# Effect of UV-C treatments followed by storage on the storability characteristics of sesame (Sesamum indicum) seeds

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**Research Article**

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# Abstract

In this study, UV-C doses 0, 2.5, 5.0 and 10 kJ.m$^{-2}$ were applied to investigate the changes in the storability characteristics during the storage of sesame seeds. The fungal growth, aflatoxin content, water activity, colour parameters ($L^*$, $a^*$, $b^*$ values, and $\Delta E$) and free fatty acid content were evaluated. The fungal growth, water activity, and $L^*$ values were found less in the UV-C treated sesame than in control samples in both fresh and stored samples. However, these doses increased ($p < 0.05$) $a^*$ and $b^*$ values and the free fatty acid of the sesame seeds. The Partial Least Squares regression analysis stated that the application of 5.0 kJ.m$^{-2}$ followed by 6 months of storage reflects the most valid treatment doses for UV-C treatments of sesame seeds. Consequently, potentially afford effective and rapid quarantine security as an alternative to chemical fumigation protocol to extend the shelf life and enhance the storability characteristics of sesame seeds.


# Introduction

Sesame seed is among the essential oilseeds grown in many parts of Africa and Asia (Abou-Gharbia et al., 1997). This is because it has a high quality of oil, protein, and other macro and micronutrients. It contains about 35–60% oil, 19–30% protein, 13.5% carbohydrate, and 5% ash (Nimmakayala et al., 2011; Elleuch et al., 2007; Tunde-Akintunde and Akintunde, 2004). Unfortunately, due to the high nutritional values of sesame seeds, the seeds are mostly attacked before and after harvest by many species of pests, resulting in severe qualitative and quantitative losses. Recently, several physical and biological preservative methods such as pasteurization, canning, freezing, refrigeration and chemical preservatives have been explored to improve food safety (Agrios, 2005).

Ultraviolet radiation type C (UV-C, wavelengths of 200–280 nm) is an alternative technique used to control food spoilage by primary and secondary radiolysis, producing chemical reactions in foods. The UV-C is considered one of the alternative technologies approved by the US Food and Drug Administration for application in the food industry (USFAD, 2000). Recently, the interest in applying the UV-C is increased due to its advantages in extending food shelf life. The great attraction of the food processing industry in this preservation method is due to UV-C action. Lima et al. (2018) stated that the extension of food shelf life resulting from UV-C treatment could be due to the enzymes' inactivation and the microbial load reduction. The UV-C causes DNA damage to the pathogenic microorganisms, resulting in their inactivation and death (Shama, 2007).

Moreover, UV-C is associated with many physiological changes in agricultural products that reduce postharvest losses, improve nutritional value, and extend their shelf life (Shama and Alderson, 2005). Hassan et al. (2020) concluded that UV-C doses of 3.5, 7.0 and 10.4 kJ m$^{-2}$ could reduce the microbial load, eliminate Salmonella and *E. coli* and enhance the total phenolic content and total flavonoids and the antioxidant activity of the spice. Additionally, UV-C treatments (0.8528, 1.2318 and 1.7238 (mW/cm$^2$) were able to deactivate lipase enzymes and reduce the rate of FFA formation in crude palm oil during storage for 28 days (Said et al., 2020).

Likewise, UV-C radiation has several advantages, such as easy implementation, low cost, lack of toxic wastes, and does not induce radioactivity in foods (Chun, Jooyoun, Chung, Won, & Song, 2009; Koutchma et al., 2009). On the other hand, as one of the pathways of the UV-C radiation is the free radical generation, adverse effects may occur, including oxidation of proteins and lipids, which leads to colour changes and lipid oxidation limiting the quality of food products and industrial application (Koutchma et al., 2009; Lázaro et al., 2014; Molina, Sáez, Martínez, Guil-Guerrero, & Suárez, 2014; Monteiro et al., 2017). However, the widespread application of UV-C in the food industry depends mainly on Several factors like dose rate, amount of dose absorbed, presence or absence of oxygen and temperature (Bottino, Rodrigues, Ribeiro, Lazaro, & Conte-Junior, 2017; Rizzotti, Levav, Fracchetti, Felis, & Torriani, 2015). So far, few studies have evaluated the effect of UV-C radiation in oilseeds. Therefore, the study of different UV-C doses was applied in to investigate the changes on the storability characteristics during the storage of sesame seed.

