

[24] M. Tenenhaus, J. Pagès, L. Ambroisine, C. Guinot C, PLS methodology for studying relationships between hedonic judgments and product characteristics, Food Qual. Prefer. 16 (2005) 315–325.

[25] T.Y. Tunde-Akintunde, B.O. Akintunde, Some physical properties of sesame seed, Biosyst. Eng. 88 (2004) 127–129.

[26] M.S. Tapia, S.M. Alzamora, J. Chirife, Effects of water activity (aw) on microbial stability: as a hurdle in food preservation. Water activity in foods, Fundament. App. (2007) 239–271, https://doi.org/10.1002/9780470376454.ch10.

[27] G.U.L. Braga, D.E.N. Rangel, É.K.K. Fernandes, S.D. Flint, D.W. Roberts, Molecular and physiological effects of environmental UV radiation on fungal conidia, Curr. Genet. 61 (2015) 405–425.

[28] X. Wu, W. Guan, R. Yan, J. Lei, L. Xu, Z. Wang, Postharvest Biology and Technology Effects of UV-C on antioxidant activity, total phenolics and main phenolic compounds of the melanin biosynthesis pathway in different tissues of button mushroom, Postharvest Biol. Technol. 118 (2016) 51–58.

[29] G.H. Goldman, E. Kafer, Aspergillus nidulans as a model system to characterize the DNA damage response in eukaryotes, Fungal Genet. Biol. 41 (2004) 428–442.

[30] H.L. Degala, A.K. Mahapatra, A. Demirci, G. Kannan, Evaluation of non-thermal hurdle technology for ultraviolet-light to inactivate Escherichia coli K12 on goat meat surfaces, Food Control 90 (2018) 113–120.

[31] C.V. A, C. da, S. Canto, M.L.G. Monteiro, B.R.C. da Costa-Lima, C.A. Lázaro, E.T. Marsico, et al., Effect of UV-C radiation on Salmonellaspp. reduction and oxidative stability of caiman (Caiman crocodilus yacare) meat, J. Food Saf. 39 (2018), e12604, https://doi.org/10.1111/jfs.1260.

[32] A.C.V.C.S. Canto, B.R.C. Costa-Lima, S.P. Suman, M.L.G. Monteiro, F.M. Viana, et al., Color attributes and oxidative stability of longissimus lumborum and psoas major muscles from Nellore bulls, Meat Sci. 121 (2016) 19–26.

[33] M. Naradisorn, Effect of Ultraviolet Irradiation on Postharvest Quality and Composition of Food. Food Losses, Sustainable Postharvest and Food Technologies, Academic press an imprint of Elsevier, 2021, p. 255.

[34] W. Yan, J. Frégeau-Reid, Breeding line selection based on multiple traits, Crop Sci. 48 (2008) 417–423.