# Material And Methods

### Sample preparation and UV-C treatment

Sesame seeds were cleaned manually, freed from broken seeds and impurities, and then stored in plastic bags at 4°C during the study. UV-C treatments were performed in a metal box (65 x 90 × 45 cm3) according to Hassan et al. (2020) with slight modification. Samples of sesame seeds were packed in bags and exposed to the UV-C lamp (TUV-75 w G75 T8 220 V, Philips, Holland with peak emission at 254 nm) to doses of 2.5, 5.0 and 10.0 kJ m$^{-2}$, respectively. The sample packages were located at a distance of 15 cm from the UV-C source. Untreated samples were defined as control. Three replicates of each treatment were performed.

### Water activity

The Water activity in control and UV-C treated sesame seeds was measured using a hygrometer equipped with a temperature-controlled system (humimeter RH2, Schaller, Austria).

### Fungal growth and aflatoxin content

The fungal growth in untreated and treated sesame seeds was determined according to AOAC (2005) standard methods. Fungal growth was estimated as colony-forming unit per gram (log cfu/g). The aflatoxin analysis (AFG1, AFG2, AFB1 & AFB2) was conducted with HPLC according to

AOAC Official Methods 2005.08 (AOAC, 2005).

### Color parameters

The colour of sesame seeds was measured using a colourimeter (Chroma Meter CR 400, brand Minolta, Japan). The parameters L* (luminosity), a* (negative = green and positive = red), and b* (negative = blue and positive = yellow) were measured. The total colour difference (*Δ E*) estimated using the following equation

### Determination of free fatty acid content

The free fatty acid of control and UV-C treated sesame samples was determined according to the Zhao et al. (2007) method. Free fatty acids were calculated as mg KOH requisite to neutralize them on the dry matter at the one-gram grain.

### Statistical analysis

All data were the mean of triplicate. Data were analyzed using one-way ANOVA, and the Significant differences were calculated ($P < 0.05$) using the least significant difference (LSD). Multivariate analysis was conducted using HJ-Biplot PCA algorisms as described in the XLSTAT software (Vidal et al., 2020). Linear Partial Least Squares Regression test (PLS) validated and optimised UV-C dose using the XLSTAT software (Tenenhaus et al., 2005).

## Results And Discussion

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

Water activity ($a_w$) is an essential measure of viable water for chemical reactions, microbial growth and shelf-life stability of a product. The changes in the water activity ($a_w$) of the UVC treated sesame seeds alone or followed by storage are shown in Table 1. The $a_w$ for untreated sesame seeds was found to be 0.196 and was significantly ($P < 0.05$) decreased to 0.184, 0.182 and 0.177 when the sesame was treated with 2.5, 5.0 and 10.0 $kJm^{-2}$, respectively. During the storage, the seeds' aw was found to be significantly higher than that of unsorted seeds. It was increased as the storage time was increased for each UVC dose.

The fungal growth of the UV-C treated sesame seeds before and after storage was illustrated in figure 1. Before the treatment, the fungal load in the sesame seed was found 4.56 log cfu/g. Exposition of the seeds to the UV-C causes a significant ($P < 0.05$) reduction in the fungal load of the seeds. It was decreased ($P < 0.05$) as the dose was increased. The lowest fungal load value 4.1 log cfu/g was recorded when the seeds were treated with 10.0 $kJm^{-2}$. After storage, the fungal load was decreased for untreated and treated samples, particularly those stored for 12 months. The lowest fungal colonies were observed among the stored seeds when the seeds were treated with 10.0 $kJm^{-2}$. It was found to be 4.07 and 3.8 log cfu/g for the storage period of 6 and 12 months, respectively.

The reduction of the fungal load in the treated samples might result from the UV-C's deadly effect on fungal DNA transcription and replication, which diminishes spore multiplication (Braga et al., 2015). Moreover, UV-C treatment motivates enzymes that respond to the synthesis of phenolic compounds, which acts directly as a defensive response or indirectly by strengthening the cell wall (Shenga et al., 2018, Wu et al., 2016). Although fungi can repair DNA damage caused by UV-C radiation over the storage period (Goldman and Kafer, 2004, Wen et al., 2019), our finding revealed that the UV-C radiation was able to efficiently decrease fungal load in sesame seed up to 12 months of storage particularly at 5.0 and 10.0 $kJm^{-2}$.

Table 2 describes the aflatoxin content (B1, B2, G1, and G2) in control and UVC treated sesame seeds before and after storage. It was clear that the aflatoxin content of the control samples is lower than Method Quantification Limit (MQL) even after storage. The aflatoxins were also not detected in the UVC treated samples even after storage for 12 months. Although the untreated seeds and UVC treated seeds were stored at optimal conditions for fungal growth, the level of aflatoxin in the seeds was not raised. This might be attributed to controlling postharvest processing practices essential to maintaining the safety and quality of agricultural products.

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

Table 3 describes the effect of the UV-C treatments followed by storage times on the colour of the sesame seeds. The values of the lightness (L*), Redness (a*) and yellowness (b*) of the seeds showed significance to the UV-C doses as well as to the storage time. Before UV-C treatment, the L* value was found to be 64.6. The lightness of the seeds (L*) was progressively decreased after the UV-C treatment. It was reduced ($P < 0.05$) to 62.2m 61.8 and 60.6 when seeds were treated with 2.5, 5.0 and 10.0 $kJ^{-2}$, respectively. On the other hand, during the storage of the control and UVC-treated seeds for 6 and 12 months, the lightness of the sesame seeds was significantly ($P < 0.05$) decreased for each UV-C dose.

The sesame seeds' a* and b* values were increased by increasing the UV-C doses (Table 2). However, there was no significant ($P < 0.05$) impact of the UV-C amounts on the a* values of the sesame seeds. Untreated seeds with UV-C exhibited lower a* values (0.5) and b* value (23.0) than sesame treated with UV-C between 5.0 to 10.0 $kJm^{-2}$ at each storage time. Nevertheless, ($P < 0.05$) a* values were found for the stored seed treated with UV-C, the stored samples showed higher a* values than those without storage for each UV-C dose. The highest a* and b* values 5.6 and 29.3 were recorded in the seeds treated with 10.0 $kJm^{-2}$ and stored for 12 months.

The total colour difference ($\Delta E$) in sesame seeds treated with 0.0, 2.5, 5.0 and 10.0 $kJm^{-2}$ was described in figure 2. It was clearly observed that the $\Delta E$ in the seeds significantly ($P < 0.05$) increased as the doses was increased. The $\Delta E$ was found to be 2.6, 3.06 and 4.28 when the seeds treated with UV-C doses of 2.5, 5.0 and 10.0 $kJm^{-2}$. Similar observation was also recorded in each storage time. Also, the$\Delta E$ was found to increase significantly ($P < 0.05$) during the storage of UVC-treated sesame seeds. For each UVC dose, the $\Delta E$ value significantly increased as the storage time was increased.

Our findings demonstrate that the UV-C application at 2.5, 5.0 and 10.0 $kJm^{-2}$ resulted in perceived colour changes by visual observation. The changes in colour due to the UV-C treatments in chicken meat and goat meat are also reported by Lázaro et al. (2014) and Degala, Mahapatra, Demirci, and Kannan (2018). Change in colour after UV-C treatment might be due to Lipid oxidation and protein denaturation of seeds leading to exposure of hydrophobic groups and increased free water changing meat surface reflectance (Koutchma et al., 2009, Canto et al., 2016). Moreover, this colour change might be due to the effect of UV-C on the main groups of pigment that contribute to the seeds' colour (Naradisorn, 2021).

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

Figure 3 represents the effect of UV-C treatments followed by storage on the free fatty acid of sesame seeds. It was observed that there was a dramatic increase in the FFA levels in sesame seeds with the rise of the UV-C dose. It was increased from 2.6 mg/g to 2.8, 2.9 and 2.9 mg/g when sesame seeds exposure to the UV-C at 2.5, 5.0 and 10 $kJm^{-2}$, respectively. Likewise, for each UV-C dose, the content of the FFA was increased when the seed was stored for 6 and 12 months. Interestingly, the higher increasing level of the FFA (11.5 & 15.4%) was observed in the untreated seeds when they were stored for 6 and 12 months. However, the level of increase of FFA content was ranged between 3.6 to 7.7% in the treated samples. Said et al. (2020) stated that the destruction of lipase activity might reduce FFA formation in treated samples during storage due to periodic UV-C irradiation.

The FFA content is an index of rancidity and contributes to the development of off-flavour and off-odours in oil during storage. Hence, as an effective method to destroy the enzymes and, in this way, prevent the formation of free fatty acid in stored seeds and stabilise their shelf life.

### *Principal component analysis and Partial Least Squares regression analysis*

*The Principal Component Analysis (PCA) shows the interrelationships between UV-C doses and storability and quality characteristics of a sesame seed (Figure 4A). The axes contribution of the principal components F1 and F2 is explained as 68.42% and 25.34%, which resulted in high variability (93.76%) of the plotted components. Moreover, the strongest positive correlation was also observed between UV-C treated sample and seeds storability and quality parameters rather than between control samples and parameters. According to Yan and Fregeau-Reid (2008), the variable eccentricity and observation that appear <90° angle is positively correlated, while that of angels > 90° is related with negative correlation, and those with a 90° angle do not show a correlation in the biplot. Consequently, the UV-C doses alone or followed by storage periods were grouped into three groups in the biplot according to their impacts on the storability characteristics of the sesame seeds. The control (0 $kJm^{-2}$) 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.*

The Partial Least Squares regression analysis (PLS) was illustrated the interactive effects of the UV- C (*x* variables) on the measured parameters (*y* variables) of the sesame seeds (Fig. 4B). According to this model, the UV-C doses were grouped into four groups regarding their effect on the fungal growth, FFA, colour values (L*, a* & b*), changes in colour $\Delta E$ and water activity ($a_w$). The PLS model revealed that the UV-C treatments alone or followed by 6 or 12 months' storage of sesame seeds showed a positive validation score for most of the studied parameters. However, the PLS specified that the application of UV-C at 5.0 $kJm^{-2}$ followed by 6 months' storage reflects the most proper treatment for functional food applications, which might consider for food industry applications.

## Conclusion

This study explored to validate the doses of UV-C radiation of sesame seeds to optimize the dose, enhancing sesame seed's storability and quality characteristics. As a result, the UV-C treatments are effective in fungal decontamination and inhibiting aflatoxin production even after 12 months' storage. In addition, it caused a reduction in the FFA formation, particularly in stored seeds. The UV-C irradiation causes a change in the sesame seed's colour. In addition, it decreases the L value and increases the a and b values. Regarding the validation model, 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 other quality parameters and the storability properties of the sesame is needed 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

### Authors contribution

**Amro B. Hassan:** Methodology, Data curation, Visualization, Writing- Original draft preparation, Writing - review & editing.

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**Conflict of Interest**

The author reports no declarations of interest.

**Availability of Data and Material**

All data generated or analysed during this study are included in this published article.

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# Tables

**Table 1** Effect of UV-C treatments followed by storage on the water activity of sesame (*Sesamum indicum*) seeds

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

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.

**Table 2** Effect of UV-C treatments followed by storage on the aflatoxin of sesame (*Sesamum indicum*) 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 (*Sesamum indicum*) 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.

## Figures

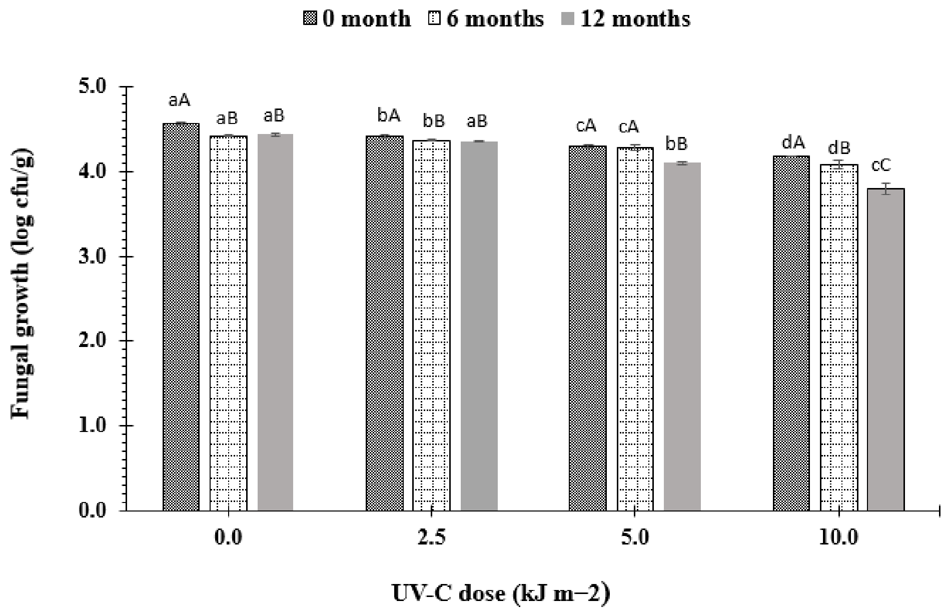



Figure 1

Effect of UV-C treatments followed by storage on the fungal growth (log cfu/g) of sesame (*Sesamum indicum*) 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.

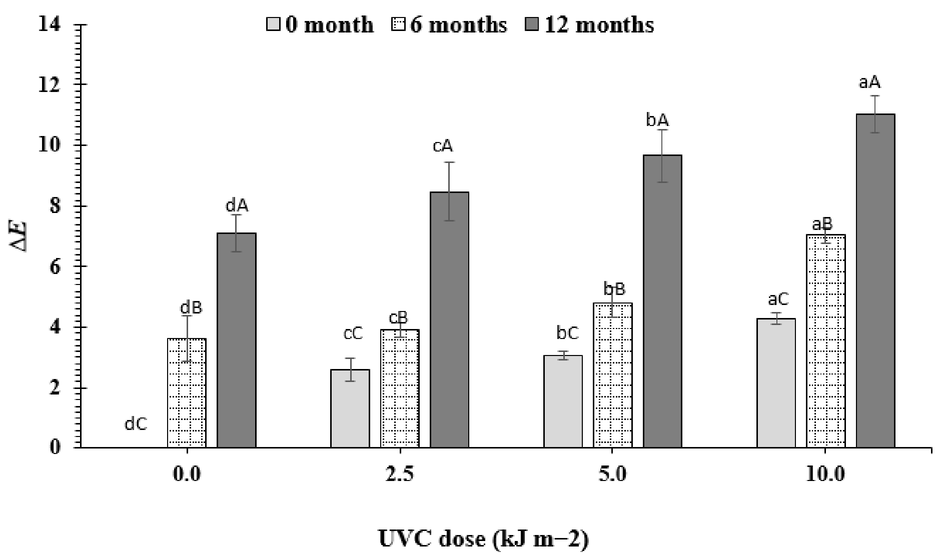
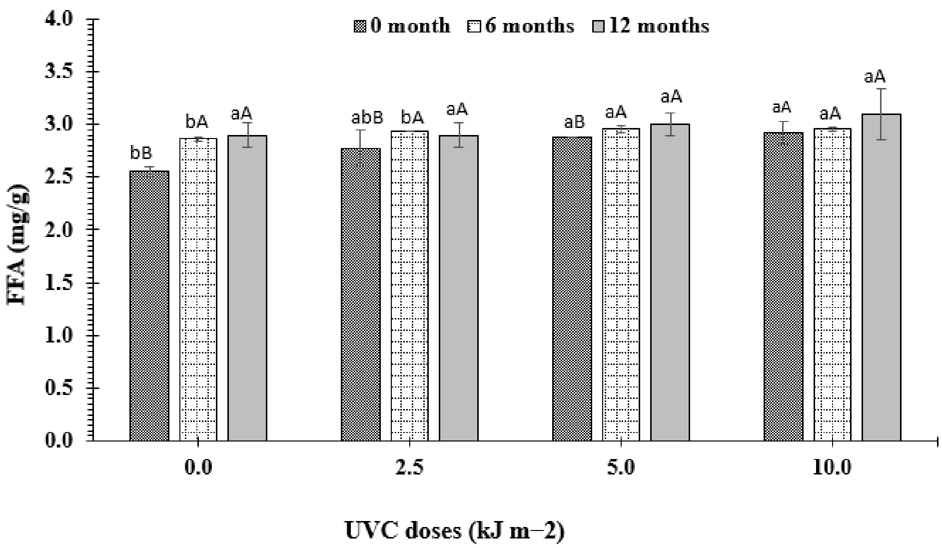



Figure 2

Effect of UV-C treatments followed by storage on the changing colour ($\Delta E$) of sesame (*Sesamum indicum*) 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.




### Figure 3

Effect of UV-C treatments followed by storage on the free fatty acid (mg/g) of sesame (*Sesamum indicum*) 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.

### Figure 4

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